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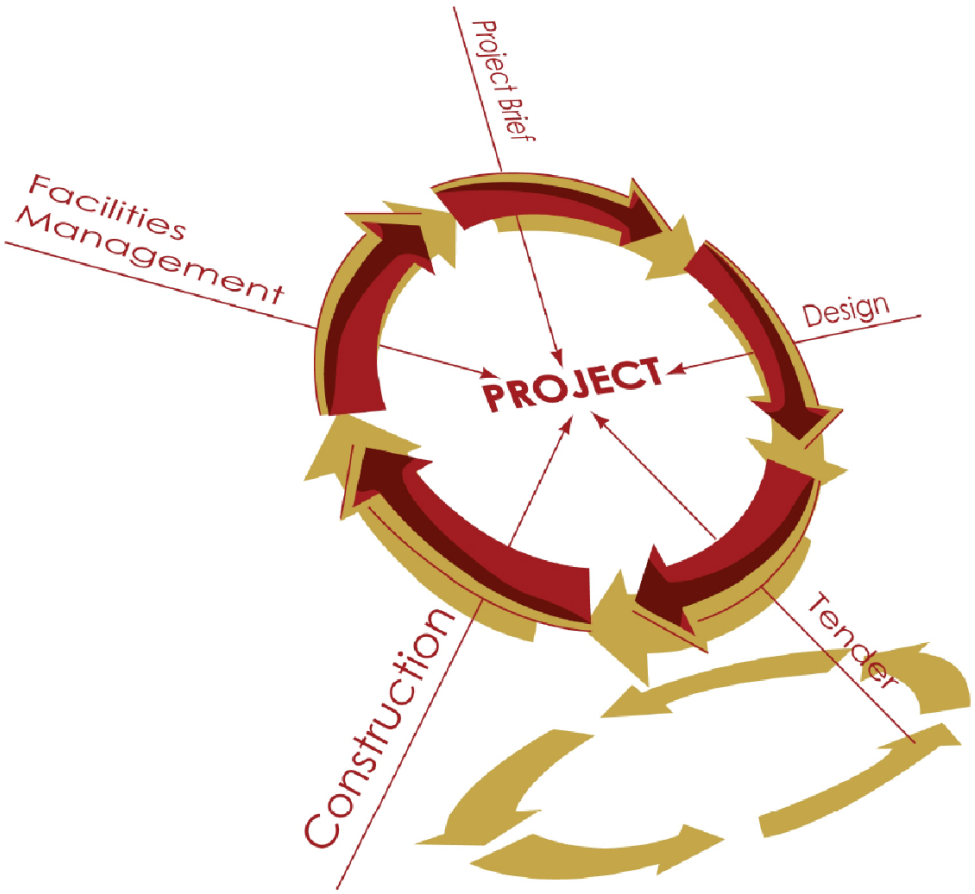

CREAM CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA
CIDB MALAYSIA

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Contents

Introduction

Welcome to this special issue in Malaysian Construction Research Journal (MCRJ) for the 4th International Conference on Built Environment and Engineering 2024 (IConBEE2024). This conference has served as a platform for the discussion, dissemination, and exchange of cutting-edge knowledge in the fields of built environment and engineering. With the overarching theme of "Smart, Sustainable, and Environmental Solutions for Societal Resilience," the conference organizer eagerly invites submissions of research papers, working papers, industry initiatives, and graduate students research symposiums or presentation proposals. The conference successfully hosted by School of Construction and Quantity Surveying, College of Built Environment, Universiti Teknologi MARA, Shah Alam in Pulau Pinang on 15th – 17th October 2024.

The global construction industry serves as a critical barometer of national economic growth, primarily because governments frequently act as the sector's principal clients. With the advent of the 21st century and the rapid progression into the digital era, the industry has undergone significant transformations. The integration of advanced digital technologies has enabled key stakeholders to collaborate seamlessly across distances and geographical boundaries, spurring the emergence of new trends and innovative approaches to longstanding challenges. While technological advancements continue to reshape the sector, equal emphasis must be placed on the "soft" dimensions—particularly the human capital that underpins the effective operation and management of these advanced systems. The successful delivery of cutting-edge projects increasingly depends on the skills, knowledge, and adaptability of the workforce in navigating both hard and soft technological landscapes.

This special issue explores the interplay between construction technology and the broader business and management domains, with a particular focus on the theme **"Smart, Sustainable and Environmental Solutions for Societal Resilience."** The included articles examine a range of pressing issues and challenges facing the construction industry and propose strategies to address them. Each contribution has undergone a rigorous peer-review process, conducted by independent experts well-versed in the respective subject areas, ensuring the highest standards of academic rigor and relevance.

By presenting insights from business and management perspectives, this volume aims to illuminate the multifaceted nature of the construction industry and the potential for multidisciplinary research within the built environment. The discussions underscore the pivotal role of human capital as implementers of policies, practices, and technologies that drive innovation and resilience in the global construction sector. This collection offers valuable contributions to both academic and professional audiences, equipping practitioners with foresight into future challenges and practical solutions to navigate them effectively.

Editorial Advisory Board

Secretariat Special Issue

Editorial

Welcome from the Editors

Welcome to this special issue in Malaysian Construction Research Journal (MCRJ) for the 4th International Conference on Built Environment and Engineering 2024 (IConBEE2024). We would like to express our sincere gratitude to our contributing authors, reviewers, organisers and readers.

This special issue in MCRJ for (IConBEE2024) contains twenty (20) exciting papers covering the theme of "Smart, Sustainable, and Environmental Solutions for Societal Resilience". It is hoped that the readers would greatly benefit from the scientific content and quality of papers published in this issue:

A brief introduction of each article is given hereunder:

Mohd Suharizal Mahamad Subri et al., examines the quality of immovable asset data in the public sector, emphasizing the interconnected roles of people, processes, and technology. Immovable assets, such as buildings and infrastructure, are pivotal for public service delivery and economic growth. However, fragmented public sector operations pose challenges to maintaining data accuracy, completeness, and reliability, which are crucial for effective asset management and policy-making. Combining literature reviews, case studies, and expert interviews, this research identifies key factors affecting data quality and proposes a comprehensive framework for its improvement. It underscores the significant implications of poor data quality on decision-making and resource efficiency.

Nur Edrina Muhammad Nazrin et al., investigates the transformative potential of digital data in shopping centre rental valuation, focusing on Pavilion Kuala Lumpur as a case study. Utilizing an exploratory design and purposive sampling, data were sourced from websites, geospatial platforms, and software. The findings highlight the utility of digital data in assessing shopping centre performance, retail unit characteristics, tenant mix, accessibility, and catchment attributes. By integrating digital insights with traditional valuation methods, this study offers a more comprehensive valuation approach. Its contribution lies in recommending innovative digital data applications, enabling valuers to make informed decisions in the dynamic retail property landscape.

Nur Azlina Hariffin et al., investigates land subsidence in Klang, Selangor, Malaysia, using Interferometric Synthetic Aperture Radar (InSAR) to complement conventional monitoring methods. Satellite interferometry tracked subsidence patterns from March 2022 to September 2023, with Sentinel-1 revisiting the area every twelve days. Validation was performed using Global Navigation Satellite System (GNSS) data from the MyRTKnet Continuously Operating Reference Station (CORS), focusing on vertical motion from March to October 2022. Results revealed deformation rates ranging from 10.3 mm/year to -19.4 mm/year, visualized with color gradients. Additionally, a declining trend in Line of Sight (LOS) measurements was observed during the study period.

Nor Rima Muhamad Ariff et al., This study explores the challenges of integrating Big Data Analytics (BDA) into Malaysia's Facilities Management (FM) practices. Through thematic analysis of semi-structured interviews with five FM experts, the research identifies 21 challenges categorized into people, process, and technology domains. The most significant barriers stem from the people component, including skill gaps and resistance to change. These findings underscore the importance of targeted strategies to enhance staff training, streamline processes, and upgrade technology. By addressing these barriers, the study highlights the potential for successful BDA adoption in FM, contributing valuable insights to advance research and practice in this field.

Dona Rose Amer Koesmeri et al., explores the critical need for age-friendly architecture to support the well-being of older adults in micro-environments. Employing a systematic literature review (SLR) guided by PRISMA 2020, it examines publications from 2007–2024 to identify essential architectural features for age-friendly designs. Analysis of 36 studies reveals five themes, 11 core domains, and 101 variables, highlighting gaps in existing assessment models, particularly in Malaysia. The findings emphasize the importance of culturally tailored frameworks and standardized protocols to ensure safety, independence, and inclusivity for the elderly. This research offers evidence-based recommendations to advance age-friendly architecture and inclusive societal development.

Siti Balqis Mohd Tun et al., This study investigates the use of Interferometric Synthetic Aperture Radar (InSAR) technology for monitoring land subsidence in Lestari Perdana, Seri Kembangan, Malaysia, following a significant subsidence event on January 26, 2022. By employing Sentinel Application Platform (SNAP) and Stanford Method for Persistent Scatterers (StaMPS) on Satellite-1A data, coherence images and time-series deformation maps were generated to assess ground movements. Results revealed shifts in the soil and highlighted high-risk zones. This research emphasizes the importance of continuous monitoring to inform urban planning, safeguard infrastructure, and enhance community preparedness, offering a proactive approach to managing subsidence-prone areas effectively.

Siti Fatimah Mazlan et al., investigates the challenges and strategies for adopting Internet of Things (IoT) technologies in Malaysia's Facility Management (FM) industry, focusing on the Klang Valley region. Despite the sector's growth, IoT adoption remains limited, hindered by factors such as security concerns, high deployment costs, a shortage of experts, and insufficient skills and knowledge. Employing a quantitative approach with questionnaire data, the study proposes strategies including expert development, IoT training, government-industry-academia collaboration, and financial support. These findings offer actionable insights for stakeholders to drive IoT adoption, advancing FM digitalization in Malaysia and contributing to policymaking and future research.

Lilis Shereena Safiee et al., research on the Government assets require effective management due to their significant financial investment and the recurring mismanagement issues highlighted in the Auditor General’s Report. Outsourced Facilities Management (OFM) faces challenges in meeting demands for fiscal efficiency, necessitating a holistic Knowledge Management (KM) approach with Knowledge Sharing (KS) as a critical component. This study examines the influence of KS determinants on OFM performance in government buildings, using the Theory of Planned Behaviour and a survey of 112 OFM personnel. Findings reveal that Self-Attitude and Nature of Knowledge significantly enhance

performance, while other factors showed limited impact. Recommendations aim to optimize KS initiatives within OFM.

Absyar Azman et al., examines the defect management in construction projects, focusing on the factors leading to defects in newly constructed buildings in Seremban, Negeri Sembilan, during the Defects Liability Period (DLP). Using a survey of project team members under G7 contractors registered with CIDB Malaysia, data was analyzed via SPSS. Findings revealed poor workmanship and low-quality materials as primary causes of defects, compounded by inadequate compliance with contract quality standards. The study highlights the need for proactive measures like adopting QLASSIC and PQP frameworks to improve quality management, offering valuable insights to contractors for minimizing defects and enhancing project outcomes.

Md Yusof Hamid et al., explores the challenges and potential enhancements of digitalizing Facility Management (FM) in higher education institutions, specifically focusing on University A. As part of Industry 4.0, the need for digital adoption in university FM is critical for effective facility management. The research, based on semi-structured interviews with relevant personnel from the Infrastructure Development Department, identifies challenges such as budget constraints, infrastructure limitations, and lack of clear vision and mission. Using descriptive analysis, the study offers recommendations to improve the integration of digital tools in university FM, aligning with the institution's strategic objectives.

Azlan Ariff Ali Ariff et al., explores the potential of green roofs as accessible public spaces in Malaysia, addressing their environmental, social, and economic benefits amidst urban sprawl. Through focused group discussions with local construction professionals, including architects, town planners, and developers, the research identifies challenges and opportunities in enhancing green roof accessibility. Initial findings highlight barriers such as location, safety, and technical limitations, while proposing solutions drawn from global best practices adapted to Malaysia's tropical climate. The study aims to provide practical strategies for improving green roof accessibility, contributing to sustainable urban development and a better quality of life in Malaysia.

Saiful Anuar Jaafar @ Ibrahim et al., develops a conceptual framework for automated multiple object detection in scanned topographic maps, integrating GIS and deep learning techniques. Despite extensive advancements in satellite imagery, topographic maps have received limited research attention. The study reviews existing methodologies for automated object detection, focusing on deep learning approaches and map vectorization processes. Key findings include the identification of trends, strengths, and limitations in current methodologies, and the proposal of a novel dataset technique to improve geospatial data structure. The study contributes to bridging research gaps and enhancing automated object detection techniques in geospatial analysis.

Nurul Syafiqah Hanim Zainal et al., investigates the prevalence of building defects in residential properties and their impact on residents' quality of life. Using a quantitative approach, data was collected through a structured questionnaire, capturing residents' perceptions of common defects such as structural issues, plumbing problems, and electrical faults. These defects are primarily attributed to poor construction practices and inadequate

maintenance. The study reveals that defects lead to safety hazards, health issues, financial strain, and emotional stress, significantly affecting residents' well-being. The findings provide valuable insights for policy-makers, developers, and building professionals to reduce defects and improve living conditions in Selangor's residential buildings.

Nurul Hafizah Azmi et al., addresses flood risk management in Malaysia, focusing on identifying optimal locations for evacuation centres in Terengganu. Using Geographical Information System (GIS) tools and the Step–Wise Weight Assessment Ratio Analysis (SWARA) Multi-Criteria Decision-Making (MCDM) approach, five criteria–slope, population, location, accessibility, and land use–were assessed. Expert-completed questionnaires determined the criteria weights, with slope identified as the most critical factor (weight: 0.236). A suitability map was generated to guide site selection, emphasizing locations outside flood-prone areas with minimal environmental impact. The findings provide a robust framework for decision-makers, advancing flood resilience and supporting sustainable development objectives.

Marlyana Azyyati Marzukhi et al., explores the psychological impact of open spaces on urban dwellers during the COVID-19 pandemic, focusing on depression, anxiety, and stress. Using a quantitative approach and the UMHQ-DASS21 questionnaire, data from 241 respondents in PPR Pantai Ria, a COVID-19 red zone in Kuala Lumpur, were analysed. Findings indicate significant symptomatology linked to open space perceptions, with strong correlations between psychological distress and exposure to open spaces. The research highlights the need for policy enhancements by the Ministry of Health, Ministry of Housing and Local Government, and urban planners to address mental health challenges and improve urban environments in post-pandemic settings.

Noorfaizah Hamzah et al., investigates the use of coconut coir fibre to enhance the strength and engineering properties of clay soil, addressing geotechnical challenges in Malaysia caused by weak soil bearing capacity. Clay soil samples were reinforced with varying percentages of coconut coir fibre (0.25%–1.25%) and analysed under Optimal Moisture Content (OMC) and Maximum Dry Density (MDD). Results showed that 1.00% coconut coir fibre yielded the highest improvements in unconfined compressive strength and soil density while reducing moisture content. These findings highlight coconut coir fibre as an effective and sustainable solution for soil reinforcement, offering cost-efficient advancements in geotechnical engineering.

Sallehan Ismail et al., explores the potential of Gigantochloa Scortechinii (Buluh Semantan) bamboo as a sustainable alternative to synthetic fibres for composite materials in construction. Focusing on bamboo's physical, chemical, and mechanical properties along its culm, samples were analysed based on ISO 22157 and TAPPI standards. Results revealed that fibres from the top of the culm exhibited superior mechanical strength, lower moisture content, and higher density due to increased lignin content compared to middle and basal sections. These findings highlight the viability of G. Scortechinii as a renewable material, addressing gaps in commercialization and supporting sustainable development in Malaysia.

Siti Rashidah Hanum Abd Wahab et al., addresses the challenge of prioritizing maintenance expenses in strata developments by proposing a standardized maintenance charge rate for improved budgeting accuracy. Conducted in the Klang Valley, the research involved semi-structured interviews and focus group discussions across various strata properties, including low-, medium-, and high-cost residential buildings. Findings highlight the reliance on historical expenditures, which often fail to predict future maintenance needs accurately. Key factors influencing charges include building age, facilities, occupancy rates, and maintenance frequency. Through expert validation, the proposed rate was refined, offering a framework for equitable and sustainable maintenance charge allocation, fostering better living environments and resident satisfaction.

Anees Ahmed Vighio et al., examines the challenges and opportunities for implementing Building Information Modeling (BIM) in Pakistan's construction industry, where limited use of information technology hampers efficiency. Based on literature reviews, surveys, and interviews, key barriers to BIM adoption include insufficient training, lack of skilled BIM managers, knowledge gaps among stakeholders, resistance due to transparency concerns, and limited contractor expertise. A conceptual framework was developed, categorizing implementation strategies into government, organizational, and employee-focused actions. The proposed framework aims to address these challenges and facilitate BIM deployment, promising enhanced efficiency, cost savings, and transparency in Pakistan's construction sector.

Cheng Siew Goh et al., explores the potential of Artificial Intelligence (AI) to revolutionize the construction industry, addressing low productivity caused by manual operations and labor dependence. Through a questionnaire survey of industry stakeholders, the research examines current AI applications and future opportunities in construction. Findings reveal that stakeholders generally view AI positively, identifying progress monitoring and scheduling as key application areas. The study highlights AI's potential to enhance productivity, automation, and reliability in construction workflows. By investigating state-of-the-art AI solutions and stakeholder perceptions, the research provides empirical evidence and insights to support broader AI adoption and digital transformation in the construction sector.

ASSESSING THE IMMOVABLE ASSET DATA QUALITY: THE CRITICAL ROLE OF PEOPLE, PROCESS, AND TECHNOLOGY ACROSS PUBLIC SECTOR

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Abstract
This paper explores the quality of immovable asset data across public sectors, focusing on the interdependent roles of people, processes, and technology. Note that high-quality data is essential for effective asset management, policy–making, and service delivery. However, ensuring data quality in the public sector presents unique challenges due to the complex and often fragmented nature of public sector operations. This research identifies key factors influencing data quality in public sector asset management and proposes a comprehensive framework for assessing and improving immovable asset data quality. The study combines literature reviews, case studies, and expert interviews to provide a holistic understanding of the critical role of people, processes, and technology in achieving high-quality immovable asset data. Therefore, ensuring the quality of immovable asset data is a critical challenge for public sector organizations. Immovable assets, such as buildings, roads, and infrastructure, are foundational to public service delivery and economic development. Effective management of these assets relies heavily on data accuracy, completeness, and reliability. Moreover, poor data quality can lead to suboptimal decision-making, increased costs, and inefficiencies in asset utilization and maintenance. This research paper investigates the factors influencing data quality in public sector immovable asset management, focusing on the critical roles of people, processes, and technology.

Keywords: *Asset Management; Immovable Asset Management; Asset Management Information System; Data Quality*

INTRODUCTION

In the realm of asset management, data quality is paramount, as decisions regarding maintenance, investment, and resource allocation hinge on the integrity of data. The dimensions of data quality – accuracy, completeness, consistency, and reliability – are essential for effective asset management. Katina et al. (2021) emphasized that traditional asset management frameworks are often inadequate in addressing the complexity, uncertainty, and interdependencies inherent in modern systems, especially in the context of sustainability. Meanwhile, data quality refers to the condition of data, which can be assessed based on specific attributes such as accuracy, completeness, reliability, relevance, and timeliness (Mashoufi et al., 2023). In essence, high-quality data ensures that all the critical information regarding asset performance is precise, current, and easily accessible, thereby supporting sound decision-making processes (Foidl & Felderer, 2023). This underscores the significance of maintaining data that is not only accurate but also relevant to the context and needs of the organization. As such, reliable data forms the backbone of strategic decisions, particularly in

managing immovable assets where up-to-date information can drive timely interventions, resource allocation, and long-term planning. Without data that meets these standards, decision-makers may face challenges that hinder the efficiency and effectiveness of asset management practices. Furthermore, issues with data quality can result in significant financial losses and operational inefficiencies, making it imperative for public sector organizations to prioritize data quality to ensure efficient asset management and service delivery. At the same time, immovable assets, such as buildings, land, and infrastructure, are critical components of public sector portfolios. Note that effective management of these assets requires accurate, complete, and timely data. However, public sector entities often struggle with factors like outdated systems and limited human capital. High-quality data is crucial for informed decision-making, efficient resource allocation, and transparent governance. Therefore, accurate data helps in planning maintenance activities, budgeting, and complying with regulatory requirements, whereas poor data quality can lead to costly errors, inefficiencies, and a loss of public trust.

People are critical to ensuring data quality, as their skills, commitment, and motivation directly influence data management outcomes. Human factors, including management commitment, extrinsic rewards, and motivation, are pivotal in managing public immovable assets. According to the Resource-Based View (RBV), human capital is a critical component of organizational success (Gerhart & Feng, 2021). Effective data management requires skilled and motivated personnel committed to maintaining high data quality standards. As such, thematic analysis of participant responses in this study highlighted management commitment and extrinsic rewards as key sub-themes. Consequently, participants emphasized the significance of proper training, clear roles and responsibilities, and motivation through rewards to enhance data quality. For instance, Participant 4 noted that ensuring data quality starts with creating accurate data and adhering to structured procedures, underscoring the critical role of people in the data quality process. Notably, technology is a crucial enabler of data quality in asset management. Thus, effective implementation of technology, system integration, and information system configuration are essential for managing large volumes of data accurately and efficiently. The literature suggests that modern data management tools and systems can significantly enhance data quality by automating data collection, validation, and analysis processes (Batini & Scannapieco, 2006). Furthermore, participants in this study underscored the importance of technology in simplifying data collection and ensuring data accuracy. For example, Participant 3 highlighted that technology should facilitate easy data collection and management, reducing human error and enhancing data reliability. In addition, system integration ensures that disparate data sources are consolidated, providing a single source of truth for asset management.

The design of data collection processes and the identification of barriers to data quality are critical for effective asset management. Other than that, standardized processes ensure that data is collected consistently and accurately across different departments and functions (Otto & Reichert, 2014). The participants in this study emphasized the need for simplified and standardized data collection processes to improve data quality. Participant 2 stressed the importance of standard procedures and codes to ensure consistency and facilitate data analysis. Additionally, addressing barriers such as data privacy and online threats is crucial for maintaining data integrity. Participant 4 highlighted that having solid processes in place, along with people training and technology, is essential for improving data quality. Combining the insights from the literature and participant responses, this paper proposes an integrative

framework for improving immovable asset data quality in public sector organizations. The framework emphasizes the interdependent roles of people, processes, and technology in ensuring high data quality. Therefore, by focusing on training and development, standardized processes, and advanced technological tools, public sector organizations can enhance their data management practices, leading to better asset management and service delivery.

Moreover, when developing processes, it is essential that they are streamlined to ensure data reliability. The findings also highlight that the capability of the organization's technology or system to organize and systematically manage data is crucial, especially considering the need for Life Cycle Costing (LCC) data of assets. The study further underscores that asset information is essential for organizational strategic planning, yet the current data systems do not fully reflect the LCC of immovable assets. This signals the need to generate key outputs for effective asset management through data analysis of these assets. Correspondingly, the interview also brought attention to the importance of open-source solutions that facilitate communication and information sharing between systems with integrated operational control, alongside the necessity for a central data repository. It is vital to implement structured processes to support those involved in the data quality initiative. In addition, these processes should be clearly outlined before the initiative begins, establishing the rules and guidelines for activities related to the creation or manipulation of data. This encompasses defining the people, procedures, and technologies integral to the data quality efforts. Additionally, maintaining a data quality issue log within the organization creates a structured way to track and categorize incidents. This enables the organization to assess the severity of issues and uncover patterns that may be indicative of deeper, systemic data quality problems (Otto & Ofner, 2011).

The implementation of high data quality standards is crucial for managing public immovable assets effectively. Key data quality dimensions include accuracy, completeness, consistency, timeliness, accessibility, relevance, integrity, usability, and security. Subsequently, accurate data ensures effective decision-making, while completeness provides detailed asset information for maintenance and performance. Meanwhile, consistency prevents errors and ensures uniform data usage across departments. At the same time, timeliness allows for proactive asset management, and accessibility facilitates quick decision-making. Relevance ensures data applicability to strategic goals, and integrity maintains data accuracy and coherence over time. In addition, usability makes data comprehensible for decision-makers, and security protects data from unauthorized access. Investing in high-quality data improves decision-making, operational effectiveness, compliance, and technology integration. Hence, detailed and timely data aids in proactive maintenance, operational coordination, and secure data management, enhancing overall asset management. Organizations must deepen their commitment to data management dimensions to improve public asset management.

In the modern economy, effective asset management drives growth and innovation despite challenges such as funding and bureaucracy. International standards guide the development of asset management systems, ensuring that management goals are met and positively impacting financial health and profitability. By emphasizing all dimensions of data quality, organizations can develop robust asset management strategies that support long-term business survival and growth. Note that improved asset management positively impacts financial health and profitability, emphasizing the significance of all data quality dimensions

in asset management strategies. Moreover, effective profit reinvestment in fixed assets is crucial for business survival and growth, highlighting the integral role of data quality in asset management.

The commitment to high data quality standards in managing public immovable assets is crucial for ensuring effective governance, strategic resource allocation, and the overall efficiency of public services. Thus, by integrating people, technology, and processes within a comprehensive framework, public sector organizations can significantly enhance their asset management practices, thereby fostering greater public trust and contributing to economic stability and growth.

METHOD

The foundational conceptual framework for this study was developed through an extensive review of the literature, which highlighted the critical dimensions that influence data quality in asset management. These dimensions are specifically categorized into People, Technology, and Organizational Processes. The conceptual framework, depicted in Figure 1, encompasses various key components under these categories, each playing a unique role in shaping the overall strategy for managing immovable asset data quality.

The "People" dimension focuses on the human factors essential for maintaining high data quality standards. This includes the skills, commitment, and motivation of personnel involved in data management. Notably, effective training programs, clear roles and responsibilities, and motivational incentives are vital components. This dimension underscores the importance of management commitment and the need for a skilled workforce to ensure data accuracy, completeness, and reliability. Meanwhile, the "Technology" dimension highlights the role of advanced technological tools and systems in enhancing data quality. This includes the implementation of modern data management tools, system integration, and information system configuration. Technology facilitates the automation of data collection, validation, and analysis processes, reducing human error and ensuring consistent and accurate data. The integration of disparate data sources into a cohesive system provides a single source of truth, which is crucial for effective asset management.

The "Organizational Processes" dimension emphasizes the importance of standardized and simplified data collection processes. Standard procedures and codes ensure consistency and accuracy across different departments and functions. This dimension also addresses barriers to data quality, such as data privacy concerns and online threats, by implementing robust processes and security measures. Effective process design and management are crucial for maintaining data integrity and facilitating seamless data analysis. Underpinning the framework are the specific dimensions of data quality: accuracy, completeness, consistency, timeliness, accessibility, relevance, integrity, usability, and security. These dimensions are essential for ensuring that data is reliable and useful for decision-making, resource allocation, and compliance with regulatory requirements. As such, accurate and complete data provide detailed information for maintenance and performance assessments. On the other hand, consistency ensures uniform data usage across the organization, while timeliness and accessibility support proactive asset management and quick decision-making. Relevance ensures data aligns with strategic goals, integrity maintains data coherence over time, usability makes data comprehensible for stakeholders, and security protects data from unauthorized access.

The integrative framework proposed in this study combines insights from the literature and participant responses. It emphasizes the interdependent roles of people, processes, and technology in ensuring high data quality. By focusing on training and development, standardized processes, and advanced technological tools, public sector organizations can enhance their data management practices. At the same time, this holistic approach leads to better asset management and improved service delivery. The implementation of high data quality standards is crucial for managing public immovable assets effectively. Furthermore, investing in quality data enhances decision-making, operational effectiveness, compliance, and technology integration. Considering the perspective of government immovable asset data quality, the significance of accurate and reliable data becomes even more pronounced. Government assets, such as public buildings, infrastructure, and land, are substantial in terms of both financial value and public utility. Moreover, accurate data is essential for the efficient allocation of resources, planning of maintenance activities, and adherence to regulatory requirements. High-quality data supports transparency and accountability, which are critical for maintaining public trust and ensuring that taxpayer funds are used effectively.

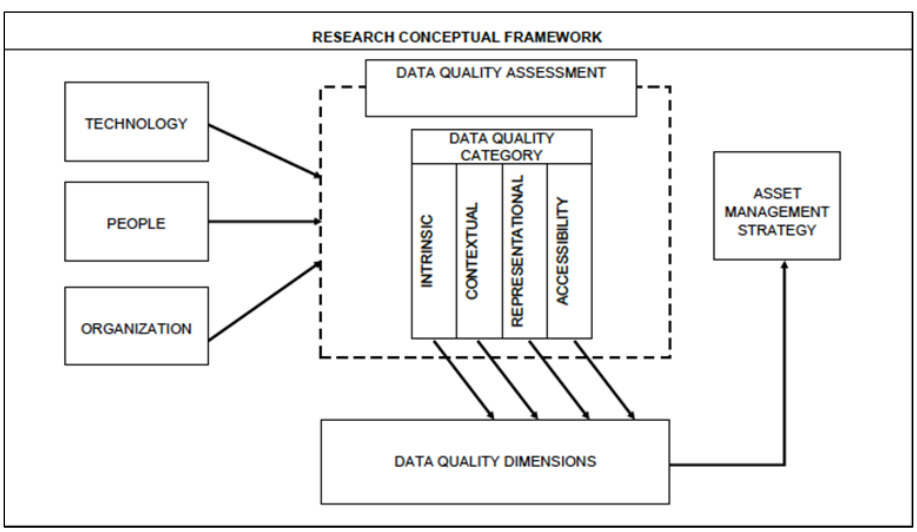


Figure 1. Research Conceptual Framework

The initial framework serves as a blueprint for identifying the key components that impact the effectiveness of data management strategies within the context of immovable assets. The framework emphasizes three main dimensions: People, Technology, and Organization. People involve human factors such as management commitment, staff competencies, and motivation, all of which are crucial for maintaining data quality and integrity. Meanwhile, technology focuses on the technological infrastructure, including data management systems and integration capabilities, which are essential for efficient data processing and storage. The organization covers the processes and structural aspects of data governance necessary for establishing a robust data quality framework. To enrich and validate the initial theoretical framework, empirical data were collected through expert interviews, focus group discussions, and exploratory questionnaires. This multi-method approach provided a deeper understanding of the practical aspects of data quality management. Consequently, expert interviews offered insights into industry-specific challenges and best practices, highlighting the roles of technology and organizational strategies in enhancing data quality. Focus group discussions facilitated interactive discourse, revealing common issues and collective insights into the

organizational and human factors influencing data quality. On the other hand, exploratory questionnaires quantified practitioners' perceptions, providing empirical support for the relationships proposed in the initial conceptual framework and identifying new dimensions pertinent to the asset management industry.

The integration of empirical data involves detailed expert interviews, focus group discussions, and exploratory questionnaires. Expert interviews provided essential insights into key aspects of management commitment, technology implementation, and system integration capabilities, helping to understand their practical implications on data quality. Meanwhile, focus group discussions gathered collective feedback on personnel competencies and training, extrinsic rewards and motivation, and the effectiveness of data collection processes. Accordingly, these interactions highlighted critical areas of improvement and affirmed the significance of robust process designs in enhancing data quality. Exploratory questionnaires provided a statistical backbone for the structural model, validating the relationships between constructs and assessing the direct and indirect effects of People, Technology, and Processes on data quality dimensions such as Accuracy, Reliability, and Timeliness. The structural model specification positions People, Technology, and Processes as independent variables fundamentally influencing various aspects of data quality. Management commitment is hypothesized to directly impact Accuracy and Reliability, reflecting the top-down influence on data management practices. Notably, data quality dimensions serve as dependent variables, exploring how well each aspect of data quality is supported by the underlying processes and systems in place. Path specification, based on empirical evidence, suggests specific linkages and interactions, such as the role of technology in enhancing data security and completeness through technological integration capabilities.

In Partial Least Squares-Structural Equation Modelling (PLS-SEM), specifying the measurement model involves defining how Latent Variables (LV), also known as constructs, are measured using observed variables or indicators (Hair et al., 2019). Hence, determining whether these constructs are reflective, or formative is crucial, as this distinction affects the direction of causality between constructs and their indicators (Hair et al., 2017). Reflective indicators are assumed to be effects of the LV, implying that changes in the LV will lead to corresponding changes in the indicators (Andreev et al., 1981). This suggests that all indicators in a reflective model are expected to be highly correlated since they reflect the same underlying construct. For instance, in a research study, constructs like "People," "Technology," "Process," and "Data Quality" are modelled reflectively, indicating that each indicator depends on the construct it measures. This is visually depicted in Figure 2, where reflective indicators exhibit high intercorrelation, illustrating their collective reflection of the LV. Conversely, formative measurement models posit that the indicators cause the LV (Haenlein & Kaplan, 2004). In this case, each indicator contributes uniquely to the formation of the construct, meaning the indicators can have positive, negative, or zero correlations with each other. Moreover, formative indicators collectively define the construct, and altering or removing an indicator can significantly change the meaning of the construct. This is particularly crucial when modelling constructs formed by distinct attributes, such as organizational resources or capabilities.

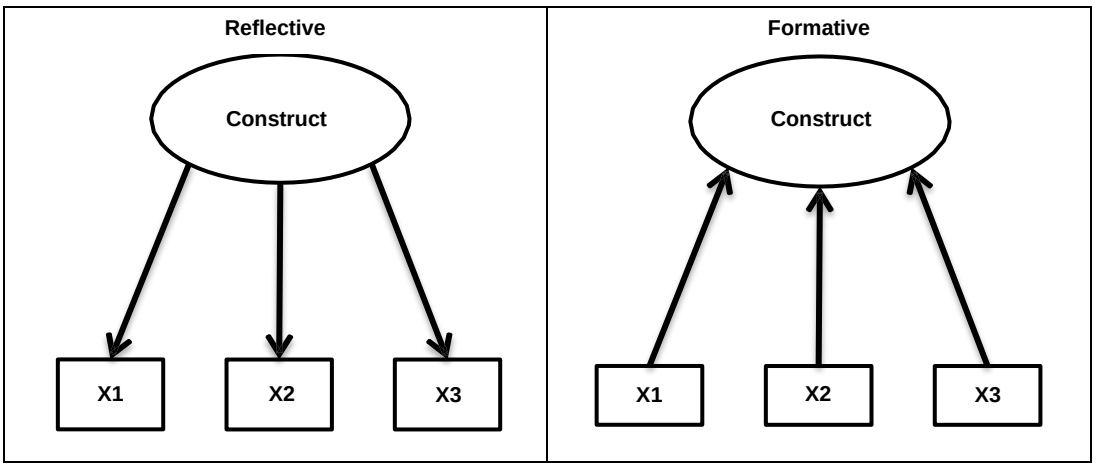


Figure 2. Reflective vs. Formative Measurement Models

Reflective measurement models are widely used in business research and are based on classical true-score test theory and factor analysis models (Henseler et al. 2009). In these models, indicators are designed to measure the same underlying LV, and changes in the LV cause corresponding changes in the indicators. Reflective models assume that causality flows from the construct to the indicators, meaning that variations in the construct lead to variations in its indicators. For example, in a study involving the construct "People," indicators might reflect various aspects of human resources in asset and facility management. If the "People" construct improves, all related indicators should demonstrate improvement. Note that indicators in a reflective model are expected to be highly correlated and interchangeable, meaning that removing an indicator does not affect the construct's validity, provided that reliability is maintained (Coltman et al., 2008).

On the other hand, formative measurement models operate differently. In these models, indicators are not necessarily correlated and do not measure the same underlying phenomenon. Instead, formative indicators cause the LV, with each indicator capturing a different component of the construct. This implies that any change in the indicators alters the conceptual domain of the construct. For example, for a construct like "Technological Tools," specified formatively, each indicator would represent different aspects of technology, such as software, hardware, training, and support. However, changes in any of these indicators would reshape the "Technological Tools" construct. Formative indicators are not interchangeable, and careful selection of indicators is crucial, as deleting or adding an indicator changes the nature of the construct. Proper identification of constructs as either reflective or formative has significant implications for research outcomes. As such, misidentifying constructs can lead to biased results and misinterpretations. Furthermore, correctly identifying the constructs ensures the use of appropriate analytical methods and tools, which is essential for accurate measurement and interpretation. Thus, theoretical considerations should guide the decision to specify a construct as reflective or formative based on the study's objectives and conceptual framework. This differentiation is crucial since constructs are not inherently reflective or formative. The specification depends on the conceptualization of the construct and the study's objectives. Accordingly, failing to differentiate between reflective and formative constructs can result in severely biased results.

In the context of this study, the use of reflective measurement models aligns with the theoretical framework, where constructs such as "People," "Technology," "Process," and "Data Quality" are expected to influence their indicators. The high intercorrelation among indicators in reflective models supports the idea that these indicators collectively reflect the underlying constructs. For instance, "People" is measured by indicators such as management commitment, employee competence, and adherence to standards. Note that these indicators are expected to move together, reflecting the overall construct of human resource effectiveness in asset and facility management. Similarly, "Technology" is assessed by indicators like IT infrastructure and MIS support, which should be highly correlated as they collectively capture the technological support for asset management. Specifying the measurement model is a foundational step in PLS-SEM analysis. Therefore, understanding the distinction between reflective and formative measurement models is critical for correctly specifying the constructs in PLS-SEM analysis. Reflective models, with their high indicator intercorrelation, are suitable for constructs where indicators are effects of the LV. Formative models, on the other hand, are appropriate when indicators form the construct and may not be correlated. By correctly identifying whether constructs are reflective or formative and ensuring appropriate indicators, the study can achieve robust and credible results. This process aligns with methodological recommendations and underscores the importance of theoretical grounding in developing and validating constructs in research. This careful consideration enhances the validity and reliability of the research findings, providing a solid basis for subsequent analysis and interpretation.

RESULTS AND DISCUSSION

The management of public immovable assets hinges on the quality of data, which is profoundly influenced by several critical factors, primarily the people involved in data management. However, effective management of public immovable assets depends on data quality, which is shaped primarily by human factors such as staff expertise, motivation, and leadership. The intersection of human factors, technology, and process design creates a complex landscape that demands critical examination. As such, the RBV underscores the importance of human capital as a key asset for achieving competitive advantage, emphasizing that the integration of skilled personnel is vital in this domain. This notion is reinforced by insights from various participants, who highlight that effective data management begins with a commitment to quality, supported by both management and the motivation of the individuals involved. Management commitment is a cornerstone of data quality. As noted by Participant 1, the establishment of a robust data management system requires a strong focus on data quality. This commitment ensures that the data management practices align with organizational goals and that the systems in place can produce reliable data. However, despite the acceptance of these practices, there remains a need for increased emphasis on both the quality of the data itself and the systems used to manage it. Participant 2 also emphasized that technology alone is insufficient. It must be complemented by the expertise of experienced personnel who can validate and verify data, ensuring its accuracy.

For government agencies managing immovable assets, the commitment from senior management is crucial. This commitment translates into prioritizing data quality and allocating resources to develop and implement robust data management systems. Thus, effective management must not only endorse the importance of data quality but also actively support initiatives that enhance it. This involves setting clear standards, providing necessary

training, and fostering a culture where data integrity is paramount. As emphasized by Participant 1, while the development of management systems is necessary, it is equally vital to focus on the quality of the data itself. This suggests that government agencies must establish a cultural shift where data quality is perceived as a strategic asset rather than just a technical requirement. Furthermore, the RBV highlights that skilled personnel are a valuable resource that can offer a competitive advantage. In government asset management, this means investing in training and development programs to enhance the capabilities of staff involved in data management. Participant 2's observation underscored the need for experienced personnel who can validate and verify data effectively. This is particularly crucial in the public sector, where data accuracy impacts operational efficiency and public trust and accountability.

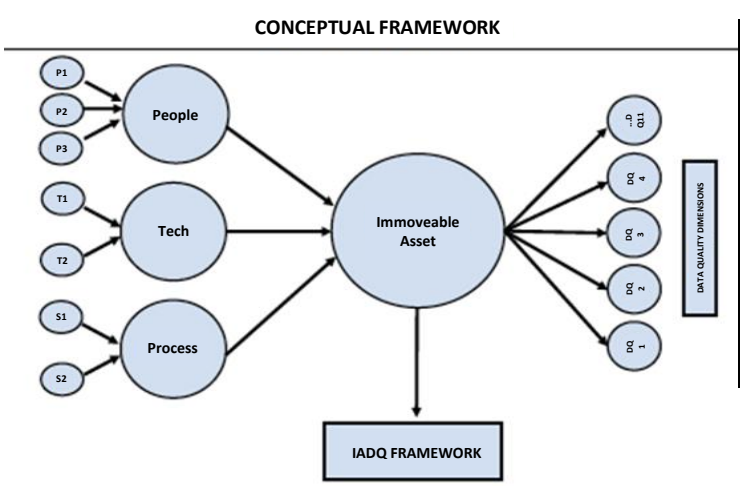
Motivation and extrinsic rewards play a significant role in enhancing data quality. Government agencies must design data management processes that consider the human factors involved. Thus, simplifying data collection procedures and providing incentives for accurate data entry can significantly enhance motivation and performance. Participant 5 highlighted that simplifying data collection processes can improve motivation and the quality of data entry. When data collection is streamlined and less burdensome, individuals are more likely to produce accurate and reliable data. Participant 6 reinforced this by noting that while technology is essential for data management, the human element remains crucial for validating data and avoiding inaccuracies. This is particularly relevant in government settings where bureaucratic procedures can often be cumbersome. Streamlining these processes and recognizing the efforts of data collectors can improve overall data quality.

Participant 6's perspective on the importance of human oversight in conjunction with technology highlighted the need for a balanced approach. Despite technological advancements, experienced personnel remain essential for data validation and accuracy. Hence, government agencies must ensure that their data management strategies incorporate both advanced technological tools and the expertise of skilled staff to mitigate errors and ensure the reliability of data.

Technology plays a pivotal role in managing government immovable assets by enhancing data quality by automating processes, reducing human error, and ensuring data consistency. Advanced systems can streamline data collection, improve accuracy, and facilitate effective data management. Participant 3's emphasis on using technology to simplify data collection and enhance integration underscored the importance of implementing systems that support seamless data management. Accordingly, government agencies must invest in technologies that enable effective data collection, integration, and analysis, ensuring that these systems are aligned with organizational needs and capable of handling large volumes of data. Furthermore, system integration is crucial for managing the complex data environments typical of government asset management. Integrating various data systems helps prevent redundancy, reduces errors, and enhances overall data reliability. As noted by Participant 1, technology should complement human efforts by providing tools that enhance data accuracy and management capabilities. Therefore, government agencies must ensure that their systems are capable of integrating with other platforms, facilitating efficient data exchange, and supporting comprehensive data analysis.

Participant 7 further emphasized that experienced and motivated personnel are necessary to address challenges in data maintenance and quality assurance, ensuring that data management processes remain effective and reliable. Technological implementation and system integration are also critical components in ensuring data quality. Participant 3 highlighted that technology should be employed to simplify data collection and improve accuracy. Notably, open-source systems that facilitate communication and integration between different platforms are particularly valuable, as they help address issues such as data redundancy and integration, thereby enhancing overall system efficiency. Additionally, system integration ensures that data systems can effectively manage interfaces and relationships, contributing to data reliability and effectiveness, as noted by Participant 1.

Furthermore, the configuration of information systems is essential for reliable data management. Participant 4 stressed the importance of keeping up with technological advancements to avoid falling behind in data management practices. Effective information systems should streamline data collection and access, supporting improved data quality. A well-designed data collection process is crucial for maintaining data quality, as highlighted by Participant 2. Simplified procedures and standardization facilitate effective data collection and analysis, helping to overcome policy challenges and improve overall efficiency. Addressing barriers to data quality, such as data privacy concerns and online threats, is also critical. Participant 4 emphasized the need for robust processes to manage these challenges effectively. Participant 7 added that large volumes of data and maintenance issues can complicate data registration and management, making it essential to have well-defined processes and competent personnel in place. Overall, establishing comprehensive frameworks that integrate the right people, technology, and processes is key to ensuring data reliability and supporting better decision-making and strategic planning in public immovable asset management. Based on the empirical data, the conceptual framework has been thoroughly refined to facilitate SEM-PLS analysis. This refinement allows for a precise examination of how the factors of People, Technology, and Organization impact various categories of Data Quality–namely Intrinsic, Contextual, Representational, and Accessibility (Lee et al., 2006) (Pipino et al., 2002). These data quality categories, in turn, significantly influence the overarching Asset Management Strategy, offering a structured method to enhance asset management practices through improved data quality.



INDEPENDENT VARIABLES		
PEOPLE	P1	MANAGEMENT COMMITMENT
	P2	PERSONNEL COMPETENCIES AND TRAINING
	P3	EXTRINSIC REWARDS AND MOTIVATION
TECH	T1	IMPLEMENTATION OF TECHNOLOGY
	T2	SYSTEM INTEGRATION AND CAPABILITY
PROCESS	S1	DATA COLLECTION PROCESS DESIGN
	S2	DATA COLLECTION CLASSIFICATION FOR IMMOVEABLE ASSET
DEPENDENT VARIABLES		
DATA QUALITY DIMENSIONS	DQ1	ACCURACY
	DQ2	RELIABILITY
	DQ3	CONSISTENCY
	DQ4	SECURITY
	DQ5	TIMELINESS
	DQ6	COMPLETENESS
	DQ7	RELEVANCE
	DQ8	CURRENCY
	DQ9	UNDERSTANDABILITY
	DQ10	CONSICENESS
	DQ11	AVAILABILITY

Figure 3. Refined Conceptual Framework Using Integration of Empirical Data

The SEM-PLS framework was meticulously developed to explore and validate the intricate relationships between People, Technology, Process, and Data Quality dimensions. The refinement of the structural model was guided by empirical data collected from diverse sources. This data was instrumental in shaping the model to accurately capture and reflect the complexities inherent in managing data quality for immovable asset management. Figure 3 below illustrates the structural model, demonstrating how each element interconnects and contributes to a comprehensive asset management strategy. This model underscores the critical role of data quality in optimizing asset management and highlights the interplay between various factors that influence data quality and, ultimately, asset management effectiveness.

CONCLUSION

The pivotal role of people in maintaining high data quality is crucial and cannot be underestimated. Human elements such as management commitment, extrinsic rewards, and overall motivation are essential in the management of public immovable assets. The RBV of the firm posits that human capital is a key driver of organizational success (Gerhart & Feng, 2021). Effective data management demands not only skilled personnel but also individuals who are motivated and committed to upholding stringent data quality standards. Furthermore, the analysis of participant feedback in this study underscored the importance of management dedication and the provision of extrinsic rewards as significant factors. Participants emphasized that proper training, clearly defined roles and responsibilities, and motivation through incentives are crucial for enhancing data quality. For instance, Participant 4 highlighted that maintaining data quality begins with creating accurate data and adhering to structured procedures, highlighting the fundamental role of personnel in ensuring robust data quality.

Technology plays a fundamental role in enabling high data quality in asset management. The effective deployment of technological solutions, system integration, and proper configuration of information systems are critical for managing extensive data volumes with precision and efficiency. Moreover, existing literature suggests that advanced data management tools and systems can substantially improve data quality by automating data collection, validation, and analysis processes (Batini & Scannapieco, 2006). Participants in this study stressed the importance of leveraging technology to streamline data collection processes and ensure data accuracy. For instance, Participant 3 noted that technology should simplify data management and minimize human error, thus enhancing data reliability. Moreover, system integration is vital for consolidating disparate data sources into a unified repository, which serves as a single source of truth for effective asset management.

The design and implementation of data collection processes are vital for effective asset management. Standardized processes ensure that data is gathered consistently and accurately across various departments and functions (Otto & Reichert, 2014). Participants in this study highlighted the necessity of having simplified and standardized data collection procedures to enhance data quality. In particular, Participant 2 emphasized that standardized procedures and codes are essential for ensuring consistency and facilitating comprehensive data analysis. Additionally, addressing potential barriers such as data privacy concerns and online security threats is critical for preserving data integrity. Participant 4 highlighted that solid processes,

combined with effective training and technological support, are crucial for improving data quality.

This framework highlights the critical interplay between people, processes, and technology in ensuring high-quality data for effective asset management. Therefore, by prioritizing training and professional development, implementing standardized processes, and utilizing advanced technological tools, public sector organizations can significantly improve their data management practices. This, in turn, will lead to more effective asset management and enhanced service delivery.

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DIGITAL DATA FOR SHOPPING CENTRE RENTAL VALUATION: AN EXPLORATORY STUDY

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Abstract
The traditional paradigm of shopping centre rental valuation is poised for a significant transformation due to the untapped potential of readily available digital data. This research aimed to explore various types of digital data, along with their sources, and to investigate their potential applications in shopping centre rental valuation. This research employed an exploratory research design, selecting Pavilion Kuala Lumpur as a case study through a purposive sampling technique. Data were collected from diverse digital sources, including websites, geospatial platforms, and computer software. The findings demonstrate that digital data can provide valuable insights into shopping centre performance, retail unit characteristics, tenant mix composition, accessibility, catchment area characteristics, and other locational attributes. The integration of these digital data with traditional valuation methods leads to more holistic shopping centre rental valuations. The contribution of this research lies in identifying and recommending innovative applications of digital data, empowering valuers to make more informed valuation judgments in the rapidly evolving retail landscape.

Keywords: *Digital data; Rental valuation; Retail*

INTRODUCTION

Valuation is essential for the property sector, and accurate valuations are crucial. Traditionally, data availability was a critical aspect of valuation, and valuers' main strength was the data they held (Motta and Endsley, 2003). However, in light of the abundant availability of data, it is no longer the availability of data and market knowledge that differentiates valuers. It is, in fact, what they do with the data that differentiates them from their counterparts (Wilkinson et al., 2017). Within the valuation profession, the impact of technology and evolving client expectations is particularly significant (Nei et al., 2023). Traditional approaches to real estate valuation, relying heavily on historical market data, are no longer sufficient in this dynamic environment (Abdul Salam et al., 2021). However, despite the abundance of technology and data, its complete potential has not been utilized in valuation practices, often leading to valuers dedicating substantial time to data-related tasks (Yap and Munizaga, 2018). Recognizing the transformative impact of technology, particularly digital data and automated valuation, valuers need to enhance their knowledge and understanding of newly available data (RICS, 2017). While digital data offers valuable insights across industries, its untapped potential in real estate valuation remains an opportunity worth exploring (Brinch et al., 2020).

In Malaysia, property valuation heavily relies on transaction data, whether from sales or leasing, sourced from the government's Valuation and Property Services Department (JPPH).

The use of digital data in real estate studies has evolved beyond traditional sources (Lifang et al., 2023; Wu et al., 2022; Taşcılar and Arslanlı, 2022; Azizi and Rudnytskyi, 2022; Sánchez-Lozano et al., 2021; Chen and Xu, 2021). These studies highlight the diverse types of digital data available and their potential applications in real estate valuation. The issue is that despite the evolution of digital data in real estate studies, its application in shopping centre rental valuation remains unexplored (Brinch et al., 2020). This gap in research and practice suggests a significant opportunity to integrate digital data into the valuation of shopping centre rents. The contribution of this research lies in identifying and recommending applications of digital data that can empower valuers to make more informed valuation judgements.

AIM AND OBJECTIVES OF THE RESEARCH

Aim: To leverage the potential of digital data integration to improve shopping centre rental valuation.

Objectives:

i. To explore various types of digital data, along with their sources.
ii. To investigate the potential applications of digital data in shopping centre rental valuation.

LITERATURE REVIEW

Digital Data in Real Estate Studies

Digital data in real estate studies have evolved significantly, moving beyond reliance solely on traditional data sources. This transformation is characterized by two primary categories–transactional and non-transactional data. Within transactional data, Liu et al. (2018) employed data from the property listings website Fang.com to predict house values. Similarly, Clark and Lomax (2018) utilized data from Zoopla.com to predict residential rental prices in the English housing rental market. Akyüz et al. (2022) developed a hybrid algorithm using data from Sahibinden.com to create distinct housing clusters and make price predictions for each cluster. Chen and Xu (2021) proposed a novel scheme to crawl and mine housing transaction data from Lianjia.com, providing key information on unit price, geographical location, house area, type, orientation, and decoration type.

Non-transactional data sources have proved equally valuable. Wu et al. (2022) utilized Geographic Information Systems (GIS) data from the Geographical Information Monitoring Cloud Platform, combined with Gross Domestic Product (GDP) data from the Wuhan Municipal Bureau of Statistics website, to determine benchmark land prices using an automated valuation framework based on a back propagation (BP) neural network. Furthermore, spatial coordinates were extracted from rental websites such as Lianjia, Fangtianxia, and 58.com by Lifang et al. (2023) to explore the spatial distribution and price characteristics of housing rental prices in Wuhan. Additionally, GIS was instrumental in estimating the location attributes of houses for Sánchez-Lozano et al.'s (2021) study, which determined the impact of hotel-related and offer-specific variables on online room prices. Next, social media data also plays a crucial role in real estate studies. Taşcılar and Arslanlı (2022) gathered geo-tagged posts from Instagram and geo-referenced tweets from Twitter, using them to forecast commercial real estate prices in Istanbul. Kou and Gedik (2019)

incorporated behavioural information from Twitter and Facebook through crawler programs and Google Trend Index data to enhance the accuracy of housing price predictions in Australia. Incorporating imagery and visual data also proved to be significant. Azizi and Rudnytskyi (2022) incorporated unstructured visual data, including property images and satellite views, into their rental pricing models using the Swiss Real Estate Dataset (SRED). Wu et al. (2016) employed GIS to analyse potential factors influencing housing prices by examining Shenzhen housing transaction data, encompassing locational and neighbourhood attributes such as proximity to essential facilities.

Shopping Centre Rental Valuation

Valuation, seen as art and science, requires market value opinions backed by comprehensive information detailed in the valuation report. The valuation process is critical for determining the market value of tangible and intangible assets, forming the basis for significant decisions. It demands compliance with the Malaysian Valuation Standards (MVS) and International Valuation Standards (IVS), ensuring a consistent and transparent approach (RICS, 2017). Malaysian valuation practice follows a structured method involving client instruction, analysis of nearby property transaction values using JPPH data, property inspection, identification of suitable valuation methods, market value determination, and comprehensive report preparation (Nei et al., 2023).

In shopping centre rental valuation, valuation is intricately tied to lease terms, primarily base rent and percentage rent. Base rent is a fixed amount tenants must pay regardless of sales, while percentage rent is a predetermined percentage of sales, payable when sales exceed a threshold, with tenants paying the higher of the two (Raslanas and Lukošienė, 2013). This enables landlords to charge higher rents for successful tenants. Retail units in the same shopping centre often have varying rental rates, with base rent inversely related to sales externalities and revenue percentages varying with base rent (Guven et al., 2019). These dynamics add complexity to the valuation process.

Factors Influencing Shopping Centre Rental Rate

Shopping centres, categorized as commercial real estate, are influenced by several factors that determine the rental rates of their retail units. Older shopping centres typically offer lower rental rates compared to newer ones due to outdated facilities (Goh et al., 2020). The shopping centre location, with those in densely populated areas and easy accessibility, experiences higher rental rates. The location of a retail unit within a shopping centre also influences its rental rate. Prime locations, the floor level of a retail unit, especially those on the ground floor, with better visibility and accessibility often result in higher rental rates (Lundgren et al., 2022). The size of a shopping centre is also an influence on rental rates. Larger shopping centres are preferred due to the convenience of a one-stop centre (Huri et al., 2022). A diverse tenant mix attracts a broader customer base and increases rental rates (Zhang et al., 2020). Accessibility and amenities such as public transport and parking enhance shopping centre attractiveness, driving customer inflow. This translates to higher rental rates, as attractive shopping centres create a vibrant retail environment with increased tenant sales (Liu et al., 2020). The type of tenant, particularly anchor tenants, significantly influences rental rates, with their presence attracting more foot traffic and benefiting smaller tenants. Anchor tenants often enjoy lower rental rates due to their customer drawing power (Goh et al., 2020).

RESEARCH METHODOLOGY

This research employed an exploratory design to investigate the untapped potential of readily available digital data for shopping centre rental valuation. This research focused on exploring the breadth and depth of data obtainable through various digital sources, aiming to discover potential applications and identify suitable data for use in valuation practices. Utilizing purposive sampling, a non-probability sampling method, Pavilion Kuala Lumpur (KL) was selected as the case study due to its prominence as a major shopping centre in the Klang Valley, serving as a benchmark for others in the region. Pavilion KL, known for its high-end status and diverse array of luxury and international brands, was chosen to represent the upscale consumer market segment and provide abundant digital data opportunities. In-depth information was obtained through observation, allowing for a detailed understanding of the digital data's application in the context of Pavilion KL.

Secondary data was collected from reputable online platforms, ensuring current, reliable, and relevant data acquisition. The approach included web scraping techniques to extract data directly from websites, focusing on tenant mix composition, retail unit characteristics, and other pertinent details. Geocoding facilitated the assignment of geographical coordinates to the extracted data, enabling spatial analysis to explore potential relationships impacting rental values. Quantum Geographic Information System (QGIS) was utilized for data visualization and analysis, facilitating the identification and evaluation of digital data sources and their contributions to shopping centre rental valuation processes. This methodological framework ensures a comprehensive exploration of digital data's potential in enhancing the efficiency of shopping centre rental valuations.

Case Study

Pavilion KL, classified as a super regional shopping centre by NAPIC (2021), serves as the case study for this research.

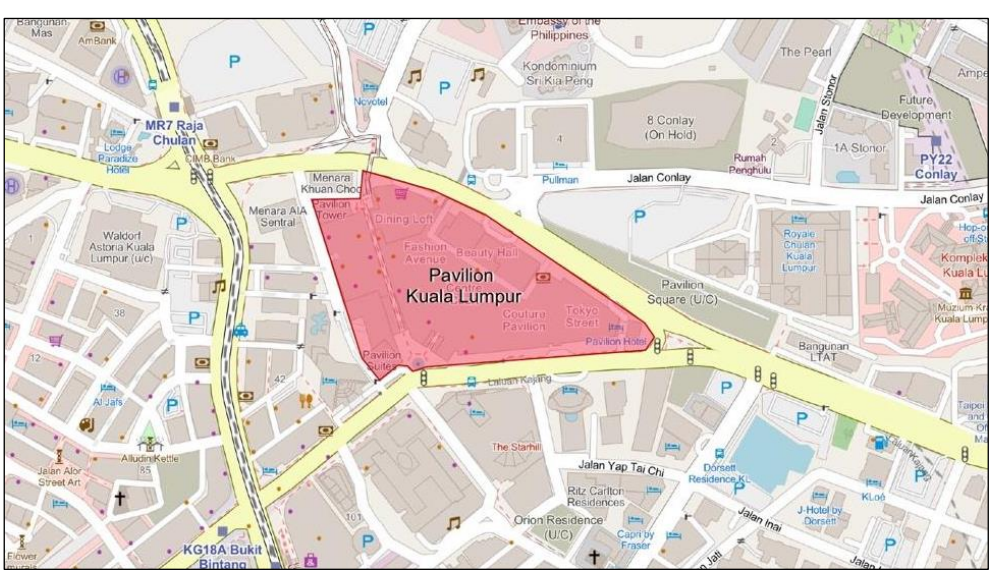

Figure 1. Map of Case Study - Pavilion KL (Created using ArcGIS Online)

Table 1. Case Study Profile – Pavilion KL

Parameter	Details
Classification	Super regional shopping centre
Address	168, Jalan Bukit Bintang, 55100 Kuala Lumpur, Malaysia
Completion date	20 September 2007 (Phase 1); 9 December 2016 (Phase 2)
No. of retail floors	7
Gross Floor Area (GFA)	2,356,397 square feet
Net lettable area (NLA)	1,610,000 square feet
No. of retail units	Over 600
No. of carpark bays	2,626 bays
Occupancy rate	95.2%
Appraised value	RM 5,150 million
Date of latest valuation	31 December 2023
Ten largest tenants	Cartier, Dadi Cinema, Food Republic, Forever 21, Hermes, Mercato, Padini Concept Store, Parkson, Richard Mille, Zara

(Source: Pavilion KL Overview and Factsheet, 2024; Pavilion REIT Annual Report, 2023)

RESULTS AND DISCUSSION

This research discovered digital data types and sources relevant to shopping centre rental valuation. The findings are divided into two main parts. Firstly, the 'Digital Data Types and Sources' part discussed the identified types of digital data and their sources, detailing how they can be utilized in shopping centre rental valuation. Secondly, the 'Case Study Discussion' part provided an analysis of a case study, illustrating practical applications of the identified digital data in real-world valuation scenarios.

Digital Data Types and Sources

Google Earth and Google Maps

Valuers can utilize Google Earth and Google Maps to enhance property inspections and valuations. Google Earth provides satellite and aerial imagery for verifying property existence and identifying nearby amenities (Koeva et al., 2021). Google Maps, leveraging GPS technology, offers accurate positioning by triangulating signals from at least three satellites (Kiran et al., 2022). The "Nearby" feature helps valuers identify competitor shopping centres and create driving time isochrones, visually representing areas reachable within a specific timeframe. By factoring in competitors, valuers can adjust these isochrones to reflect the true catchment area of the shopping centre.

OpenRouteService (ORS) and OpenStreetMap (OSM)

OpenRouteService (ORS) is an open-source platform that offers comprehensive routing and isochrone generation (Prayogi et al., 2022). It aggregates data from various sources, primarily OpenStreetMap (OSM), a collaborative geospatial database under the Open Database License (ODbL). OSM's open-source nature introduces certain limitations. The data quality can be inconsistent, with some regions benefiting from frequent contributions while others may have sparse or outdated information. The lack of standardized data entry methods

and contributions from users with varying skill levels can lead to inaccuracies compared to proprietary datasets (Ehrig-Page, 2020). OSM data can be utilized to evaluate accessibility metrics relevant to shopping centre valuation, such as travel times to public transport and potential foot traffic based on pedestrian access. As a constantly evolving platform, OSM provides data on facilities and amenities, public transport infrastructure, pedestrian walkways, and surrounding developments.

BBBike

BBBike is an open-source software tool that provides valuers with essential spatial data for shopping centre valuation. It leverages data from OSM, a collaborative geospatial database known for its extensive coverage, and incorporates user-generated Points of Interest (POIs), including road networks, public transport hubs, commercial areas, and residential zones (Lovelace, 2021). BBBike identifies and analyzes POIs within a shopping centre's catchment area, allowing valuers to evaluate factors influencing value, such as accessibility, competition, and demographics. Proximity to public transport and pedestrian pathways significantly affects customer foot traffic (Liu et al., 2020). The tool also helps identify nearby shopping centres and their offerings, providing insights into the competitive landscape and analyzing residential areas within the catchment to assess the potential customer base. Data from BBBike can be integrated into QGIS for spatial analysis, offering a comprehensive view of the catchment area.

Geocode by Awesome Table

Geocode by Awesome Table is instrumental in extracting latitude and longitude coordinates from addresses, a process that converts data to absolute values (Sharba et al., 2020). Utilizing tenant brand names, lot numbers, and shopping centre names, this extension streamlines the address generation process for geocoding. By leveraging the Google Maps database and utilizing the full address generated, the extension automatically extracts coordinate data. The resulting geographical coordinates can be analyzed for micro-location within shopping centres, as the location of retail units affects rental rates (Huri et al., 2022).

Quantum Geographic Information System (QGIS)

QGIS is an open-source, cross-platform desktop GIS that enables geographical data assembly, storage, manipulation, analysis, and display (Vikhot et al., 2022). It allows users to create, edit, visualize, and analyse data. QGIS can also be enhanced with plugins designed to streamline workflows or perform specific types of analysis (Ehrig-Page, 2020). QGIS is crucial for analysing shopping centre locations by leveraging data from various layers. For example, POIs from BBBike can be mapped and analysed within QGIS. QGIS supports the analysis of shopping centre catchment areas through buffer analysis, which represents designated radii. Additionally, sing hub lines distance analysis, QGIS can assess distances between retail units and key locations within shopping centres, such as entrances and central areas.

Malaysia Geospatial Online Services (MyGOS)

MyGOS, a government-developed online platform, facilitates secure information sharing and offers real-time access to geospatial data, including information on shopping centre locations. By leveraging MyGOS, valuers can acquire and analyse these spatial data to better understand a shopping centre's location within the broader geographical context.

Shopping Centre Website

The directory on the shopping centre website, organized by trade categories, provides essential information for analysing tenant mix. It includes brand names, lot numbers, types of tenants, and floor levels for each retail unit, offering a comprehensive view of their positioning within the shopping centre. Lot numbers plotted on the mall map allow visualization of each retail unit's location. Additionally, data on available amenities and facilities can be used to evaluate the overall attractiveness of the shopping centre.

National Property Information Centre (NAPIC) Website

National Property Information Centre (NAPIC) is a Malaysian government agency monitoring property market performance. It provides accurate, comprehensive, and timely property demand and supply data to government agencies, developers, and industry stakeholders (Ishak et al., 2024). NAPIC's website offers various publications and datasets, including property market reports, rental data, transaction data, occupancy rates, stock data, and property indices such as the Klang Valley Shopping Centre Rental Index (KV-SCRI). Much of this data, including the latest market reports and visualizations, is freely accessible to the public, facilitating informed decision-making in property valuation.

Case Study Discussion

The Pavilion KL case study highlights digital data integration into the retail valuation process. Utilizing tools such as Google Earth and Google Maps, this research identified 19 schools within a 30-minute drive from Pavilion KL, emphasizing its location in a well-established neighbourhood. This contextual information enhances the understanding of Pavilion KL's catchment area, contributing to a comprehensive assessment of its market potential.

ORS and OSM data were used to identify nearby public transportation options. The MRT Bukit Bintang station (369 metres) and Monorail Bukit Bintang station (387 metres) were identified as key transit points that enhance Pavilion KL's accessibility. Additional details from Pavilion KL's website, including its five entrances (Main Entrance, Bukit Bintang Entrance, Chulan Entrance, Porte Cochere Entrance, and Couture Pavilion Entrance), provided further insights into its accessibility. Notably, accessibility to transit has a significant positive effect on retail property values (Liu et al., 2020).

Web scraping techniques were employed on Pavilion KL's shopping centre website to extract data on over 600 retail units. The data collected, including brand names, lot numbers, floor levels, tenant types, and trade categories, is presented in Table 2 to demonstrate the range of available information from digital sources.

Table 2. Data Available from Digital Sources

Tenant	Lot No.	Floor Level	Coordinate	Tenant Type	Trade Category
Mercato	Lot 1.01.01, Lot 1.01.02	Level 1	3.14980, 101.71279	Anchor	Supermarket
Dadi Cinema	Lot C5.01.00, Lot C6.01.00	Level 5, Level 6	3.14969, 101.71254	Anchor	Entertainment
Guardian	Lot 1.26.00	Level 1	3.14847, 101.71437	Non-Anchor	Health and Beauty
Michael Kors	Lot 2.10.1A	Level 2	3.14858, 101.71310	Non-Anchor	Fashion Accessories
Paris Baguette	Lot C3.03.00	Level 3	3.14960, 101.71256	Non-Anchor	Food and Beverage
Harvey Norman	Lot 5.24.04	Level 5	3.14848, 101.71467	Non-Anchor	Home and Furnishing
U Mobile	Lot TL1.100.00	Level 1	3.14808, 101.71266	Non-Anchor	IT and Telecommunications
Mail Boxes Etc	Lot 2M.06.00	Level 2	3.14896, 101.71341	Non-Anchor	Services and Specialty
BookXcess	Lot 6.49.01	Level 6	3.14963, 101.71327	Non-Anchor	Books and Stationery
Toys"R"Us	Lot 7.103.00	Level 7	3.14838, 101.71266	Non-Anchor	Hobbies, Pets, and Toys

(Source: Author, 2024)

Spatial analysis using QGIS was conducted to measure distances between retail units and various POIs. BBBike POIs data was downloaded in shapefile format and imported into QGIS, allowing mapping and analysis of these points. This analysis provided valuable insights into the spatial relationships within Pavilion KL (see Table 3). Furthermore, QGIS was used to create buffer zones around Pavilion KL, establishing a 10-kilometre radius to capture the distribution of POIs (see Table 4). This 10-kilometre radius is consistent with established methods in geospatial studies on shopping centres (Cheng et al., 2007). The supply and demand factors influencing retail property rentals vary, with rental adjustments occurring more quickly in tourist-dominated areas compared to local-dominated ones (Yang et al., 2021). This highlights that a shopping centre's location within a dense and accessible area and proximity to key amenities can significantly enhance its rental potential, making the location a critical determinant in retail valuation.

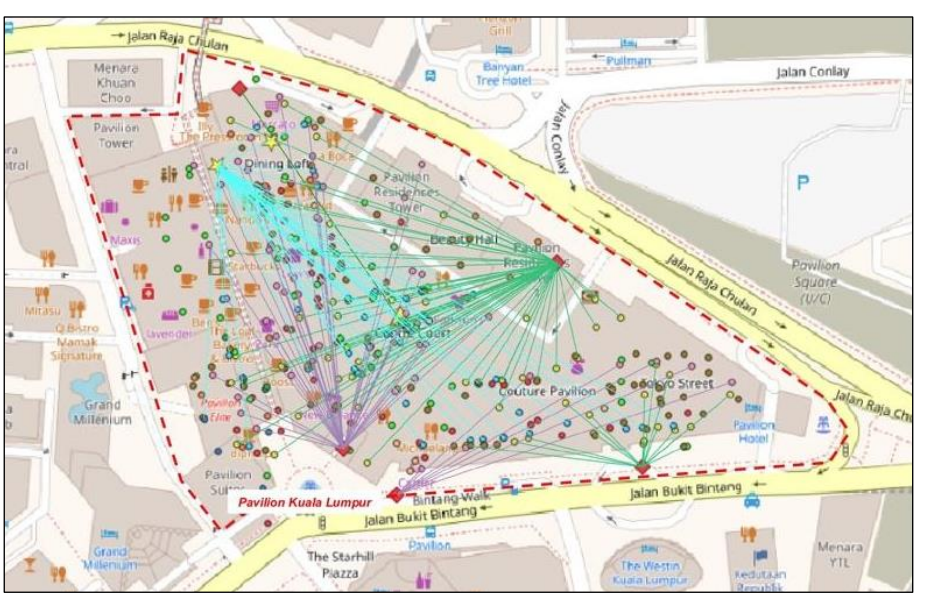

Figure 2. QGIS Hub Lines Distance Analysis

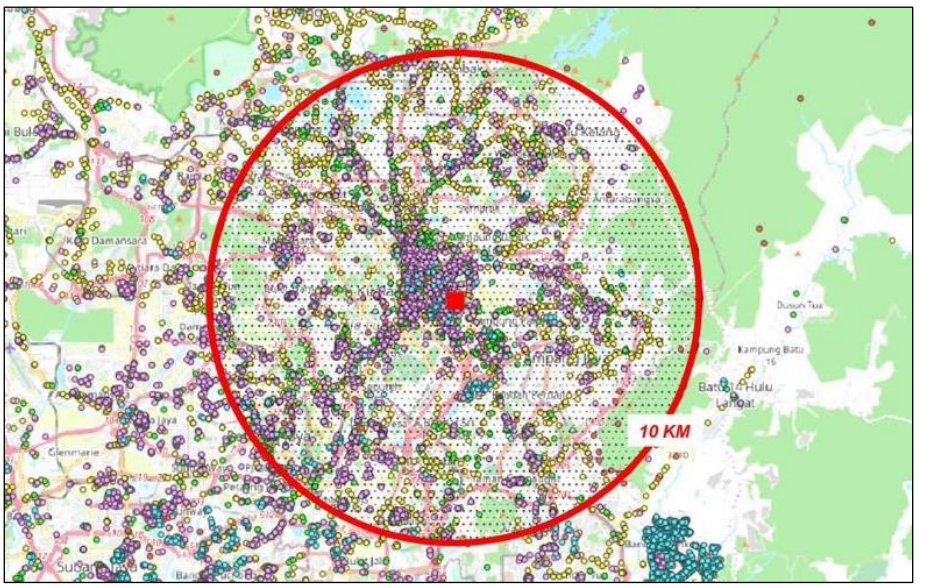

Figure 3. QGIS Buffer Analysis

Table 3. QGIS Hub Lines Distance Analysis Results

InputID	TargetID	Distance (metres)
% Arabica	Main Entrance	67.56
Cartier	Bukit Bintang Entrance	18.69
Cleanruum	Chulan Entrance	147.66
Saint Laurent	Couture Pavilion Entrance	91.97
Balenciaga	Porte Cochere Entrance	85.71
Koong Woh Tong	Anchor tenant - Mercato	25.84
KyoChon	Anchor tenant - Mercato	58.25
Lavender Bakery	Anchor tenant - Mercato	65.72
Puma	Anchor tenant - Dadi Cinema	28.56
Birkenstock	Anchor tenant - Dadi Cinema	25.49

(Source: Author, 2024)

Table 4. QGIS Buffer Analysis Results

InputID	TargetID	Numpoints
Pavilion KL	Residential	159
Pavilion KL	Commercial	2,971
Pavilion KL	Amenities and Facilities	1,489
Pavilion KL	Recreational and Cultural	127

(Source: Author, 2024)

Table 3 highlights the positioning of various retail units relative to entrances and anchor tenants, such as Cartier, which benefits from its proximity to the Bukit Bintang entrance (18.69 metres). Koong Woh Tong (25.84 metres), KyoChon (58.25 metres), and Lavender Bakery (65.72 metres) located near the anchor tenant – Mercato, may benefit from the increased customer flow driven by the anchor tenant. Puma (28.56 metres) and Birkenstock (25.49 metres), close to anchor tenant – Dadi Cinema, are likely to attract those drawn to the cinema. Table 4 details the distribution of various POIs around Pavilion KL. The high concentration of commercial POIs, with 2,971 establishments, underscores a robust

commercial environment. In contrast, the lower number of residential POIs, 159 establishments, indicates that residential properties are less prevalent in the immediate area. The presence of amenities and facilities, with 1,489 POIs, reflects a significant number of essential services available around Pavilion KL. At the same time, there are fewer recreational and cultural POIs, with 127 establishments.

MyGOS provided detailed insights into Pavilion KL's precise location within the Central Business District (CBD), in Section 63 of Wilayah Persekutuan Kuala Lumpur (WPKL), in the Bukit Bintang zone. Geocoding tools can benefit more granular analysis of retail unit locations within the shopping centre. Geocode by Awesome Table simplifies the extraction of latitude and longitude coordinates, leveraging the Google Maps database to retrieve this data. These geographical coordinates can be instrumental in analysing the micro-location of retail units within Pavilion KL. Visibility positively affects retail unit rental prices, with proximity to entrances and anchor tenants being key factors influencing rental rates (Khairunnisa and Gamal, 2022). The QGIS hub lines distance analysis was used to assess the proximity of retail units to key locations, such as entrances and anchor tenants. This analysis offers valuable insights, as proximity to high-traffic areas is known to significantly influence rental rates. Additionally, the food and beverage category significantly impact rents in super regional malls, with tenancy period and location being the crucial factors (Huri et al., 2022). However, the overall tenant mix also plays a vital role in shaping these dynamics, as the synergy between different retail categories influences customer flow, affecting rental values. Figure 4 illustrates the tenant mix for Pavilion KL, generated using data from the shopping centre website. As a premium fashion mall, Pavilion KL's primary trade category is fashion, followed by food and beverages.

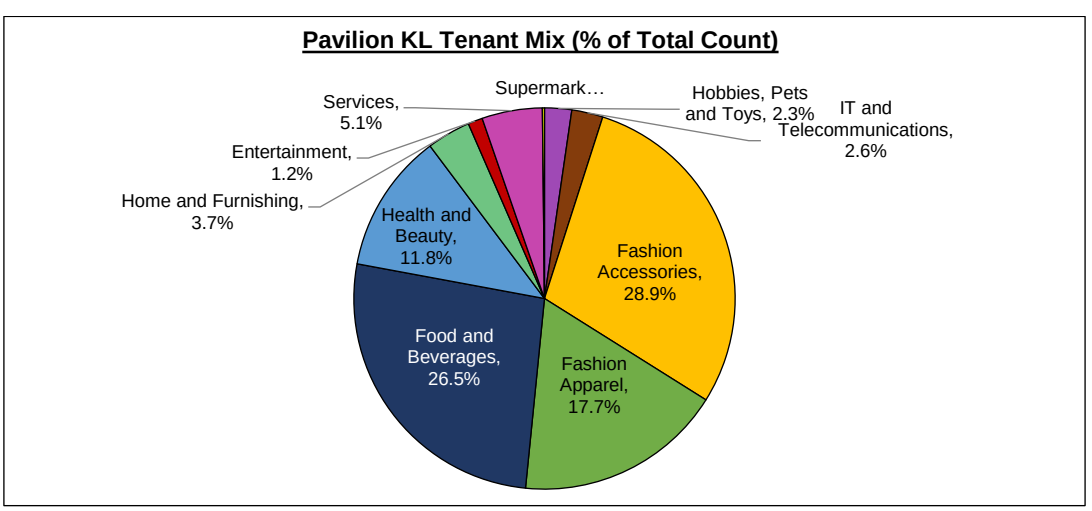

Figure 4. Tenant Mix Analysis

The analysis presented in Figure 5 displays the trends in occupancy rates for Pavilion KL from 2016 to 2023, compared to the average occupancy rates of shopping complexes in WPKL. By utilizing data from the NAPIC website, valuers can understand Pavilion KL's performance over the years. Pavilion KL generally outperformed the average occupancy rate of shopping complexes in WPKL, maintaining occupancy rates above 90% throughout the observed period. This is significantly higher than the average occupancy rate of other shopping complexes in WPKL, which was below 90% during the same timeframe.

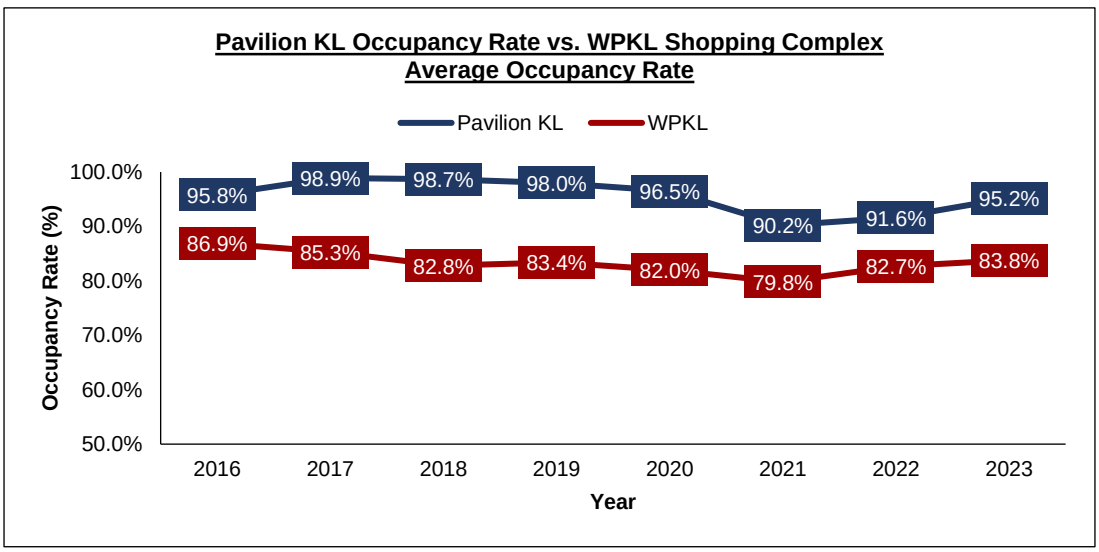

Figure 5. Occupancy Rate Analysis

The significance of the findings lies in the potential to improve rental valuation practices for shopping centres. This research demonstrates how valuers can streamline their valuation practices using digital data. By incorporating digital data, valuers can better understand the factors influencing rental rates, leading to more informed decisions and fairer valuations.

CONCLUSION

This research has demonstrated the potential of digital data integration to enhance shopping centre rental valuation. By identifying and exploring a range of relevant digital data types and sources, including Google Earth, Google Maps, OpenRouteService, OpenStreetMap, BBBike, Geocode by Awesome Table, QGIS, MyGOS, shopping centre, and NAPIC websites, this research has highlighted their role in shopping centre rental valuation. The case study of Pavilion KL showcased the practical application of these digital tools in enhancing property inspections, accessibility analysis, spatial data collection and analysis, tenant mix analysis, and occupancy rate analysis. The integration of these digital data with traditional valuation methods leads to more holistic shopping centre rental valuations, aligning with the research aims and objectives. It is important to acknowledge that limitations exist when using digital data sources. Data accuracy and completeness can vary depending on the source. However, the approach outlined in the case study offers a replicable method for shopping centre valuation in other locations, allowing for the incorporation of future data updates and improvements. To further advance the field, future research should focus on quantifying the impact of digital data on valuation accuracy and exploring the potential of advanced analytical techniques to extract valuable insights from digital data.

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MONITORING VERTICAL DISPLACEMENT OF THE GROUND SURFACE USING INSAR

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Abstract
Land subsidence is a significant natural phenomenon currently affecting regions worldwide. It occurs gradually when the ground sinks due to urban development, excavation of underground soil for construction, and rising sea levels. While the impact is not immediately apparent, it can profoundly affect society over time. This study aims to analyze land subsidence in the Klang area, Selangor, Malaysia, using Interferometric Synthetic Aperture Radar (InSAR) since it can complement conventional techniques. Satellite interferometry was used to monitor subsidence patterns from March 2022 to September 2023, with the satellite returning to the area every twelve days. In order to validate the InSAR data from Sentinel-1, Global Navigation Satellite System (GNSS) data from a Continuously Operating Reference Station (CORS) from the Malaysia Real-Time Kinematic network (MyRTKnet) was utilized. It covers vertical motion from March 2022 to October 2022. The outcomes indicated a range of deformation rates, from a maximum of 10.3 mm/year to a minimum of -19.4 mm/year, represented with corresponding color gradients. In addition, a decreasing trend was observed in the Line of Sight (LOS) Time Series between March 2022 and September 2023.

Keywords: *GNSS; InSAR; Monitoring; Line of Sight*

INTRODUCTION

Land subsidence is one of the natural phenomena that the world is facing nowadays. Subsidence occurs as the ground slowly sinks due to the development of urbanization, the removal of the underground soil for piling and the rising sea level. Furthermore, ground settling may result from the weight of engineered projects, such as buildings and bridges, being constructed on reclaimed land or from an unconsolidated foundation. Consequently, excessive compensation might result in significant safety concerns, production halts, and even fatalities (Matori and Latip, 2019). This phenomenon develops gradually, yet its consequences for society can be far-reaching. Around 150 countries worldwide experience land subsidence, which has severe consequences and triggered effects. These include densely populated urban areas like major cities in China, India, Turkey, Iran, Italy, Japan, Mexico, Indonesia and Pakistan (Hussain et al., 2022).

Furthermore, land subsidence is a critical factor affecting engineering structures such as buildings, dams, and bridges. Notably, uneven soil subsidence can lead to ground cracks, posing risks to urban facilities (Lyu et al., 2020). In many regions worldwide, building deformation has become a significant threat to both property and people. For example, flood-prone areas often experience building deformations that result in severe damage. In Selangor, rapid urban development and the construction of public transportation systems contribute to these deformation factors. Consequently, monitoring building stability is essential to prevent accidents.

To measure the long-term rate of land changes, land subsidence is monitored, and deformation is conducted. As such, several methods are being used to monitor these small land changes with fast-advancing technology. Essentially, the methods can be grouped into geodetic and non-geodetic techniques. Geodetic monitoring techniques are a suite of tools scientists and engineers use to measure tiny changes in the Earth's surface. The method that can monitor the deformation measurement is the Global Positioning System (GPS). Notably, the advantage of using GPS is that the intervisibility of interest points is not required. It can also be used for observation during the day and night under varying weather conditions. The recent development of measuring techniques, such as rapid static positioning, can reduce the observation time to a mere few minutes. Meanwhile, non-geodetic monitoring techniques are often used in conjunction with geodetic techniques to provide a more complete picture of the deformation process. Tiltmeter is among the frequently used non-geodetic monitoring methods. Notably, tiltmeters are instruments that measure changes in the tilt of the ground. It is often used to monitor the stability of slopes and to detect volcanic activity.

Due to atmospheric delay brought on by varying satellite orientations, atmospheric variations, and lengthy acquisition intervals, as well as limitations imposed by spatial and temporal deconvolution, Persistent Scatter Interferometric Synthetic Aperture Radar (PS-InSAR) was designed to overcome the standard InSAR approach's incoherence restriction over extended time intervals and large regions (Fiorentini et al., 2021). Furthermore, PS-InSAR can change and enhance the subsidence assessment, decreasing it from 10 to 20 mm to 2-3 mm. The advanced methodology is a subclass of multitemporal InSAR methods that allow us to recover ground displacement proceeds to the millimetre precisely. Furthermore, the PS-InSAR technique helps detect urban land subsidence because constructed infrastructure and amenities provide higher-density Persistent Scatter (PS) locations and significantly boost the signal-to-noise ratio of interferograms (Tofani et al., 2013). In order to detect land subsidence using Sentinel-1 data in metropolitan areas, PS-InSAR is widely used in Beijing, Algeria, London, Mashhad (Middle East), Los Angeles, Spain, coastal areas of Africa and Poland (Hussain et al., 2022). In this study also, the Sentinel Application Platform (SNAP) and Stanford Method for Persistent Scatterers (StaMPs) software were implemented in order to estimate the Line of Sight (LOS) via Sentinel-1 Synthetic Aperture Radar (SAR) data, vertical deformation using InSAR and conventional technique and calculate the rate of subsidence.

Malaysia is one of the Asian countries experiencing land subsidence in specific areas. A study by Muhammad et al. (2020) revealed an alarming increase in the rate of land subsidence in Malaysia. The primary cause of this phenomenon is the rapid development of urban areas and city infrastructure. Zawawi et al. (2023) highlighted the high risk of land subsidence in coastal cities around Malaysia due to rising sea levels. Meanwhile, research on sea level rise in Malaysia revealed an estimated annual rise between 0.67 and 0.74 mm. Notably, the combination of sea level rise and land subsidence poses a significant challenge, potentially leading to the submergence of coastal cities. Moreover, Asian countries that have been experiencing a phenomenon known as land subsidence include China, Indonesia, and Malaysia. Over the past few years, land subsidence has become increasingly common throughout Malaysia, which is concerning. The reason for this is the rapid growth of urban infrastructure. In addition, other researchers stated that land subsidence has become a more significant issue in Malaysia, affecting multiple cities in some way over the years (Julzarika

et al., 2023). The arrival of residential areas, a rise in population density, more easily available transit options, and topographical changes have all contributed to the development of cities.

Although conventional techniques for monitoring land deformation are still valuable, they have certain drawbacks compared to the InSAR technique. Traditional methods like precise levelling and total station measurements typically involve placing instruments at specific points. This provides detailed data for those points but may not capture the bigger picture of deformation across a wider area. Moreover, conventional techniques often require repeated site visits to measure changes over time, leading to data gaps and making it challenging to detect slow-moving deformation. Meanwhile, the advantage of using InSAR is that it utilizes satellite data to provide high-resolution images covering vast areas. This allows for comprehensive monitoring of deformation across entire regions, capturing the bigger picture of land movement.

The occurrence of land subsidence in Malaysia necessitates studies to detect and monitor this phenomenon. Early awareness is crucial, particularly for local residents. Therefore, proactive action is necessary to prevent future tragedies. In particular, studies to detect land subsidence offer several benefits to the community. For instance, early detection allows for timely intervention and mitigation efforts, minimizing the need for expensive repairs after significant subsidence. The benefit is also a reduced burden on life. Furthermore, proactive measures can help lessen the disruption and hardship caused by subsidence in daily life, infrastructure, and property. Moreover, early identification of subsidence zones allows for the implementation of preventative measures and evacuation plans, safeguarding public safety. Accordingly, by prioritizing these studies and acting based on their findings, Malaysia can effectively manage land subsidence and protect its communities.

Hence, this study aims to interpret the land subsidence at Klang by implementing the InSAR technique. As a result, 19 images acquired from Sentinel-1A were processed using the SNAP and the StaMPS. Note that the results of this study include a deformation map and a time series analysis.

METHOD

Study Area

The study area selected is Klang, Selangor. Klang is a district of Selangor, Malaysia, and it is easily accessible from Kuala Lumpur in 45 minutes by car via the New Klang Valley Motorway and from Klang in 15 minutes by car via Jalan Meru. Meru's location, just 10 km from Klang town and closer to Bandar Setia Alam, which connects directly to NKVE, has allowed it to flourish during the past ten years with significant industrial and residential development. Due to the industrial development in the city of Klang, the vertical displacement of the ground needs to be monitored as calamities such as flash floods and subsidence frequently occur in that particular area. Apart from that, a report by the behavioural and social science research firm Center for Governance and Political Studies, published in November 2019, illustrated how many Malaysian cities, including large portions of Klang, may be underwater by 2050.

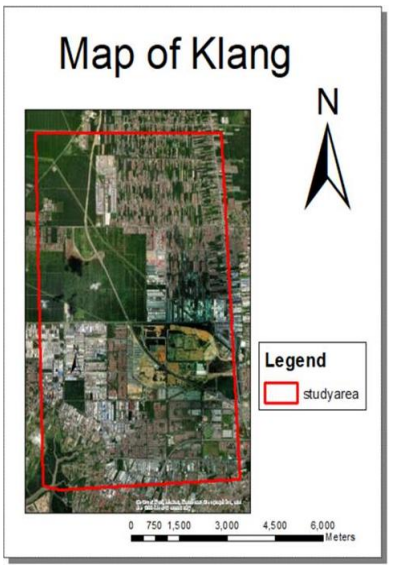

Figure 1. The Map of Klang, Selangor

Data Collection

InSAR

For a duration of one (1) year and six (6) months, Klang's area was monitored using InSAR, with a satellite revisit every twelve days. The Alaskan Satellite Facility is the primary open source from which InSAR image data is collected. Therefore, in terms of InSAR data, 19 images covering the full year and a half from March 3, 2022, to September 6, 2023, were downloaded from the website. Table 1 provides the list of the data:

Table 1. 19 Imagery and Data for PS-InSAR

File Type: S1A IW SLC				Flight Direction: Descending Mode		
Master/Slaves	**Acquisition**	**Track**	**Orbit**	**Bperp (m)**	**Btemp (days)**	**Model Coherence**
Master	5/10/2022	91	45313	0	0	1.00
Slaves	3/3/2022	91	42163	85.09	216.00	0.75
Slaves	8/4/2022	91	42688	46.38	180.00	0.80
Slaves	2/5/2022	91	43038	11.46	156.00	0.85
Slaves	7/6/2022	91	43563	201.87	120.00	0.74
Slaves	1/7/2022	91	43913	119.86	96.00	0.82
Slaves	18/8/2022	91	44613	162.86	48.00	0.82
Slaves	11/9/2022	91	44963	226.97	24.00	0.79
Slaves	10/11/2022	91	45838	25.72	-36.00	0.95
Slaves	4/12/2022	91	46188	139.37	-60.00	0.83
Slaves	9/1/2023	91	46713	33.08	-96.00	0.88
Slaves	2/2/2023	91	47063	131.29	-120.00	0.79
Slaves	10/3/2023	91	47588	95.81	-156.00	0.79
Slaves	3/4/2023	91	47938	122.69	-180.00	0.75
Slaves	9/5/2023	91	48463	105.62	-216.00	0.73
Slaves	2/6/2023	91	48813	171.69	-240.00	0.67
Slaves	8/7/2023	91	49338	185.53	-276.00	0.63
Slaves	1/8/2023	91	49688	17.45	-300.00	0.71
Slaves	6/9/2023	91	50213	99.36	-336.00	0.64

MyRTKnet CORS Station MERU

In order to validate with the InSAR data set from Sentinel-1, the measurement of ellipsoidal height from a Continuously Operating Reference Station (CORS) station from the Department of Survey and Mapping Malaysia (DSMM) was compared. To eliminate systematic errors in GNSS models and achieve high positional accuracy from a single receiver, Global Navigation Satellite System (GNSS) data sets are verified using online GNSS post-processing software, such as Australia Online GPS Processing Service (AUSPOS).

Data Processing

InSAR

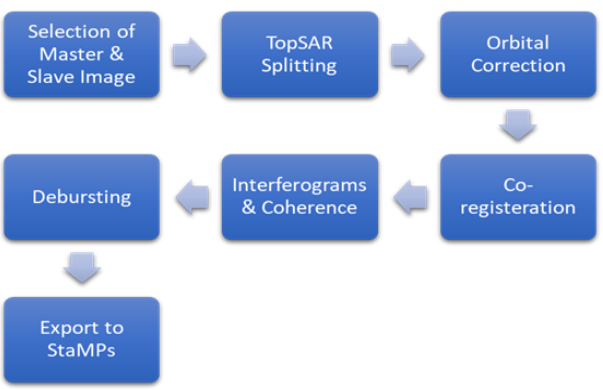

Figure 2. DInSAR Processing

Differential Interferometric Synthetic Aperture Radar (DInSAR) processing is a technique to generate coherence and interferograms, and both elements are vital in Stamp processing. Figure 2 displays a brief overview of the process.

The first step is the selection of master and slave images. It is crucial to choose a master image that is nominallypositioned in relation to the other images (slave) in terms of spatial and temporal baseline values in order to achieve better coherence and high co-registration accuracy. Next is TopSAR splitting. In this stage, sub-swaths of the primary image were chosen or divided according to the size of the study area. The next step is orbital correction. An accurate orbital information can lead to false displacement measurements, affecting the reliability of InSAR. Consequently, co-registration is the process where all the images are geometrically aligned using the primary image as a base or reference to the secondary images. Subsequently, the difference between the phase values of two co-registered SAR images will form differential interferograms. After that, deburstring combines the sub-swaths and bursts of each individual interferogram and coherence product to create spatially continuous products. Finally,the product produced is exported into the StaMPS software. PS-InSAR processing is a technique that generates the deformation map over time. This processing was conducted using StaMPS software. The following is a brief overview of the process:

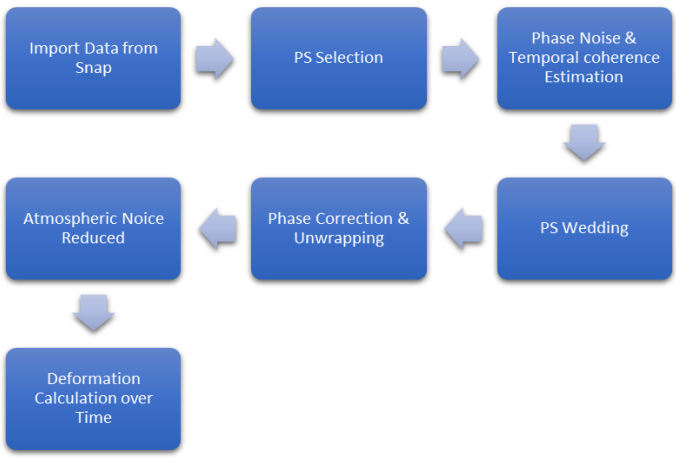

Figure 3. PS-InSAR Processing

The data processed in the SNAP software were imported into StaMPS via MATLAB. The amplitude and phase characteristics of the PS should be considered to aid in PS selection. After that, the spatiallycorrelated and uncorrelated phase noise values were estimated and improved upon through a few iterations. The next stage is the PS wedding. Among these were PS candidates whose candidates declined because of signal contribution from nearby pixels, as well as duplicate PS candidatesthat resulted from incorrect geocoding. Plus, the noisy phase with a standard deviation value greaterthan one will be executed. An unwrapped phase is a continuous representation of the phase informationcontained within a signal. Thus, the phase unwrapping restored each PS point to the correct multiple of 2π. Spatial filtering was used to estimate and eliminate any spatially correlated errors from the deformation estimate. The Atmospheric Phase Screen (APS) results from changes in the signal speed on the line between the antenna and the terrain surface caused by the heterogeneity of the atmosphere (ionosphere and troposphere) and its variation over time and space. In order to eliminate the APS, a toolbox for reducing atmospheric InSAR noise (TRAIN) was implemented to mitigate atmospheric effects in InSAR data. TRAIN provides various methods, and linear correction was used for tropospheric correction. Lastly, the result of the velocity map was visualized by indicating the value ofrate deformation in mm/y.

Subsequently, the mean LOS displacement rates, expressed in millimetres per year (mm/year), were estimated using the unwrapped phase observations. Positive displacement rates indicate that the PS pixels are moving towards the satellite (uplift), while negative values signify subsidence, with the PS pixels moving away from the satellite.

MyRTKnet CORS Station MERU

The data received from DSMM were formed raw and needed to be merged for 24 hours. The GFZRNX toolbox, developed by the GNSS community, is compatible with Receiver Independent Exchange (RINEX) meteorological, navigation, and observation data. Once the RINEX data were merged to form 24 hours a day, the data was directly submitted to the AUSPOS. The parameters used for AUSPOS are stated in Table 2.

Table 2. The Parameters Used for AUSPOS

Parameters	MERU
Modelled Observable	Double differences of the ionosphere-free linear combination.
Software	Bernese GNSS Software Version 5.2.
Elevation Cut-off Angle	7º
Sampling Rate	30 seconds
A Priori Tropospheric Mapping Function	DRY-GMF
Mapping Function	GMF

Once the RINEX data was received from DSMM, the data were then processed by the AUSPOS (online GPS data processing) to provide latitude, longitude, and ellipsoidal height. The ellipsoidal height for all epochs was analysed to obtain the deformation rate by subtracting the reference date from all epochs. The deformation time series result obtained from the Malaysia Real-Time Kinematic network (MyRTKnet) CORS station was compared with InSAR. This comparison helps to assess the agreement between the two techniques for measuring ground motion.

RESULT AND ANALYSIS

Deformation Map

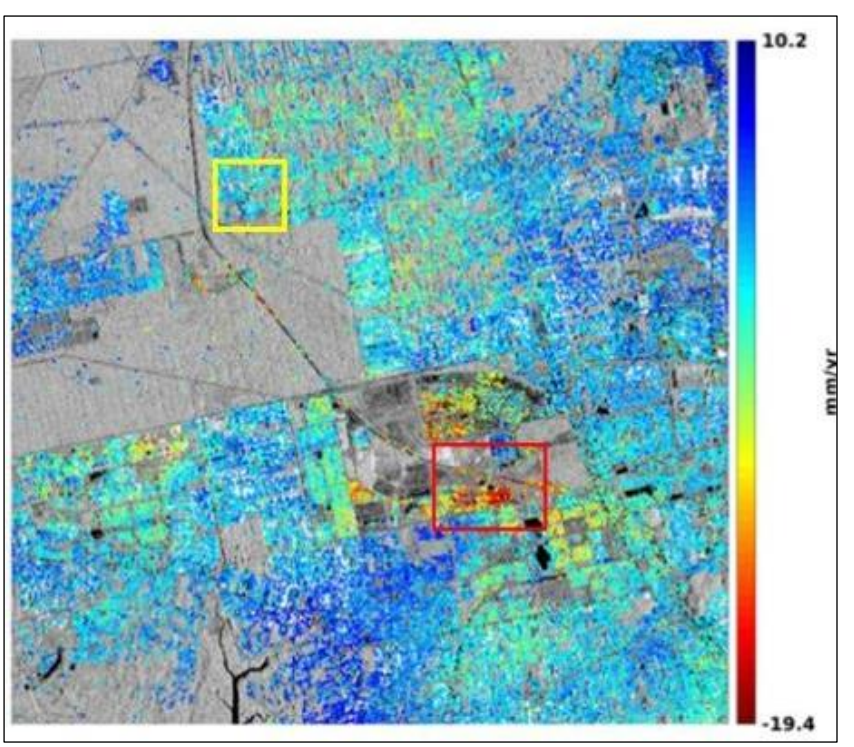

Figure 4. LOS Velocity Map

Figure 4 indicates the deformation rate between 10.3 mm/year at maximum and -19.4 mm/year at minimum, along with the corresponding colour ramps. The red box represents the area of subsidence. Meanwhile, the area for validation is covered in the yellow box.

Subsidence Area

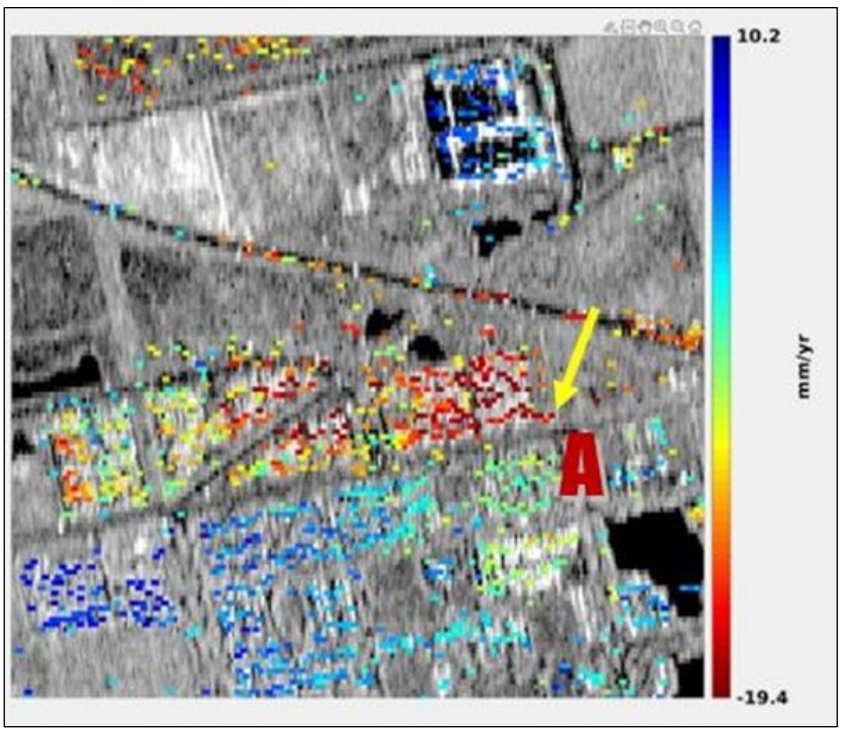

Figure 5. Red Box Area

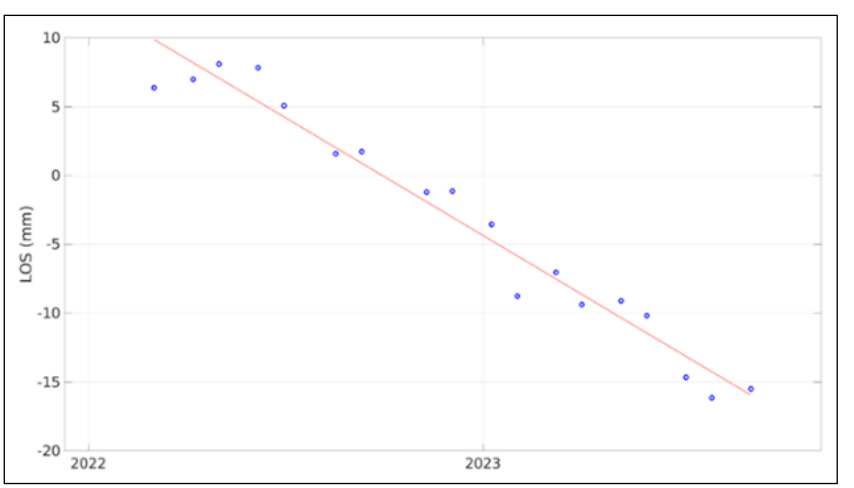

Figure 6. LOS Time Series of Area A

Figure 5 illustrates the zoomed area for the red box within the deformation map. Some places are undergoing subsidence, according to the area of interest inside the red box. Figure 6 displays the deformation time series for area A.

Validation Area Using MyRTKnet CORS Station

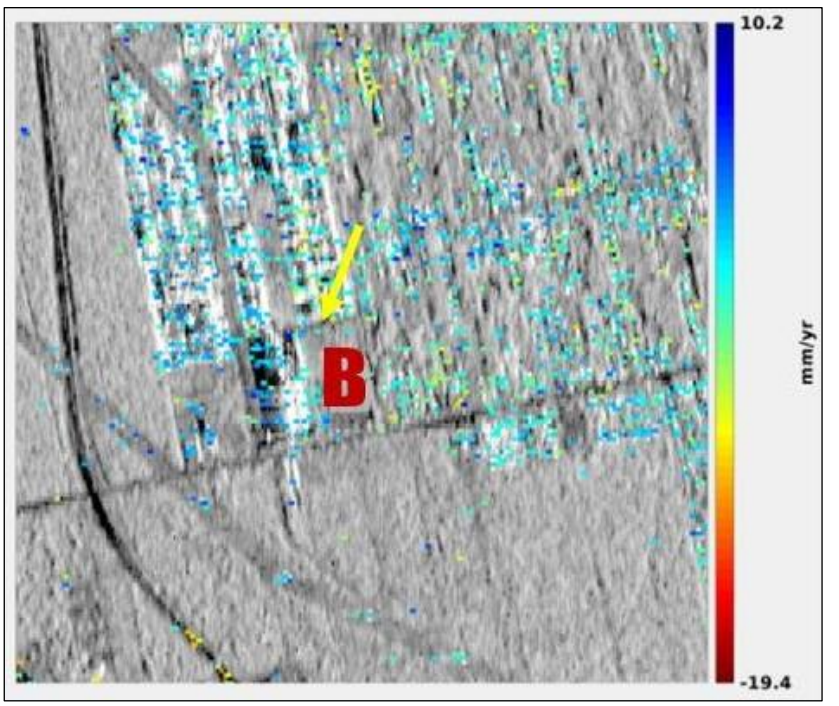

Figure 7. Yellow Box Area

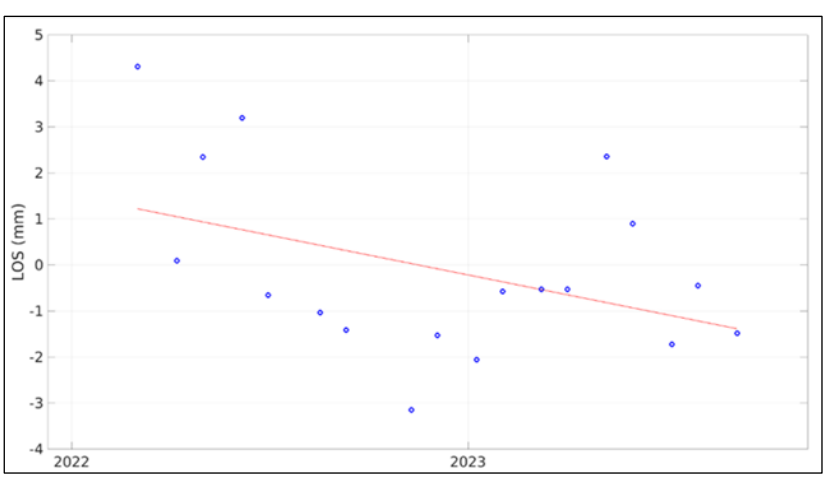

Figure 8. LOS Time Series of Area B

Figure 7 depicts a zoomed-in area of the yellow box in Figure 4 within the Deformation Map, indicating the location of the MyRTKnet CORS station (MERU) for validation. Figure 8 displays the deformation time series of area B.

For areas A and B, the decreasing pattern appears in both deformation time series between March 2022 and September 2023. Consequently, the deformation time series of A was demonstrated to be steeper than that of B. This indicates that the study area, location A, experienced land subsidence throughout the year.

Comparison Between InSAR and MyRTKnet CORS Station

The MyRTKnet CORS station was used to compare the InSAR observation, aiming to validate the processing scheme run by the PS-InSAR method. The PS point B was selected to validate with the CORS station. Furthermore, the SAR Master image selection was chosen to demonstrate the "zero deformation" of temporal resolution between both monitoring techniques.

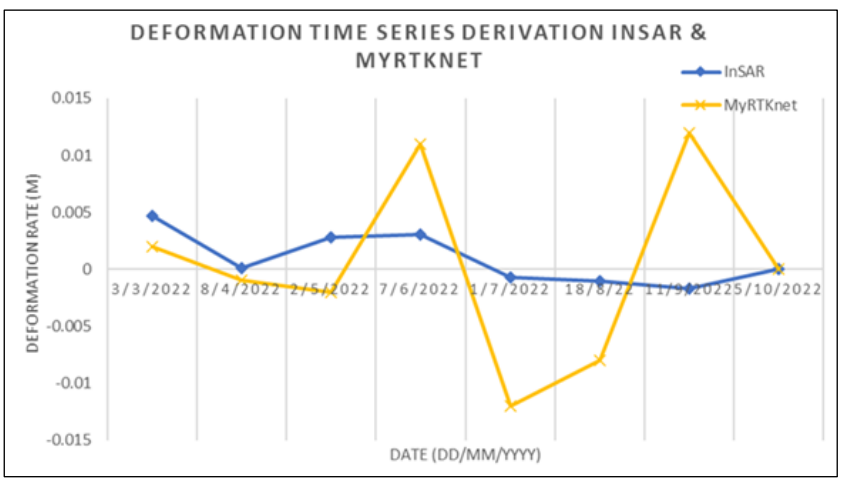

Figure 9. Deformation Time Series Derivation InSAR and MyRTKNet

Figure 9 visualizes a graph of the deformation rate of the PS points from the InSAR and MyRTKnet CORS station deformation survey. Consistency in the settlement trends was reported using the two distinct monitoring techniques. Hence, on the whole, InSAR and MyRTknet exhibit a stable trend.

Table 3. Availability for Data Validation

	Actual	Observed	
Date	**CORS (m)**	**InSAR (m)**	**Difference (m)**
3/3/2022	0.002	0.005	-0.003
8/4/2022	-0.001	0.000	-0.001
2/5/2022	-0.002	0.003	-0.005
7/6/2022	0.011	0.003	0.008
1/7/2022	-0.012	-0.001	-0.011
18/8/2022	-0.008	-0.001	-0.007
11/9/2022	0.012	-0.002	0.014
5/10/2022	0	0.000	0.000
		Min	**0.001**
		Max	**0.014**
		RMSE	**0.008**

Table 3 summarizes the availability of CORS and InSAR data for validation. The findings from both methods exhibit the trend of stable ground being levelled down in millimetres, which is extremely accurate. Through the calculation, the difference between both techniques was within 0.015 m, and the maximum was 0.014 m, while the minimum was 0.001 m. The Root Mean Square Error (RMSE) is interpreted as the evaluation index, and the value was

0.008 m. The achieved RMSE falls within the acceptable range, as evidenced by the maximum of 6.20 mm/year reported in their study using a larger dataset. Accordingly, there are slight differences since the area is stable. Therefore, the more the acquisition date, the less value the RMSE will have.

CONCLUSION

The velocity map suggests some parts of the study area that have undergone land subsidence. Generally, the deformation rate was between 10.3 mm/year at maximum and -19.4 mm/year at minimum. Apart from that, the time series of point A (the subsidence area) and point B (MERU CORS station) were completely illustrated. Additionally, the ground subsidence was validated at Klang, and results were obtained by utilizing the MyRTKnet CORS station. The validation was conducted in the B area, where the MERU station is located. From the result, both techniques indicate that the B area was stable, and the RMSE between both techniques was 0.008 m. In addition, the discussion and implications of the results could be further expanded to explore the broader impact on urban planning and disaster management in the Klang area since it is still in dealing with geotechnics for further explanation and investigation.

ACKNOWLEDGEMENT

We would like to express our gratitude to the Ministry of Higher Education Malaysia (MOHE) for supporting this study via the Fundamental Research Grant Scheme – FRGS/1/2021/WAB07/UiTM/02/1. Besides, we would like to thank the European Space Agency for providing open-source data and developing SNAP software. Thanks also to Andy Hooper for providing the StaMPS software, which was instrumental in achieving the results, and David Bekaert for providing TRAIN software for reducing atmospheric noise. Lastly, we also thank AUSPOS for the online GPS processing service.

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BIG DATA ANALYTICS TRANSFORMATION: CHALLENGES FACING THE MALAYSIAN FACILITIES MANAGEMENT PRACTICE

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Abstract
This study investigates the challenges of implementing Big Data Analytics (BDA) in Malaysia's Facilities Management (FM) practices. Amidst the growing importance of BDA in enhancing FM operations, this study's objective is to uncover the specific barriers faced within this context. Employing semi-structured interviews with five FM experts, the study utilizes thematic content analysis to analyse the data. Key findings reveal that implementing BDA in Malaysian FM practices encounters 21 distinct challenges, broadly categorized under people, process, and technology. The people component, comprising challenges such as skill limitations and resistance to change, is identified as the most significant obstacle. These findings have crucial implications for FM practices, highlighting the need for facilities managers to develop comprehensive strategies that address these multifaceted challenges. The study concludes that overcoming these barriers is vital for successfully integrating BDA into FM and calls for targeted efforts to enhance staff training, streamline processes, and upgrading technology. These insights contribute to the broader understanding of BDA implementation in FM and pave the way for future research in this field.

Keywords: *Big Data Analytics (BDA); Facilities Management (FM); Implementation Challenges; Malaysia; Facilities Managers*

INTRODUCTION

In recent years, the global digital transformation has led to a dramatic increase in the amount of data and information generated and collected across a broad array of industries. The volume of data continues to double every three years as information pours in from digital platforms, wireless sensors, and billions of mobile phones (Misra *et al.*, 2022). This data explosion has led to the popularity of the 'big data' notion (Shafqat *et al.*, 2020; Bazzaz Abkenar, Haghi Kashani, Mahdipour, & Jameii, 2021). Big Data refers to a large amount of data that exceeds the capacity of conventional database software to capture, store, manage, and analyze (Lutfi *et al.*, 2023). This type of data holds the potential for collection, storage, retrieval, integration, preprocessing, analysis, and interpretation, thereby enabling the discovery of new insights or the extraction of valuable knowledge (Bibri, 2018).

As with other industries, the FM sector has undergone a significant transformation, spurred by the advent of the Internet of Things (IoT), cloud technology, and big data analytics (BDA) (Atta & Talamo, 2020). This evolution has globally redefined the FM landscape, particularly in the past decade, which has witnessed increased data generation within the

sector. As Konanahalli, Oyedele, Marinelli, and Selim (2018) observe, the enhanced instrumentation of facilities and assets has enabled comprehensive data capture on every facet of building performance. Consequently, the amount of data available for operational purposes today surpasses that of previous years. These technological advancements have facilitated the integration of building equipment, systems, and data sources but also enabled the transformation of vast volumes of big data pertinent to building operations into actionable insights through analytics (Konanahalli *et al.*, 2018; Yang & Bayapu, 2019).

Historically, FM relied on traditional methods, focusing primarily on reactive maintenance and static operational models. However, the rise of BDA has fostered a shift towards a more proactive and data-centric approach in FM practices. The integration of BDA is increasingly recognized as a crucial driver for enhancing operational efficiency, optimizing resource allocation, and improving decision-making processes within the FM sector (Gao & Pishdad-Bozorgi, 2019). The impact of these technologies spans various aspects of FM, including predictive maintenance, energy management, and the promotion of sustainable practices (Razali, Jamaluddin, Abdul Jalil, & Nguyen, 2020). Contemporary research highlights the significance of big data in revolutionizing FM. By leveraging big data, FM professionals are equipped to foresee potential system failures, refine energy usage, and implement effective sustainable practices. This leads to considerable cost reductions and a heightened level of operational excellence (Ahmed, Tezel, Aziz, & Sibley, 2017; Mawed & Aal-Hajj, 2017).

The burgeoning interest in BDA across various industries, including FM, has been notable in recent years. This trend is not isolated, as evidenced by the initiatives of several governments, including Australia (Hardy & Maurushat, 2017) and the UK (Konanahalli *et al.*, 2018), which have underscored the necessity of revolutionizing industries through the increased adoption of BDA. Similarly, the Malaysian government has been actively fostering the growth of BDA, recognizing its potential as a pivotal driver of economic growth and innovation across sectors (Hashim, Saiful Bahry, & Shahibi, 2021). In alignment with this global movement and its commitment to advancing the Information and Communication Technology (ICT) sector, the Malaysian government inaugurated the Public Sector Big Data Analytics Pilot Project. This initiative underscores the government's strategy to integrate BDA into public sector operations, paving the way for enhanced efficiency and data-driven decision-making. Furthering this agenda, agencies like the Malaysia Digital Economy Corporation (MDEC) and MIMOS Berhad have been established (Wahab, Hamzah, Sayuti, Lee, & Tan, 2021). MDEC, operating under the Ministry of Communications and Multimedia, has been tasked with spearheading the development of Malaysia's Big Data Framework (MDEC, 2022). This framework aims to cultivate a national BDA ecosystem, positioning BDA as an engine for economic expansion across all sectors.

The significance of BDA in Malaysia's economic strategy is further highlighted by an MDEC-commissioned study conducted by International Data Corporation (IDC), which projected the BDA market in Malaysia to expand from US$ 1.1 billion in 2021 to US$ 1.9 billion by 2025 (IDC, 2021). In its endeavor to establish Malaysia as a regional hub for BDA, MDEC has also launched the ambitious ASEAN Data Analytics Exchange (ADAX), reflecting a concerted effort to position Malaysia at the forefront of BDA innovation and application in the ASEAN region (MDEC, 2019). These developments indicate a clear and proactive stance by the Malaysian government in supporting the adoption of BDA across

industries. This governmental backing is particularly crucial for sectors like FM, which stand to benefit significantly from data-driven insights and analytics, thereby contributing to the broader vision of technological advancement and economic growth in Malaysia.

A number of international corporations operating in Malaysia, such as Ballard Chalmers, Accelteam Sdn. Bhd., Strateq Group, and iCrest Sdn. Bhd. has successfully integrated BDA to analyze their recorded data, indicating a growing acceptance of BDA in the Malaysian business landscape. The FM sector confronts distinct challenges in adopting this data-driven approach. This sector, critical in maintaining a wide range of facilities, including commercial complexes, residential buildings, and governmental structures, has not fully embraced the global trend towards data-driven management practices. The prevailing use of BDA within the Malaysian FM sector is primarily confined to descriptive analytics. This limited application highlights that BDA processes are still in their infancy in FM practices across Malaysia (Razali *et al.,* 2021). Despite the theoretical understanding of BDA as a means to systematically analyze, extract information, and scrutinize big data, there is a noticeable gap in the understanding and implementation of the full scope of BDA potential in the FM sector. This can result in insufficient data management and analytics practices.

In light of this situation, there is a need for a detailed investigation into the specific challenges that hinder the full-scale adoption and effective utilization of BDA in the Malaysian FM sector. Identifying and understanding these challenges will contribute to academic discourse and provide practical insights for FM practitioners, potentially guiding policy formulation and strategic decisions in the sector. Therefore, the objective of this study is to explore the purpose and level of success in the implementation of BDA within Malaysian FM practices, with a specific focus on identifying and articulating the challenges that impede full-scale adoption. By providing a detailed analysis of these challenges, this study seeks to offer a comprehensive understanding that can guide future advancements and strategic decisions in the sector.

The remainder of this article is structured as follows: Section 2 presents a literature review on the current state of research on BDA in FM. Section 3 details the research method, outlining the approach and techniques employed in this study. This is followed by Section 4, which provides the results and discussion, offering an in-depth analysis and interpretation of the findings. Finally, Section 5 concludes the article, summarizing the key insights and implications of the study.

LITERATURE REVIEW

Big Data Analytics in FM Practice

According to ISO 41011 (2017), FM is an "*organizational function which integrates people, place and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business*." FM accounts for 80% of the total lifecycle cost of a building, and it is commonly recognized as a substantial service industry that enhances and supports an organization's primary business activity (Bröchner, Haugen, & Lindkvist, 2019; Durdyev, Ashour, Connelly, & Mahdiyar, 2022). ICT has evolved, transforming FM industry practices to data-driven processes that could enhance corporate organization values (Atta & Talamo, 2020; Aziz, Ariff & Nawawi, 2020). This

implies that effective management and analytics are essential for all documents related to building maintenance, financial systems, resource management, health and safety compliance, space management, hospitality, contract management, and domestic services from various stakeholders (Jain, Yoon, Kang, & Hastak, 2021; Hisamuddin, Mohammad & Lokman, 2023). Big data and big data analytics came into the picture of FM since they can integrate, visualize, and continuously monitor and record building data such as space utilization, consumption of energy, indoor air quality, etc. (Daissaoui, Boulmakoul, Karim, & Lbath, 2020; Konanahalli, Marinelli & Oyedele, 2022).

Several case studies exemplify the successful implementation of Big Data in FM. For instance, Ali, Mohd Nawi, Hamid, Jalil, & Hussain (2021) presented a case study of an integrated facilities management (IFM) service provider that utilized IoT and BDA to optimize performance and service quality, resulting in significant cost savings. Mawed and Aal-Hajj (2017) highlight how a case study within the UAE FM industry leveraged big data to improve operational performance across its portfolio. Another study by Yang and Bayapu (2019) explored the challenges faced by a higher education institution FM unit in integrating Big Data, such as inconsistency in data entry and structure, interoperability issues between various software tools and a lack of software training. In addition, Walker, Ruane, Bacardit, & Coleman (2022) conducted a comprehensive study on a large FM provider, where data science was applied to enhance FM by developing routing algorithms, utilizing natural language processing for work orders, and optimizing charging point placement, thereby achieving increased productivity, efficiency, and decision support in operational tasks. Recent technological advancements have further enhanced the potential of big data in FM. Predictive analytics, machine learning algorithms, and advanced data visualization tools have become increasingly prevalent, as noted by Verma *et al.* (2019). These technologies facilitate more efficient management of facilities and enable FM professionals to proactively address potential issues, thereby reducing downtime and improving overall service quality.

BDA, which presents a transformative opportunity for the FM sector (Gingue, 2022), has seen a growing implementation in a wide array of industries worldwide over the past decade (Batko & Ślęzak, 2022; Chalupa & Petricek, 2024). This global trend is also mirrored in various sectors in Malaysia (Chong, Abdul Rasid, Khalid, & Ramayah, 2023; Falahat, Cheah, Jayabalan, Lee, & Kai, 2023). Although the application of BDA is on the rise in Malaysia, the literature review suggests that there has been limited research conducted on BDA in Malaysia, with particularly scarce research focused on BDA for FM. To date, Ishak, Wan Mahdi, Wei Lun, & Md Yassin (2023) provide the only substantial study within the Malaysian context examining BDA in FM, and it is limited to implementation readiness. However, a more comprehensive approach is required to address the varied challenges and guide the effective implementation of Big Data in FM. This entails not only exploring technological readiness but also delving into people, processes, and technological barriers that may impede the full realization of BDA's potential in FM practices.

Challenges to Big Data Analytics Implementation in FM

Despite the potential benefits of BDA in FM, its implementation is not without significant challenges, as evidenced in the literature. Adopting BDA often necessitates a foundational shift in operational protocols, which can be costly and complex (Bilal *et al.*, 2016). The expenses are not limited to the technological aspects alone, such as software and hardware,

but also extend to the training of personnel and restructuring of data management systems (Kalema & Mokgadi, 2017). This substantial initial investment can be a deterrent, particularly for FM projects operating under tight budget constraints or those with limited financial flexibility to accommodate such transformative changes. Another major barrier to BDA implementation is the challenge of aligning organizational culture with new data-driven approaches. Lunde, Sjusdal, and Pappas (2019) emphasize that organizational culture plays a pivotal role in successfully adopting BDA, particularly in industries where traditional practices are deeply ingrained. Resistance to change and the lack of a data-centric mindset among employees can stifle efforts to leverage BDA, necessitating a cultural shift that is often met with resistance.

Data governance challenges further impede the adoption of BDA in FM. Issues around data ownership, ethical use, and legal compliance are prominent concerns in the industry (Konanahalli *et al.*, 2022). The framework for data governance in the context of BDA in FM is often perceived as inadequately defined, leading to uncertainties in how data is handled, stored, and shared (Mayo & Snider, 2016). Ahmad *et al.* (2022) discuss the human challenges associated with data governance, including the lack of clear policies and the need for comprehensive training to ensure compliance with legal and ethical standards. The lack of clarity in data governance standards can significantly impede the effective and ethical application of BDA in FM, as Gupta and Soni (2020) emphasize the critical need for robust governance mechanisms to ensure the reliability and responsible utilization of big data.

The technological infrastructure readiness is another critical barrier to BDA adoption in FM. Marinakis *et al.* (2020) highlight that many FM organizations struggle with outdated or incompatible systems that are ill-equipped to handle the large volumes of data required for effective BDA. Issues such as data interoperability, system integration, and the lack of real-time data processing capabilities present significant hurdles. The industry is also faced with a lack of demonstrable success stories showcasing the effective use of BDA in FM. This scarcity of proven cases contributes to skepticism among FM professionals, many of whom are accustomed to traditional management practices and may be hesitant to adopt new, unproven technologies (Ahmed *et al.*, 2017). This hesitancy is compounded by a general lack of awareness, as evidenced in a survey by Konanahalli *et al.* (2018), where only a small fraction of respondents reported using BDA in their FM practices. Without clear examples of successful BDA integration, many organizations remain uncertain about the potential value it offers. Moreover, Wang, Kung, and Byrd (2018) emphasize that demonstrating successful BDA implementations can serve as a powerful catalyst for broader adoption. In FM, the tangible benefits of BDA, such as optimized maintenance scheduling, improved resource allocation, and enhanced decision-making, could provide compelling incentives for organizations to embrace this technology.

RESEARCH METHOD

Research Approach

Given the limited empirical research on big data in the FM sector, this study employs a qualitative approach to explore the subject thoroughly. A qualitative approach was selected because it allows for an in-depth examination of various aspects of the topic, focusing on understanding participants' perspectives within their specific context rather than conducting

quantitative analysis (Maxwell, 2009). This study employs a two-stage approach, beginning with a literature review on BDA in FM practices. This process ensured a broad understanding of BDA and its current application in FM. To gain practical insights, semi-structured face-to-face interviews were conducted with five FM experts actively involved in BDA implementation across various organizations. This method was chosen for its flexibility in exploring complex topics and the ability to elicit detailed responses about BDA challenges in FM (Ruslin, Mashuri, Rasak, Alhabsyi, & Syam, 2022).

Participants were selected based on their extensive experience in BDA within various organizations in Malaysia's FM sector. They were identified through purposive sampling to ensure they provided well-informed perspectives on the topic. Although the sample size was limited to five interviewees, it was deemed sufficient due to the specialized knowledge required and the thematic saturation achieved during the interviews. The decision to focus on this group of participants was also influenced by the niche nature of the topic and the challenges in accessing a larger pool of experts. This approach aligns with similar research within the construction industry, where a comparable sample size has been effectively employed (Durdyev *et al.*, 2022; Aziz & Zainon, 2023).

Data Collection and Analysis

Each interview followed a structured format with three key questions, targeting the objective of BDA in the respective organization, the level of success in BDA implementation, and the specific challenges encountered. The interviews, each lasting approximately 60 minutes, were conducted in person. Subsequently, they were recorded and transcribed verbatim. Data analysis was conducted using Atlas.ti 8, employing thematic content analysis. This methodology was instrumental in analysing the data through the lenses of people, processes, and technology, which are essential components of effective organizational transformation. This analytical structure was chosen based on the understanding that adopting digital technology for FM purposes is strictly connected to these elements (Marocco & Garofolo, 2021). This approach aims to provide comprehensive insights into the dynamics of BDA implementation in FM. Table 1 summarizes the respondents' profiles and their involvement with BDA in FM, illustrating the depth of their experience, which substantiates the credibility of the findings.

Table 1. Background of Respondents

Respondent	Organization	Designation	Years of Experience	
			In FM	In BDA
R1	University Campus	Facilities Manager	16	5
R2	Information Technology	Facilities Manager	20	11
R3	Property Management	Senior Facilities Manager	13	8
R4	Property Management	Building Manager (Facilities)	15	6
R5	Software Management	Chief Executive Officer (CEO)	30	21

RESULTS AND DISCUSSION

This section presents the findings derived from the analysis of the interview data, which were systematically coded and analysed using Atlas.ti 8. The insights presented here are structured around the three essential questions that formed the basis of our inquiry, each

addressing a distinct yet interconnected aspect of BDA in FM. The questions are as follows: (i) the primary objectives of implementing BDA within the respective organizations; (ii) the perceived levels of success achieved through the implementation of BDA; and (iii) the specific challenges encountered during the BDA implementation process. The aggregated and analysed results are presented in Table 2, which serves as a reference point for the ensuing discussion. These findings contribute to a deeper understanding of the current state of BDA in FM and pave the way for addressing the identified challenges and harnessing the full potential of BDA in enhancing FM practices.

Table 2. Survey Results - Purpose, Level of Success, and Challenges in BDA Implementation

Respondent	Purpose of BDA in the Respective Organization	Level of Success in BDA Implementation	Challenges in BDA Implementation
R1	○ Facilitate decision-making based on recorded data. ○ Expedite data retrieval process.	○ The organization still strives to implement BDA, and data transformation is ongoing. ○ Delays due to employee mentality levels.	○ Limited staff with BDA skills. ○ Employee reluctance to learn a new platform. ○ Employees are burdened with high workloads. ○ Complexity in coding. ○ Uncertainty in the BDA process. ○ Difficulty keeping up with technology. ○ Need for computer control environment.
R2	○ Access, view, and audit information via ServiceInsight 7 (SI7) ○ Record payments and claims using JD Edward (JDE).	○ Successful implementation; improvements needed in competency, processes, and technology.	○ Hesitance in providing BDA training. ○ A high volume of complaints and services. ○ Expensive data center. ○ Challenges in digitalizing operations. ○ Miscommunication among parties.
R3	○ Analyse complaints and facility requests. ○ Record and analyse tenancy documents.	○ Improvement in data management is needed based on post-mortems.	○ Occurrence of malpractices. ○ Reluctance to learn new platforms. ○ Additional project costs. ○ Tedious data management. ○ Delayed approvals. ○ Immature information. ○ Need for computer control environment.
R4	○ Transition to a paperless system.	○ Ongoing process to fix BDA adoption issues.	○ Hesitance in BDA training. ○ High workloads. ○ Additional project costs. ○ Immature information. ○ Difficulty keeping up with technology.
R5	○ Manage documents, work orders, maintenance schedules, parts, costs, and budgets.	○ Acceptable implementation level; performance limited to specific areas. Opportunities for broader application.	○ Miscommunication between parties. ○ High workloads. ○ Additional project costs. ○ Time required for BDA application. ○ Immature information. ○ Difficulty keeping up with technology. ○ Need for change management.

Purpose of BDA Implementation

The objectives of BDA implementation, as outlined by Rajaraman (2016), encompass enhancing customer interactions, detecting and preventing fraud via proactive recognition of abnormal patterns, and extending asset life through condition-based maintenance (CBM). These goals highlight the broad spectrum of applications for BDA, achievable through a comprehensive analytical approach. However, the responses from our study indicate that in FM, the application of BDA appears to be more focused, primarily serving functions such as decision-making, information storage and analysis, complaint analysis, and document management. For example, the code "decision-making" emerged as a dominant theme, highlighted by Respondent R2, who noted, "BDA allows us to base decisions on real-time data, which has significantly improved our response times and accuracy in maintenance scheduling." This quote, coded under "decision-making," emphasizes the critical role of BDA in refining organizational processes. This focused application suggests potential organizational constraints in fully harnessing the scope of BDA.

The challenges, as per the responses, seem to revolve around three central themes: people, processes, and technology. For example, Respondent R4 stated, "The purpose of BDA is shaped by the organization's goals and is influenced by a range of factors including the attitudes and mindsets of both employers and employees (people), the efficacy of the management systems (process), and the sophistication of the available systems (technology)," which was coded under both "organizational goals" and "technological sophistication." Such findings resonate with the insights provided by Rankin, Johnson, and Dennis (2015), who emphasize that the successful adoption and purposeful application of BDA are significantly influenced by the harmonization of these three factors. People's readiness to adopt and adapt to new technologies, the efficiency of processes in integrating and leveraging data, and the technological infrastructure's capability to handle large datasets are pivotal in determining the effective implementation of BDA. Therefore, a comprehensive analysis of these aspects is critical in FM. It involves not only the technological capability to implement BDA but also the organizational culture, employee training, and the refinement of processes to accommodate the complexities of Big Data.

Level of Success in BDA Implementation

In assessing the success of BDA implementation in FM, our study reveals a dichotomy in perceptions among the respondents. R2 and R5 reported a satisfactory level of success in BDA implementation, with R2 noting, "Our shift to BDA has reduced our administrative workload significantly, allowing us to focus more on strategic tasks rather than getting bogged down by paperwork." This statement was coded under "administrative efficiency" and "strategic focus," demonstrating how BDA can streamline operations and facilitate a more systematic approach to FM. These positive outcomes are consistent with existing literature, which underscores the potential of BDA to decrease administrative burden, enhance data management and analysis, provide employee development opportunities, and support the transition to paperless and systematic operations (Singh & El-Kassar, 2019; Bag, Wood, Xu, Dhamija, & Kayikci, 2020; Patel & Shah, 2023). Similarly, R5 highlighted the benefits of data-driven decision-making: "The use of BDA has made our data management and analysis processes much more efficient, leading to better decision-making and quicker response times." This was coded under "data management efficiency," reflecting the positive impact of

BDA on operational effectiveness. These accounts highlight the transformative potential of BDA from traditional manual processes to more sophisticated, data-driven approaches.

Contrastingly, the experiences of R1, R3, and R4 paint a different picture, revealing the complexities and challenges in the implementation process. R1 attributes the slow progress of BDA adoption to behavioural constraints within the organization, suggesting a disconnect between technology and user readiness. R3 and R4 further elaborate on the difficulties, pointing out issues in data management and the adaptation to technological changes as significant hurdles. These findings align with the research by Ahmed *et al.* (2017) and Oyedele, Owolabi, Oyedele, & Olawale (2020), which identify competency gaps and a lack of recognition of BDA opportunities as critical barriers to successful implementation. The juxtaposition of these experiences highlights that the successful implementation of BDA in FM is tied to the synergy between people, processes, and technology. The challenges identified by respondents R1, R3, and R4 emphasize the need for a more holistic approach to BDA integration, one that equally considers the readiness and capabilities of personnel, the efficiency and adaptability of organizational processes, and the robustness of the technological infrastructure. This comprehensive understanding is crucial for developing a thematic content analysis that effectively examines and addresses the significant issues encountered during BDA implementation in FM, paving the way for more successful integration strategies in the future.

Challenges in BDA Implementation

The analysis of BDA implementation challenges in Malaysian FM, as illustrated in Table 3, reveals significant insights into the obstacles encountered in transitioning to a data-driven approach. These challenges are categorized under the components of people, process, and technology, each presenting unique hurdles in adopting BDA.

Table 3. Thematic Analysis of BDA Implementation Challenges in FM

Factors	Specific Challenges in BDA Implementation
People	○ Miscommunication between project parties. ○ Limited staff skills and knowledge in BDA. ○ Reluctance to learn new platforms. ○ Hesitation to provide BDA awareness and training. ○ Employees are burdened with high workloads. ○ Indefinite management and leadership. ○ Occurrence of organizational malpractices (e.g., 'copy and paste').
Process	○ Delays in approvals from respective bodies. ○ Tedious data management due to complex processes. ○ Requirement to adhere to multiple meeting levels. ○ Additional project costs for data management and analytics. ○ Time-consuming BDA implementation.
Technology	○ The complexity and volume of coding practices required. ○ High costs for data center monitoring. ○ Requirement for a computer-controlled environment. ○ Need for digitalization in operations and maintenance. ○ Sophisticated change management for new technology. ○ Provision of immature information and data. ○ Challenges in keeping up with technological advancements.

The challenges within the people aspect emphasize the critical role of employee mindset and skills in the transition to BDA. For instance, R3 stated, "There's a significant communication gap between parties, which makes it hard to align on BDA initiatives," a quote

coded under "miscommunication." Similarly, R4 expressed concern about the limited skills available: "Most of our staff are not trained in BDA, and there's resistance to learning new platforms," which was coded under "limited skills" and "resistance to change." Overall, our findings highlight the critical need for effective communication, adequate training, and a change in mindset among FM staff. In this regard, the role of leadership in driving this change cannot be overstated. Facilities managers must take proactive steps in cultivating a culture that embraces digital transformation and continuous learning. As Ahmed *et al.* (2017) and Mikalef, van de Wetering, and Krogstie (2021) suggest, targeted training programs and knowledge transfer initiatives are essential in equipping staff with the necessary skills and understanding for BDA implementation. Operational processes in FM are equally impacted, with challenges pointing to the need for more efficient, digitally aligned procedures. R1 remarked, "The process is bogged down by approvals and outdated practices, making BDA implementation extremely slow," a quote coded under "delays in approvals" and "process inefficiency." The findings align with Atta & Talamo's (2020) advocacy for improved data analytics skills among FM professionals. This involves technological upgrades and reevaluating existing procedures to make them more conducive to BDA (Mawed & Aal-Hajj, 2017; Belhadi *et al.*, 2023).

On the technological front, the readiness of the FM team to launch a new platform and adaptability to technological advancements are identified as key challenges. As R2 mentioned, "The complexity of the coding required and the cost of maintaining the data center are major hurdles," which was coded under "technological complexity" and "cost barriers." Konanahalli *et al.* (2022) highlight that facilities managers should develop strategies for effectively integrating new technologies and preparing for subsequent upgrades. While each category presents its own set of challenges, the people aspect emerges as a significant barrier to effective BDA implementation in FM practices. This aligns with the observation of R1 on the importance of employee mentality in adapting to new technologies. Bröchner *et al.* (2019) indicate that the human element is crucial throughout the transformation lifecycle. This is further stressed across the literature that people are at the center of any digital transformation initiative (Agrawal, Narain & Ullah, 2020; Cichosz, Wallenburg & Knemeyer, 2020; Raza, Woxenius, Vural, & Lind, 2023). Thus, addressing the human aspect is fundamental for successfully integrating BDA in FM, necessitating a holistic approach that encompasses skill development, process optimization, and technological adaptation.

CONCLUSION

This study has provided critical insights into implementing BDA in FM in Malaysia, highlighting the intertwined roles of people, processes, and technology. Our findings reveal that while BDA offers substantial benefits for enhancing FM practices, its successful adoption is contingent upon overcoming specific challenges in these three domains. Facilities managers are at the forefront of this transformative journey and must be equipped with the necessary BDA competencies to lead and inspire their teams effectively. A comprehensive staff development plan, aligned with the ongoing transformation, is essential to facilitate a deeper understanding of the new systems among the staff. The study emphasizes the importance of introducing such systems from the outset to preempt resistance and ensure a smooth transition from existing practices. Additionally, the findings reveal that BDA transformation in Malaysian FM is still in its emerging stages compared to more established platforms. As such, there is a substantial opportunity for further research in this area. Future investigations should

focus on developing solutions to the challenges identified, with an aim to provide end-to-end strategies for effective BDA implementation. Such research would be invaluable to experienced facility managers and those who have yet to embark on this transformative path. The successful integration of BDA in FM requires a holistic approach that addresses the human, procedural, and technological aspects of this transformation. As Malaysia continues to advance in digital capabilities, the FM sector stands at a focal point where embracing BDA can lead to significant operational advancements. It is imperative for FM professionals and stakeholders to recognize and act upon the opportunities and challenges presented by BDA, paving the way for more innovative and efficient FM practices in the future.

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AGE-FRIENDLY ARCHITECTURE TOWARDS INCLUSIVE SOCIETIES IN MALAYSIA: INSIGHTS FROM A SYSTEMATIC REVIEW

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Abstract
As the global population ages, the need for age-friendly built environments becomes increasingly critical. Age-friendly architecture is essential for enhancing the well-being of older adults within micro-environments. This paper presents a systematic literature review (SLR) to identify key age-friendly architectural features by examining existing age-friendly building assessment models. Following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, the review covers publications from 2007 to 2024 sourced from Scopus, Web of Science (WoS), and Google Scholar. Keywords related to the elderly, ageing, inclusivity, age-friendly design, assessment models, and architecture guided the search for relevant studies. The review identifies a substantial gap in age-friendliness assessment models for micro-environments, particularly in Malaysia. Of 36 reviewed papers, five key themes, 11 core domains, and 101 architectural variables emerged as essential components of age-friendly design. This data highlights the absence of a comprehensive assessment model for age-friendly architecture in Malaysia. The findings offer evidence-based recommendations for designing and evaluating age-friendly architecture, accounting for cultural and local perspectives. Nevertheless, establishing standardised protocols is crucial to promote the safety, independence, and well-being of the elderly, contributing to the development of inclusive societies.

Keywords: *Age-friendly Architecture; Elderly; Inclusive Design; Assessment Model, PRISMA*

INTRODUCTION

Human civilisation's advancements have reduced mortality rates among older groups, leading to a rise in life expectancy globally. As life expectancy increases, demographic ageing becomes a sign of human progress. The twenty-first century is expected to see significant life expectancy gains worldwide (Leeson, 2018), with the World Health Organisation (WHO) projecting that adults over 65 will make up 20 to 40% of the global population between 2020 and 2050 (WHO, 2015). Malaysia also faces rapid population ageing, with its over-65 demographic rising from 7.2% in 2022 to 7.4% in 2023 and projected to reach 15% by 2050, thus classifying it as an ageing society (DOSM, 2023).

In response, the WHO advised nations in 2002 to address population ageing, designating active ageing as a core value (WHO, 2022). The elderly's physical and emotional well-being is significantly affected by urban limitations restricting access to facilities or causing isolation (Ibarloza A. et al., 2018). Research reveals that ageing populations suffer in deteriorating urban areas, highlighting the need for procedural adjustments to ensure basic access and support (European Commission, 2015). Thus, enhancing the elderly's physical, social, and emotional well-being becomes critical as their numbers grow. Notably, traditional urban designs often serve younger populations. However, they may limit older adults' access to

essential services and social engagement. Hence, inclusive design principles (McGinley, C. et al., 2022) stress adapting design to meet evolving elderly needs.

While age-friendly environments are globally recognised, existing models often lack relevance for micro settings, do not incorporate direct input from elderly communities, and are not tailored to local contexts. Moreover, no comprehensive review exists on age-friendly architecture models, particularly for Malaysia. Therefore, a systematic review is required to explore age-friendly architectural features and develop relevant insights.

Age-friendly architecture is a design approach focused on creating inclusive, safe, and supportive environments that promote independent living for older adults (Plouffe and Kalache, 2010). This concept extends beyond accessibility, incorporating universal design principles that allow people of all ages and abilities to use spaces without major adaptations (Steinfeld and Maisel, 2012). It promotes physically accessible, cognitively navigable, and socially inclusive spaces, helping to address the physical and sensory limitations of ageing (WHO, 2002). Notably, age-friendly architecture promotes social inclusion by creating spaces encouraging interaction and community engagement, which can help reduce isolation among older adults. Although designed for the elderly, such environments benefit all ages.

A review identifying key features for measuring age-friendly architecture, particularly within a local context, is essential to provide architects, designers, and policymakers with a comprehensive assessment of the built environment's benefits and limitations for older adults. Such a review would guide architectural designs that enhance the elderly quality of life (Mercader-Moyano et al., 2020). This review aims to identify essential features for age-friendly architecture by synthesising studies on existing building assessment models. It also focuses on how architectural elements impact the well-being of older populations. The objectives are to (1) explore current age-friendly assessment models and (2) identify architectural features that support elderly well-being.

METHOD

To ensure relevance and align with current systematic review practices, this study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page, M.J. et al., 2021). The review process included identification, screening, eligibility, inclusion, and data analysis phases. It provided both qualitative and quantitative data, with the quantitative aspect offering numerical insights, while thematic analysis was used to identify key themes and categories within the selected materials.

Eligibility Criteria

Predetermined inclusion and exclusion criteria were applied to ensure the publications were aligned with the review's goals. Studies were included if they: (1) reported on age-friendly assessment models, tools, or audits, (2) discussed age-friendly architecture or buildings related to the well-being of the ageing population in a micro-environment, (3) were published in English, and (4) were available in full text. However, studies focusing solely on large-scale macro-environments were excluded to maintain the focus on the needs of older adults in smaller built environments.

Information Sources & Search Strategy

A comprehensive systematic search was conducted across three major academic databases: Scopus, Web of Science (WoS), and Google Scholar. While Google Scholar has less stringent quality control, it includes publications from lower-impact journals intended to ensure relevant studies are not overlooked. The searches were restricted to publications from January 2007 to June 2024, starting from the release of the WHO's "Global Age-Friendly Cities: A Guide" in 2007.

The literature searches were conducted between 24 June 2024 and 26 June 2024, focusing on existing age-friendly assessment models, using Boolean operators search strategy across multiple academic databases. The key terms concerning outcomes were searched in the fields of titles, keywords, and abstracts on Google Scholar and Scopus, as well as in all fields on WoS. Five groups of key terms were combined, including variations and synonyms: (i) older adults, elderly, senior; (ii) Ageing or aging; (iii) inclusive, inclusivity, age-friendly; (iv) assessment, model, assessment system, audit, and evaluation; (v) architecture. Double quotation marks were used to search for the exact phrases, and asterisks were used to search for root word variations. Table 1 outlines the key terms and search syntax applied across all platforms.

Table 1. Construction of Search Syntax as Part of The Search Strategy

No.	Databases	Search	Year	Results
1	Google Scholar	("older adult*" OR elderly OR senior) AND (ageing OR aging) AND (inclusive OR inclusivity OR "age-friendly") AND (assessment OR model OR "assessment system" OR audit OR evaluation) AND (architecture)	2007-2024	17,300
2	Scopus	(TITLE-ABS-KEY ("older adult*" OR elderly OR senior) AND (ageing OR aging) AND (inclusive OR inclusivity OR "age-friendly") AND (assessment OR model OR "assessment system" OR audit OR evaluation) AND (architecture)) AND PUBYEAR > 2006 AND PUBYEAR < 2025 AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp"))	2007-2024	1,379
3	Web of Science	ALL=(("older adult*" OR elderly OR senior) AND (ageing OR aging) AND (inclusive OR inclusivity OR "age-friendly") AND (assessment OR model OR "assessment system" OR audit OR evaluation) AND (architecture))	2007-2024	69

(Source: Authors)

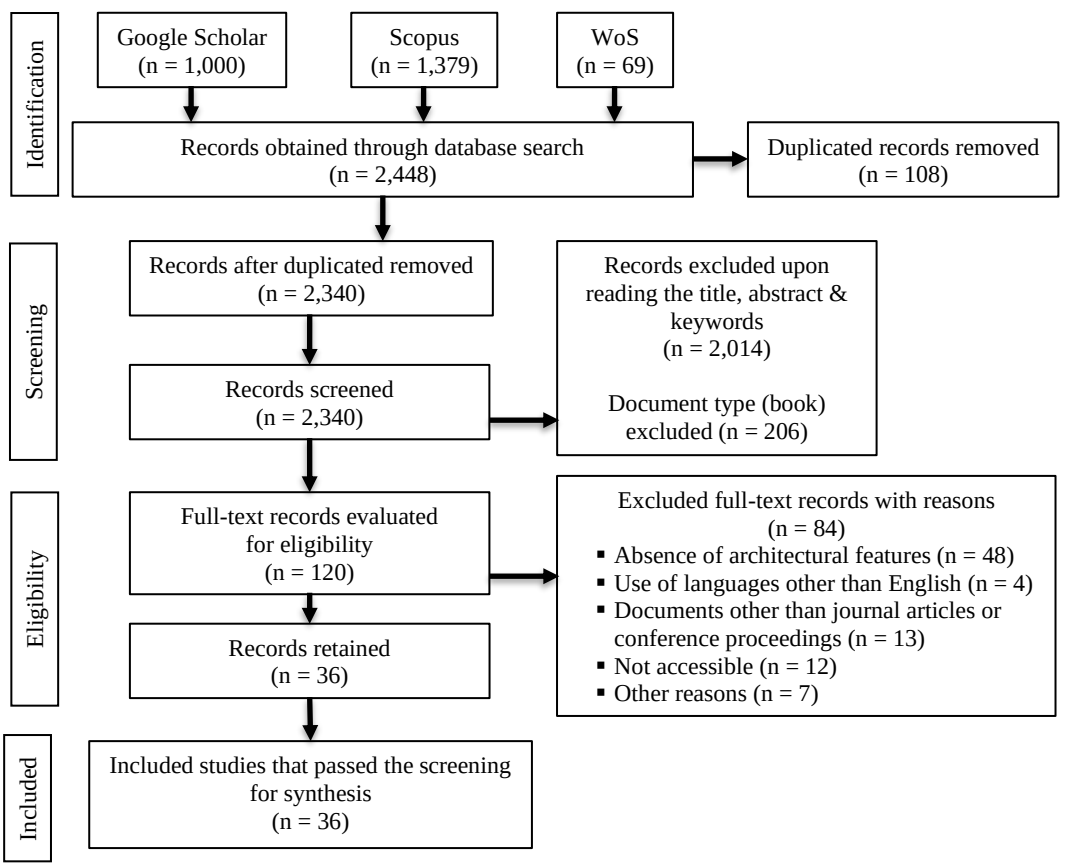
Selection Process & Data Collection

A total of 18,748 publications were collected: 17,300 from Google Scholar, 1,379 from Scopus, and 69 from WoS. To refine the review, a search was also conducted using the Publish or Perish (Windows GUI Edition) automation tool, which narrowed the Google Scholar results to the top 1,000 ranked publications, excluding 16,300 less relevant ones. Ultimately, 2,448 publications from all three platforms were included for assessment in the review.

All publications were imported into Zotero (Version 6.0.36), and duplicates (108 publications) were removed, leaving 2,340 records. Based on the inclusion criteria, 2,014 records were excluded after reviewing titles, abstracts, and keywords. An additional 206 records were removed due to being books, resulting in 120 records for full-text assessment.

After reviewing the full texts, 84 documents were excluded, leaving 36 selected for qualitative synthesis.

While many studies assess age-friendliness in the built environment, few focus on micro-environments. Therefore, this review includes macro- and meso-environmental studies on architectural features, whether or not they use assessment models, emphasizing urban and neighbourhood design elements. Meanwhile, excluded documents lack architectural focus, are non-English, are not journal articles or conference proceedings, or are inaccessible (e.g., unavailable PDFs). Other exclusions include those centred solely on medical topics, product design, smart home technologies, or Persons with Disabilities (PWD). This led to the removal of 84 documents. Figure 1 displays the selection process flowchart.



(Source: Authors, adapted from PRISMA 2000 Statement (Page, M. J. et al., 2021)

Figure 1. Flowchart for the Systematic Review

Risk of Bias

Systematic reviews are widely regarded as a reliable evidence source for readers and decision-makers. Reporting potential bias is crucial for transparency, allowing readers to assess study limitations and possible design, conduct, and analysis errors. In this review, the authors utilised the ROBIS tool to evaluate bias risk (Whiting P et al., 2015).

RESULTS

Selected Studies & Characteristics

A total of 36 studies met the eligibility criteria and were included in this systematic review. The articles, published between 2007 and 2024, indicate a growing research focus on ageing, housing, and urban design, with over half published from 2015 onward. Since 2010, there has been an increased focus on home modifications, age-friendly environments, and sustainable building renovations. Furthermore, systematic reviews and frameworks for evaluating age-friendly environments have become more common, with studies from various countries reflecting global interest.

The 36 studies were characterized by research setting, field, and design approach. Europe (25%) hosted the most studies, with additional contributions from Europe/West Asia (Turkey, 16.67%), North America (11.11%), and smaller numbers from South Asia, West Asia, Southeast Asia, East Asia, Oceania, and Africa. Eight studies (22.22%) were literature reviews with no specific location. Most studies (63.89%) focused on architecture and design, while 36.11% focused on ageing and gerontology. Qualitative methods dominated (61.11%), followed by mixed methods (22.22%) and quantitative methods (16.67%). Table 2 summarizes these characteristics.

Table 2. Characteristics of Studies

Study Settings (Location)	**%**
Europe/West Asia (Turkey)	16.67
North America (Canada, USA)	11.11
Europe (Sweden, Portugal, UK, Finland, Spain)	25
South Asia (India)	2.78
Southeast Asia (Malaysia)	5.56
East Asia (Hong Kong, China)	8.33
West Asia (Iran)	2.78
Oceania (Australia)	2.78
Africa (South Africa)	2.78
Not Applicable (N/A)	22.22
Field of Study	
Architecture & Design	63.89
Gerontology & Ageing	36.11
Research Design	
Quantitative	61.11
Qualitative	16.67
Mixed method	22.22

(Source: Authors)

This review includes both quantitative and qualitative findings. The quantitative analysis provides data from numerical perspectives, while the qualitative analysis, using thematic analysis, identifies key themes from the selected documents. Few studies focus specifically on age-friendly architecture in micro-environments. Analysis of the 36 documents in ATLAS.ti software (version 9.1.3.0) produced a word cloud (Figure 2) visualising term frequency and prominence in ageing, design, and the built environment research. “Design” appears most frequently (2,693 mentions), underscoring its significance, followed by terms

like “environment,” “housing,” and “space,” highlighting the link between physical spaces and quality of life for older adults.

(Source: Authors)

Figure 2. Word Cloud Representation of Key Themes from 36 Documents

Prominent terms like “older,” “elderly,” and “ageing” highlight the demographic focus on older adults, with studies emphasising environments that support ageing in place and improve daily living. “Health” also features strongly, pointing to the design's role in enhancing safety, mitigating health risks, and promoting well-being. “Accessibility” and “safety” focus on inclusive spaces for physical and cognitive needs. Terms like “social,” “community,” and “activities” suggest interest in how design encourages social interaction, engagement, and active living, reducing isolation and enhancing well-being. Specific terms such as “bathroom,” “kitchen,” “shopping,” and “public” spaces indicate focus areas within the home and community for safety and usability. Table 3 categorises data from the 36 studies by author, year, objectives, and key architectural or design findings.

Table 3. Data Summary of the Included Studies in the Review

Ref.	Authors, Year	Research Objectives/Questions	Main Key Findings/Design Features in the Findings
[1]	Afacan, Y., 2008	To understand the cultural perspectives of Turkish older adults on designing their homes.	The study suggested that the home features a step-free entrance, adjustable storage, large doors, clear flooring, and a kitchen and bathroom with pull-out workboards, adjustable cabinetry, grab bars, and environmental controls.
[2]	Afacan, Y., 2012	To focus on the factors that contribute to a shopping mall’s inclusivity.	The study suggested improvements in circulation, entrance, exit, wayfinding, product access, public amenities, and general improvements, including more elevators, smooth ramps, wider pedestrian walks, comfortable waiting areas, and knee spaces.
[3]	Afacan, Y., 2013	To explore the correlation between inclusive urban design principles and the needs of Turkey’s seniors.	The key features include clear signage, navigational ease, visible entrances, stepless entrances, accessible toilets, pedestrianized areas, easy door manipulation, and level changes marked with handrails and non-slip surfaces.
[4]	Afacan, Y., & Gurel, M. O., 2015	To investigate the challenges associated with public restrooms.	The study emphasized the significance of a well-lit, accessible facility with clear signage, restrooms, and easy-to-handle doors for a comfortable and safe journey.

Ref.	Authors, Year	Research Objectives/Questions	Main Key Findings/Design Features in the Findings
[5]	Afacan, Y. & Barshan, B., 2024	To investigate the bathroom requirements of older persons, with an emphasis on showers and bathtubs as the primary activity areas.	The IPA calculations highlighted three essential elements for comfort and accessibility: suitable artificial lighting, mechanical ventilation, and an easily accessible towel rail. Four themes emerge from the thematic analysis: comfort, accessibility, error-proof design, and emergency management.
[6]	Afifi, M., et al., 2014	To create four architectural staircase components.	Recommendations for Staircase Element: The design of handrails, steps, staircase geometry, and lighting. With recommended dimensions and specifications.
[7]	Ahrentzen, S., & Tural, E., 2015	To explore the impact of house and residential architecture on the likelihood of elderly engagement in active living.	The built environment, including accessibility features, spatial layout, ambient qualities, environmental cues, assistive technology, and outdoor areas, promotes active living, particularly among dementia patients.
[8]	Andersson J. E., 2011	To highlight each person's customisation of space and their integrated placement in current urban environments close to nature	The study highlighted spatial form and aesthetics as crucial for sensory stimulation in daily living, with easy access to social settings and outdoor spaces, making an ageing environment suitable.
[9]	Bamzar, R., 2019	To assess the quality of the indoor living environment of a senior housing in Hässelgården, Stockholm Municipality	To reduce falls in older persons, indoor apartments should be designed with universal design scores, quality diagnostics, and proper lighting, carpeting, and storage.
[10]	Cachadinha, C., 2012	To examine an age-friendly neighbourhood-built environment characteristic	Age-friendly neighbourhoods prioritized accessibility, safety, aesthetics, and housing options, with architectural features focusing on micro-environment aspects for ease of movement and comfort for older residents.
[11]	Carvalho, A., et al., 2012	To address the way architects reconsider public places to meet the demands of an ageing, active populace.	The proposed architectural features include tactile pavement signals, handrails, ramps, wheelchair-accessible paths, benches, ergonomic drinking fountains, car parking barriers, low-height public telephones, and wider footpaths for wheelchairs and the elderly.
[12]	Chrysikou, E., 2018	To propose interventions and policies that promote an integrated framework for active and healthy ageing.	Four scenarios necessitated a shift in the built environment paradigm: intimate, private, healthcare, and public, addressing complexity, physiological difficulties, aesthetics, and neurodiversity in each setting.
[13]	Demirkan, H., 2007	To investigate "design for all" as an established means of ensuring elderly people's physical accessibility.	'Design for All' considers both the physical and mental needs of older adults to provide physical accessibility. By taking physical characteristics and perceptual, motor, and cognitive capacities into account, it supports human diversity, social inclusion, and equality.
[14]	Demirkan, H., & Olguntürk, N., 2014	To prioritise concerns affecting users in the context of 'design for all.'	The study highlighted nine crucial home design factors: adequate lighting, room ease, space, colour contrast, functional circulation, slip-resistant flooring, privacy, safety, and accessibility in all spaces.
[15]	Ellison, C., et al., 2021	To determine what supports and hinders the implementation of house modifications.	The study examined various factors influencing home modification implementation, including individual, relationship, community, and societal influences, and suggests targeted interventions to mitigate these effects.
[16]	Joshi, R. M., & Dsouza, S. A., 2015	To determine the kinds and frequency of bathroom hazards among older Indians living in cities.	The study identified bathroom hazards, including architectural and non-architectural issues, among 198 participants, emphasizing the need for effective solutions to ensure a safe and comfortable environment.

Ref.	Authors, Year	Research Objectives/Questions	Main Key Findings/Design Features in the Findings
[17]	Kapsalis, E., et al., 2024	To assess the impact of inaccessible public space design on MobAD users' quality of life.	The study highlighted the challenges wheelchair users face in public spaces, including ramps, mosques, and bus stops, narrow aisles, uneven surfaces, poor parking, and gaps between vehicles.
[18]	Kohijoki, A.-M., & Koistinen, K., 2019	To identify design and environmental aspects that make city-centre shopping appealing to elderly consumers.	The study reported that the commercial area's unattractiveness was due to disorganized streetscape, dangerous cobblestone paving, inconsistent architectural styles, and inadequate lighting and seating.
[19]	Kwok, J., & Ng, K., 2008	To explore the organization and expectations of older people in urban areas	Designing a suitable living environment for elderly residents should include a recognizable entrance, resting spaces, wheelchair access, high-quality interiors, safety features, and balanced connections between indoor and outdoor environments.
[20]	Lak, A., et al., 2020	To understand the preferences of elders in Iranian urban areas regarding the use of public open spaces and their correlation with these factors.	The study indicated that the functional quality of a place, such as safety, aesthetics, amenities, cleanliness, comfort, density, and urban landscape, and the preferred quality of a place, such as wayfinding, aesthetics, security, and fall control, make open spaces more desirable.
[21]	Luciano, A., et al., 2020	To assess the age-appropriateness of housing by identifying aspects that support ageing in place.	A good living environment is assessed based on affordability, community connection, service access, safety, essential services, design, modification needs, and maintenance, all contributing to overall quality of life.
[22]	Maguire, Martin, et al., 2014	To provide a comprehensive method to understanding person-environment fit.	Kitchens should be designed for older users, offering ample lighting, visibility, and easy-to-reach storage solutions while also offering flexibility through customizable worktops and units.
[23]	Marquardt G., et al., 2014	To evaluate the effects of built environment design on dementia patients in long-term care facilities.	The study explored the positive impact of Special Care Unit (SCU) design on residents' behaviour, social abilities, and well-being, highlighting the importance of small-scale environments and personalized orientation aids.
[24]	Meyer, C. K., et al., 2014	To determine what supports and hinders the implementation of house modifications.	Senior housing issues include narrow walkways, inadequate technology, difficulty accessing facilities, safety hazards, noise disruptions, and hard-to-use faucets, handles, and windows.
[25]	Mnea, A., & Zairul, M., 2023	To investigate how interior home design affects older people's lives.	The study emphasized the importance of inclusive design, focusing on energy efficiency, home environment, and architectural features for elderly users, promoting safety, accessibility, and social sustainability.
[26]	Nik Mastura Nik Mohammad, Mohamed Yusoff Abbas., 2012	To understand the traits and identities of friendly neighbourhoods that encourage older people's active involvement in their communities.	Elderly individuals value nature, using trees, plants, and wildlife to navigate their environment, and also appreciate famous structures as landmarks. Social engagement through casual interactions in parks and public spaces enhances their quality of life and mental health. These elements help them interpret and manage their surroundings, contributing to overall well-being.
[27]	Sal Moslehian, A., et al., (2023	To identify and classify various design features of domestic kitchen and dining areas.	Kitchen design elements like size, storage, ergonomics, lighting, colour, and texture enhance accessibility, support meal preparation, and promote functionality.
[28]	Selhan Yalçın Usal, S., & Evcil, A. N., 2022	To investigate ageist design mistakes in indoor shopping that consider the needs of older individuals.	The study highlighted Universal Design Principles for supermarkets, emphasizing accessibility, flexibility, and simplicity, particularly for elderly individuals, to improve shopping experiences.

Ref.	Authors, Year	Research Objectives/Questions	Main Key Findings/Design Features in the Findings
[29]	Serrano-Jimenez, A., et al., 2018	To create a novel way for the analysis and decision-making process in home retrofitting.	The study identified effective methods for improving building accessibility and ensuring mobility in bathrooms and kitchens, such as portal accessibility, wider doors, and spatial adaptations.
[30]	Silva, F. da., 2012	To emphasise the significance of colour in Visual Communication for Inclusive Design, with a focus on older individuals.	Legibility is achieved with strong contrast, such as dark blue or black, on light backgrounds like white, light grey, or yellow. Poor colour combinations, like green on pink or light blue on black, reduce readability, as do decorative fonts, while basic serif or sans-serif fonts work best. Proper line spacing and avoiding glare-covered paper are also important for clear text.
[31]	Solomons, P., & Quickfall, M., 2014	To investigate the relationship between the urban environment and the elderly.	Senior community spaces should have a welcoming layout, multipurpose living room, garden views, circulation areas, natural light, comfortable seating, and artificial lighting for clear speaking.
[32]	Struckmeyer, L. R., et al., 2022	To gather information on house renovation issues, and methods for appealing and economical repurposing.	The study emphasized the significance of improving contrast and reducing visual distractions for individuals with low vision, suggesting that recycled solutions could be beneficial for their home environment.
[33]	Tan, T. H., 2022	To investigate the connection between the mental health of the elderly and their impressions of their house and neighbourhood.	The mental health of the elderly is shaped by accessibility, environmental factors, and neighbourhood conditions. Attractive, walkable communities with outdoor access promote social and physical engagement, improving well-being. Aging well in such neighbourhood is increasingly recognized as beneficial for seniors' mental health.
[34]	Wright, C. J., et al., 2017	To provide an environment framework for residential homes for people with complex disabilities.	The framework offered a comprehensive approach to home design and development, aiming to guide future decisions for inclusive housing, especially in political environments requiring design innovation.
[35]	Yu, H., & Rahman, O., 2018	To examine elderly Chinese consumers' experiences purchasing clothing	Older consumers' dissatisfying shopping experiences were impacted by poor store environments, including signage, layout, and aisle design. Safety concerns like dim lighting, slippery floors, and inadequate fitting rooms caused discomfort and frustration. Confusing layouts and unclear signage also made navigation challenging for elderly shoppers.
[36]	Yu, S., et al., 2021	To examine the relationship between the outdoor environment and outdoor daily activities for elderly people residing in old residential communities.	The following relationships exist: (1) social activities are primarily linked to noise; (2) leisure activities are significantly correlated with staff, slip-resistance measures, and road accessibility; (3) utilitarian-type activities are significantly correlated with seating, slip-resistance measures, stairway accessibility; (4) nature-exposure activities are significantly correlated with layout, greenery, and poor air quality.

Abbreviations: DA=Data analysis, Y=Yes, N=No, N/A=Not applicable, F2F=Face to face, Ref.=Reference
(Source: Authors)

Key Themes in Age-Friendly Architectural Design

The reviewed studies on age-friendly architectural features cover key themes highlighting how built environments can support elderly populations. These themes include residential design and home modification, commercial and public spaces, urban and outdoor environments, healthcare facilities and dementia care, and visual and auditory design. Table 4 provides an overview of these themes.

Table 4. Themes from The Reviewed Studies

Theme	Reference	%
Residential Design & Home Modification	[1], [5], [7], [9], [13], [14], [15], [21], [22], [24], [25], [27], [29], [32], [34]	41.67
Commercial & Public Spaces	[2], [4], [17], [18], [28], [35]	16.67
Urban & Outdoor Environment	[3], [8], [10], [11], [12], [19], [20], [26], [31], [36]	27.78
Healthcare & Dementia Care	[6], [16], [23], [33]	11.12
Visual & Auditory Design	[30]	2.78

(Source: Authors)

Theme 1: Residential Design & Home Modification

This theme focuses on creating accessible, comfortable, and safe living spaces for the elderly. Key design elements include step-free entrances [1], [5], [7], [13], [14], [24], which reduce mobility barriers and fall risks, and remote-controlled storage for safe, convenient access to items. Adjustable-height shelves [1], [5], [22], [27], toilet seats [4], and shower heads [14] adapt to residents' needs, minimising physical strain. Wide doors enhance wheelchair accessibility [1], [7], [13], [15], [21], [29], [34] and motion-activated lighting with audible alarms improves safety through sensor-based illumination.

Accessible bathroom fixtures, like grab bars, raised toilet seats, and walk-in showers, prevent slips and support independence [1], [5], [7], [9], [13], [14], [15], [21], [24], [25], [29], [32], [34]. Studies emphasise comfort, safety, and usability [1], [5], [7], [13], [14], [24], advocating for slip-resistant floors, adequate lighting, and pleasant aesthetics. The "Design for All" concept [1], [9], [13], [14], [24], [25], [27] addresses both physical and cognitive needs, catering to sensory impairments and cognitive decline.

Social connection is also emphasised, with designs facilitating interaction through communal and accessible outdoor spaces [15], [21], [25], [29]. In sum, integrating step-free entrances, adjustable features, wide doors, smart tech, and accessible fixtures supports independence, safety, and social connection, enhancing older adults' quality of life.

Theme 2: Commercial & Public Spaces

This theme emphasises designing inclusive, accessible environments that support older adults' independence and public engagement. Studies [17], [28], and [35] recommended accessible commercial spaces, such as shops and restaurants, with features like automatic doors, wide pathways, and adequate seating to reduce fatigue [2], [4], [17], [28], [35]. Clear signage and wayfinding systems with large, high-contrast text aid navigation, while auditory and tactile elements support those with impairments [4], [28], [35].

Accessible public toilets equipped with grab bars, raised seats, and emergency call buttons ensure comfort and safety [2], [4], [28]. Outdoor areas like parks benefit from level paths, shaded seating, and secure, well-lit spaces to encourage social interaction [30]. Technology integration, such as digital kiosks, supports navigation but should remain simple for ease of use [2], [17]. Community engagement is also promoted through events at centres and libraries to combat isolation [2], [17], [28], [35].

In sum, accessible features like automatic doors, clear signage, and supportive technology enhance usability, while community spaces promote inclusion and quality of life for older adults.

Theme 3: Urban & Outdoor Environment

This theme explores urban design and outdoor modifications to enhance older adults' quality of life, focusing on accessibility, safety, and enjoyment. Walkability is a key aspect, with studies [10] and [36] highlighting the importance of obstacle-free sidewalks, curb cuts, tactile paving, and auditory signals to support mobility and social interaction. Safety is essential, with research [3], [10], [11], [12], [19], [20], [26], [31], and [36] advocating for adequate lighting, surveillance, and lower traffic speeds in key areas.

Accessibility is crucial for inclusivity, as noted in [3], [8], [10], [11], [12], [20], [26], [29], and [36]. Public parks and recreational spaces should have level paths, accessible entrances, and rest areas, while efficient public transportation is vital for those no longer driving [3], [10], [11], [20], [31], [36]. Features such as low-floor buses, ramps, and real-time information improve accessibility. Green spaces are emphasised in [3], [8], [10], [11], [19], [20], [31], and [36], support physical and mental health, with accessible paths, seating, and shade encouraging relaxation and socialisation.

Age-friendly urban planning, as described in [3], [8], [10], [11], [12], [19], [20], [26], [31], and [36], promotes mixed-use areas, accessible housing, and intergenerational living to foster community. Technology integration, discussed in [8], [10], [11], and [12], enhances accessibility with smart city features providing real-time information.

The Urban and Outdoor Environment theme underscores the need for inclusive, safe spaces. By prioritising walkability, safety, green spaces, public transit, and technology, urban areas can significantly improve older adults' quality of life, supporting physical activity, social connection, and a sense of security.

Theme 4: Healthcare & Dementia Care

In healthcare and dementia care contexts, studies [6], [15], [23], and [33] highlighted design recommendations tailored to elderly needs. Key architectural considerations include hazard-minimising bathroom designs, clear visual cues for navigation, and homelike environments to reduce institutional atmospheres. Emphasis is also placed on environmental attributes, like lighting and acoustics, which impact resident behaviour and well-being, advocating for designs that enhance comfort and safety in healthcare settings.

Theme 5: Visual & Auditory Design

The studies categorised under visual and auditory design, such as [30], stress the importance of legibility and auditory clarity in public spaces. Findings indicate that high contrast between text and background enhances readability, while the use of clear signage and appropriate font choices significantly impacts user navigation. Moreover, creating environments that minimise auditory distractions is crucial for older adults, ensuring clear communication and comfortable interactions in shared spaces.

Key Domains in Age-Friendly Architectural Design

The systematic review of 36 studies identifies 11 key domains and 101 variables essential for age-friendly architecture to support older adults' needs, comfort, accessibility, safety, and well-being. These domains could inform an assessment model, with specific variables collectively evaluating a space's age-friendliness. The authors' proposed organisation of these dimensions and variables from the reviewed studies is presented in Table 5.

Table 5. Proposed Dimensions and Variables

Dimensions	Variables
1. Functional Design	**Living & Dining Spaces** 1. Flexible Living and Dining Areas 2. Ergonomically Designed Fixtures 3. Comfortable Seating and Sleeping Arrangements 4. Bedside Lighting 5. Accessible Storage and Closet Handles **Kitchen Design** 6. Sufficient Lighting and Visibility 7. Windows for Natural Light 8. Under Cupboard Lighting 9. Electrically Operated Countertops 10. Storage Accessibility 11. Adaptable Cabinets 12. Mid-Level Appliances 13. Adjustable Wall Cupboards 14. Lever Taps 15. Hands-Free Bins **Bathroom Design** 16. Low And High Shower Seating 17. Multimode Bathing Fixtures 18. Grab Bars 19. Bidirectional Doors 20. Slip-Resistant Flooring 21. Non-Skid Mats
2. Accessibility	**Entrance and Exits** 22. Stepless Entrance 23. Camera Installation at Entrance 24. Lighted Doorbell 25. Push-Button Power Door 26. Clear Path 27. Accessibility from the Car Park **Interior Circulation** 28. Non-obstructive circulation 29. Remote-Controlled Storage Systems 30. Wide Interior Doors 31. Operable Door Handles 32. Clear Floor Areas at Doors and Turning Spaces 33. Adequate Clear Space in Circulation Areas 34. Smooth Ramps and Wider Pedestrian Walks **Vertical Circulation** 35. Safe Staircase 36. Smooth Ramps 37. Functional Vertical Circulation
3. Environmental Controls and Comfort	38. Motion-Activated Lighting 39. Indoor Air Quality 40. Effective Mechanical Ventilation 41. Daylighting and Appropriate Artificial Lighting 42. Climate Control 43. Noise Reduction Measures

Dimensions	Variables
4. Wayfinding and Navigation	**Legibility and Visibility** 44. Readable Graphics on Signs 45. Use of Familiar Symbols for Navigation 46. Contrast Colours 47. Well-Marked Level Changes 48. Adequate Lighting for Night Usage **Ease of Navigation** 49. Adequate Signs 50. Simple Layouts 51. Clear Paths and Wayfinding Aids 52. No Visual Barriers 53. Clearly Visible and Obvious Entrances
5. Safety and Security	**Structural Safety** 54. Slip-Resistant Floors 55. Non-Glare Surfaces 56. Grab Bars in Wet Areas 57. Well-Maintained Flooring Materials 58. Appropriate Lighting to Prevent Falls **Environmental Safety** 59. Adequate Lighting 60. Audible Alarms 61. Security Measures in Open Spaces
6. Health and Hygiene	**Bathroom Hygiene** 62. Easily Accessible Storage 63. Exhaust Fans **General Hygiene** 64. Cleanliness and Maintenance Schedules 65. Appropriate Materials for Easy Cleaning and Maintenance
7. Public Facility Accessibility	66. Sufficient Elevators 67. Smooth Ramps & Footpaths 68. Handrails on Ramps and Stairs 69. Wide Pedestrian Walks 70. Tactile Pavement Signals 71. Adequate Clear Space in Circulation Elements 72. Disabled Toilets 73. Audio-Visual Features in ATMs or electronic kiosks 74. Adequate Seating 75. Adequate Waiting Areas 76. Wide Passages in Shops 77. Leg Room at Tables 78. Special Benches for Obese People
8. Cognitive and Sensory (Stimulus)	79. Colour And Contrast 80. Non-Slip, Non-Glare Surfaces 81. Quality Acoustic 82. Sensory Stimulation
9. Outdoor Accessibility	83. Accessibility to Outdoor Spaces 84. Pedestrianised Areas 85. Gardens and Pleasant Scents 86. Well-Lit Areas 87. Soothing Noises 88. Proper Seating and Resting Locations
10. Technological Integration	89. Smart Home Devices 90. Internet Of Things for Home Management 91. Security Systems 92. Smart Appliances and Furniture 93. Automated Lighting and Environmental Controls

Dimensions	Variables
11. Social and Community Interaction	**Outdoor and Public Spaces** 94. Accessible Pathways and Corridors 95. Comfortable Pedestrian Zones 96. Accessible Public Toilets 97. Social Seating Clusters 98. Special Benches for the Elderly and Disabled 99. Activity Nodes (e.g., Small Parks, Open Spaces) **Social Density** 100. Flexible Interaction Spaces 101. Social Contact Points

(Source: Authors)

Table 5 presents a structured overview of essential architectural features across key domains that influence usability, accessibility, comfort, and community engagement within a building. Each dimension addresses a specific focus area in design, while the variables represent architectural features or actionable elements that ensure spaces are well-suited for the needs of elderly individuals. This structure highlights core domains crucial for designing age-friendly spaces, including Functional Design, Accessibility, Environmental Controls and Comfort, Wayfinding and Navigation, Safety and Security, Health and Hygiene, Public Facility Accessibility, Cognitive and Sensory Considerations, Outdoor Accessibility, Technological Integration, and Social and Community Interaction.

The review underscores a significant gap in the availability of evaluation models for age-friendly design in micro-environments, especially in Malaysia. The domains and variables identified in this systematic review may provide a foundation for developing a comprehensive assessment model tailored to age-friendly spaces.

Risk of Bias Report

The authors assessed the risk of bias in the systematic review using the ROBIS tool, which was conducted in two phases: (1) identifying review process issues and (2) judging the risk of bias. The assessment reveals low bias concerns across several domains, reflecting high methodological rigour. Well-defined eligibility criteria ensured relevant studies were included, and thorough selection methods minimised bias. Robust data collection and appraisal processes ensured accuracy, while precise synthesis and interpretation of findings led to trustworthy conclusions. Accordingly, these low concerns highlight the review's high quality and reliability, though some limitations are discussed in the Discussion section.

DISCUSSION

The WHO Age-Friendly Cities Framework offers a comprehensive, city-wide approach to enhancing urban accessibility and inclusivity for older adults across eight domains: Community and Health Care, Transportation, Housing, Social Participation, Outdoor Spaces and Buildings, Respect and Social Inclusion, Civic Participation and Employment, and Communication and Information. This framework, widely adapted in studies as a basis for age-friendly assessment models, effectively supports broader urban infrastructure. However, it lacks detailed architectural guidance for age-friendly design at the micro-environmental level, which are spaces where older adults spend much of their time.

This study, as outlined in Table 5, addresses this gap by introducing specific architectural variables that enhance accessibility, safety, and comfort in smaller, daily-use spaces. Unlike the WHO framework's broader urban focus, the proposed model centres on granular interventions, such as slip-resistant flooring, motion-activated lighting, and ergonomic fixtures, which are crucial for older adults in navigating indoor spaces. These detailed elements underscore the importance of micro-environmental considerations that directly impact usability and autonomy in routine activities.

Additionally, while the WHO framework provides a general, universally applicable structure, it does not account for local adaptations in climate, materials, or cultural contexts. By contrast, the proposed model is designed to be adaptable, making it more suitable for Malaysia's unique needs and cultural preferences, fostering spaces that resonate meaningfully with older adults.

Limitations of the study include its narrow focus on micro-environments and potential geographical bias, which may impact generalisability. Moreover, methodological variations and a lack of standardised age-friendly guidelines also pose challenges for comparative analysis.

Nonetheless, this study has significant implications for practice, policy, and research. For practice, it offers targeted design recommendations for enhancing age-friendly design. For policy, the findings provide a basis for developing standardised age-friendly design guidelines and inform building codes for widespread adoption. In research, the study highlights the need for further exploration of micro-environments and diverse regions, advocating for more localised insights that better serve the architectural field.

CONCLUSION

This systematic review of 36 studies, spanning 2007 to 2024, reveals a strong focus on design aspects crucial to elderly-friendly environments, with an increased emphasis in recent years on integrating age-friendly principles into urban and architectural design. Key themes identified include accessibility, safety, social engagement, and health considerations. Terms like "design," "older," "people," and "environment" frequently appear, underscoring these priorities.

The review emphasises the need for evidence-based guidelines to address these priorities and identifies essential architectural features and assessment dimensions that support age-friendly spaces. Implementing such guidelines can improve quality of life by ensuring that built environments are accessible and supportive for older adults.

In Malaysia, a comprehensive age-friendly architecture assessment model remains absent, highlighting an urgent need for standardised guidelines to ensure accessible, safe living environments for the elderly. Studies by Ismail, H. et al. (2019) called for frameworks considering Malaysia's local and cultural context, promoting independence and well-being among older adults while supporting the nation's ageing population.

To address these gaps, advancing an age-friendly architecture model is crucial for Malaysia's built environment. Stakeholders, such as urban planners, architects, and

policymakers, must collaborate to create inclusive, supportive environments that cater to the ageing population, thus fostering a sustainable and inclusive future for all. This effort requires standardised guidelines, stakeholder collaboration, training, supportive policies and funding, impact monitoring, and public awareness to build truly age-friendly spaces.

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REMOTE MONITORING OF LAND SUBSIDENCE USING INSAR

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Abstract

Land subsidence, the gradual sinking or lowering of the ground surface, can occur due to both natural processes and human activities. In Lestari Perdana, Seri Kembangan, Malaysia, a significant subsidence event occurred on January 26, 2022, likely due to heavy rainfall and changing the soil layer. This study evaluates the effectiveness of Interferometric Synthetic Aperture Radar (InSAR) technology in monitoring ground movements in the affected area. This research aims to monitor land subsidence in the Lestari Perdana affected area and its surroundings by generating coherence images and a deformation map with time-series data to illustrate the extent of subsidence. Using SNAP (Sentinel Application Platform) and StaMPS (Standford Method for Persistent Scatterers) software on Satellite-1A data, this research makes it possible to track where and how much the ground is sinking. In addition, coherence images help detect shifts in the ground by demonstrating colour changes, while deformation maps highlight ground movement in specific areas. Monitoring this way is crucial as it identifies risky areas early, helping local authorities make smarter decisions to reduce potential hazards. This approach supports safer urban planning, protects infrastructure, and prepares communities for possible future events, making continuous monitoring of landslide-prone areas essential.

Keywords: *Land Subsidence; Sentinel-1A; PSInSAR; StaMPS*

INTRODUCTION

According to the Global Competitive Report (Business Today Editorial, 2023), Malaysia is recognized as one of the fastest-growing countries in the world and a leading competitive economic player among developing nations in Asia. This remarkable growth is evident in the rapid development of large urban areas, often referred to as metropolitan regions. Notably, these metropolitan areas are characterized by major cities that form a cohesive economic and social unit, along with their surrounding suburbs and nearby towns. A metropolitan city is typically defined as a significant urban center that exercises considerable economic and social influence over its surrounding regions, encompassing not only the city itself but also the smaller towns and communities within its influence (Saeidizand, Fransen & Boussauw, 2022). In recent years, Malaysia has frequently experienced natural disasters such as flash floods, landslides, and land subsidence. As such, the high frequency of these events has led to significant trauma among the population, as natural disasters can occur suddenly and without warning. The unpredictable nature of these calamities has created a pervasive sense of vulnerability, affecting residents' daily lives and mental well-being. Note that natural disasters can vary widely in scale, occurring from localized incidents to large-scale catastrophes (Walker et al., 2022). Among these, land subsidence is defined as the sudden sinking or gradual lowering of the Earth's surface (Raju et al., 2022). This phenomenon can result from a range of factors, including excessive groundwater extraction or natural

processes, and can lead to significant deformation of the ground. In addition, such deformation is often a consequence of ongoing natural disasters, which exacerbate the effects of subsidence and can cause severe structural damage to infrastructure and properties.

Deformation, especially in the context of large-scale disasters like land subsidence, landslides, and flooding, is often unpredictable and beyond human control. The sudden and severe nature of these events can lead to substantial loss and damage, which might have been mitigated with timely warning systems. If advance warnings had been issued, people could have taken precautionary measures to prepare for or avoid the worst impacts of such disasters. This underscores the critical importance of effective monitoring systems, which are essential for providing early warnings and enhancing preparedness. Therefore, by continuously observing and analysing potential hazards, monitoring systems enable timely alerts that can significantly reduce the risk and severity of disaster-related damage.

Nowadays, technological advancements have greatly enhanced the ability to monitor and map earth movement activities. However, many of these methods are point-based, which limits their application to small or localized areas and can be prohibitively expensive when large areas need to be monitored comprehensively. In the last decade, many researchers have explored alternative approaches to monitor large areas more cost-effectively, accurately, conveniently, and efficiently (Yalkvac, 2020).

This research aimed to demonstrate the potential of the satellite Interferometric Synthetic Aperture Radar (InSAR) technique for monitoring land subsidence. This technique leverages satellite-based radar imaging to detect and measure ground displacement with high precision over large areas. Accordingly, by applying InSAR, the research highlighted its effectiveness in providing detailed and reliable data on subsidence patterns, which can be critical for early warning systems, urban planning, and managing infrastructure stability.

LITERATURE REVIEW

Definition of Land Subsidence

Subsidence is a term for the downward vertical movement of the Earth's surface caused by both natural and human processes (Azmi, Md Din, 2022). The event or phenomenon of land subsidence is referred to as land subsidence. This is also common in large cities that sit on a layer of sediment, such as Semarang, Bangkok, Jakarta, and Tokyo. According to previous research on land subsidence, the phenomenon is caused by several factors, such as excessive groundwater extraction, heavy building loads, natural changes in soil layers, and tectonic forces (Lo et al., 2022).

Land subsidence is a dangerous condition when liquid from the surface flows into an area of underground limestone, creating voids or caves. If the surface above the void weakens, the soil will sink into the Earth. Geologists, geotechnical engineers, and surveyors are concerned about subsidence as it may cause the collapse of buildings and bridges. For example, pumping groundwater or petroleum has caused subsidence in many locations worldwide; this can cost hundreds of millions of dollars. Notably, subsidence is also increasing in Malaysia at an alarming rate; there are currently over 40 sites across Peninsular Malaysia with indications of subsidence ranging from 0.5 to 9 m (Charles et al., 2022).

Causes of Land Subsidence

Natural disasters such as flash floods, landslides, earthquakes, and other natural disasters can all cause tragic land subsidence. Moreover, humans were unprepared for this type of disaster. As a result, there was no preparation to prevent these natural hazards. Even with the most advanced technology available, humans have been unable to predict the time or location of natural disasters accurately.

Malaysia, which is considered a low-risk earthquake zone, has not been spared and is now vulnerable to disaster risk since it is not far from the zone where earthquakes frequently occur. As a result, land subsidence can occur due to the settling and compacting of unconsolidated sediment caused by earthquake shaking. For example, the earthquakes in Northern Japan caused a 0.50 m subsidence on the Pacific Ocean coast in Miyako, Tohoku, in 2011 (Ozawa et al., 2011).

Aside from earthquakes, groundwater-related subsidence is another significant cause of land subsidence. This type of subsidence occurs when the land sinks due to groundwater extraction. In many areas of Selangor, the volume of groundwater in storage is decreasing as a result of widespread groundwater pumping. This phenomenon is particularly prevalent in developing countries, where growing urban populations extract substantial amounts of water from aquifers, and economic growth drives increased water demand.

To sum up, land subsidence can be triggered by various factors. While understanding these causes is essential, effective monitoring of the specific area is crucial for preventing frequent occurrences of land subsidence. As such, implementing a robust monitoring system allows for early detection of subsidence-related changes and provides valuable data to predict and manage potential risks. This proactive approach is the most reliable way to safeguard the public from injuries, fatalities, property damage, and widespread destruction. Moreover, by continuously observing and analysing ground movements, authorities and stakeholders can take timely action to mitigate the impacts of subsidence and ensure the safety and resilience of affected communities.

DInSAR

Similar to other remote sensing techniques, Differential Interferometric Synthetic Aperture Radar (DInSAR) has attracted considerable interest in the field of subsidence monitoring by providing measures for ground deformation. Several elements contribute to the DInSAR approach being a helpful tool for deformation monitoring. For instance, it is sensitive to minor terrain deformations, up to a few millimetres in ideal measuring conditions. Second, DInSAR covers a vast area while maintaining a reasonably high spatial sampling density. Another significant feature is that DInSAR can possibly offer measurements with comparable quality to classic geodetic techniques.

DInSAR can be defined as the product of a slave image of a Single Look Complex (SLC) with a complex conjugate of master images. The integration of additional Synthetic Aperture Radar (SAR) images into the analysis allows for the measurement of ground deformations over time. On differential interferogram, ground deformations appear as wrapped phase fringes (value of $-\pi$ to π). If the differential deformation phase between two successive

acquisitions is more than an interval of -π to π, the actual deformation rate cannot be entirely acquired (Crosetto et al., 2015). The fringes can then be translated to ground displacement values. In DInSAR analysis, one interferometric fringe corresponds to half of the SAR system's wavelength.

An interferogram can be produced pixel by pixel by subtracting the registered two data images of SLC SAR. This technique has proven effective in tracking subsidence and other ground deformations.

PSInSAR

Advancements in InSAR technology, particularly the development of Persistent Scatterer InSAR (PS-InSAR), have significantly enhanced our ability to monitor surface deformation with greater precision. This technique can achieve millimetre-level accuracy in estimating how the ground moves. However, its effectiveness depends on several key factors. These include the number of radar images analysed, the density of detected Persistent Scatterer (PS) points, atmospheric conditions during data collection, and how far the PS points are from a reference location (Matori, 2019).

In urban environments, PS targets are typically abundant and often consist of man-made structures such as buildings, roads, fences, lampposts, pipelines, and transmission towers. The availability of these stable scatterers allows for improved temporal and spatial resolution, which leads to more accurate measurements of ground deformation over time. These advancements can be incorporated into future research efforts, providing deeper insights into subsidence phenomena and helping to enhance monitoring and mitigation strategies.

However, in non-urban areas, the technique encounters challenges. The spatial density of extracted PS points is generally lower since there are fewer prominent scatterers in the landscape, making it more challenging to obtain reliable deformation data. This limitation highlights the need for ongoing development and adaptation of InSAR techniques to ensure effective monitoring across different environments.

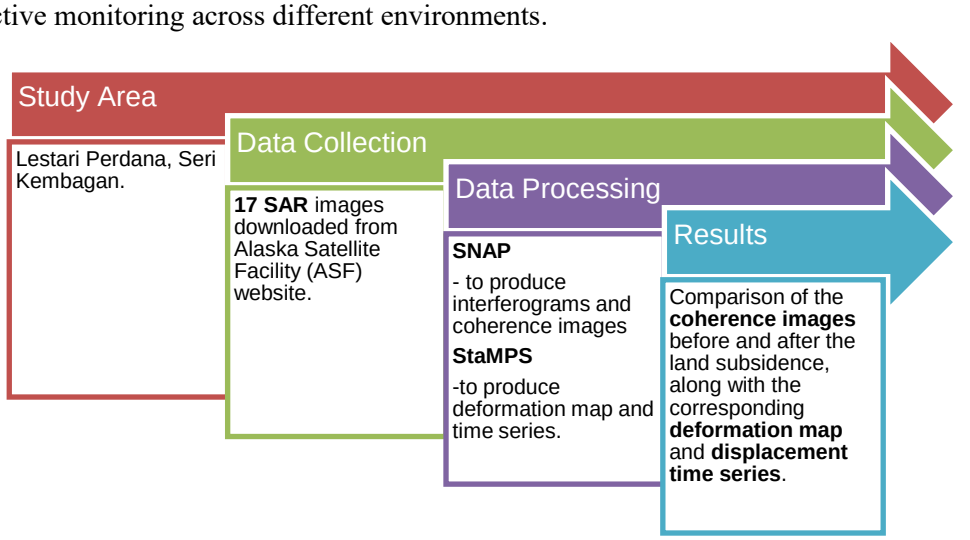

Figure 1. Research Methodology Flowchart

METHODOLOGY

This study was conducted in four (4) stages, as illustrated in Figure 1.

Study Area

Lestari Perdana, located in Petaling, Selangor, south of Kuala Lumpur, Malaysia, was selected as the site for monitoring land subsidence due to a significant soil movement incident on January 26, 2022. The exact coordinates of Lestari Perdana are 3.0046° N latitude and 101.6679° E longitude. During the incident, five cars were displaced as the ground beneath them began to collapse. Fortunately, there were no injuries. Note that this was not the first such event in the area, as a similar landslide had happened in 2017. Thus, the study area selection has underscored the importance of continuous monitoring in Lestari Perdana to prevent future risks to people and property, as the area may be vulnerable to further ground instability.

Figure 2. Lestari Perdana's Land Subsidence Incidents in 2017 and 2022

Data Collection

Sentinel-1A data is employed in this study to measure land subsidence and assess stability in Lestari Perdana. The dataset includes 17 images captured in descending image direction. One of Sentinel-1A's advantages regarding this study is its extensive coverage area – 250 km – when using Interferometric Wide (IW) swath mode, allowing global image acquisition. Sentinel-1A also offers high spatial resolution, measuring 5 m in range by 20 m in azimuth, which enables detailed observation of ground changes. With C-band radar, Sentinel-1A can collect data in all weather conditions, ensuring reliable imaging without interference due to cloud cover. These features support comprehensive analysis in regions like Lestari Perdana, where regular updates on ground stability are crucial. Table 1 below summarizes the Sentinel-1A datasets used in this research.

The analysis period ranges from October 1, 2021, to April 30, 2022. The six-month period was selected purposefully to capture the ground's behaviour before and after the subsidence event, providing us with a complete understanding of the deformation process. In addition, monitoring this time range is critical for detecting any gradual or rapid earth shifts that could endanger infrastructure and public safety.

Table 1. Sentinel-1A Datasets Used

NO	DD/MM/YYYY	FRAME NUMBER	TRACK NUMBER	ORBIT NUMBER	IMAGES	DIRECTION
1	02/01/2022	582	91	41288	**Master**	Descending
2	10/10/2021	582	91	40063	Slave	Descending
3	22/10/2021	582	91	40238	Slave	Descending
4	03/11/2021	582	91	40413	Slave	Descending
5	15/11/2021	582	91	40588	Slave	Descending
6	27/11/2021	582	91	40763	Slave	Descending
7	09/12/2021	582	91	40938	Slave	Descending
8	21/12/2021	582	91	41113	Slave	Descending
9	14/01/2022	582	91	41463	Slave	Descending
10	26/01/2022	582	91	41638	Slave	Descending
11	07/02/2022	582	91	41813	Slave	Descending
12	19/02/2022	582	91	41988	Slave	Descending
13	03/03/2022	582	91	42163	Slave	Descending
14	15/03/2022	582	91	42338	Slave	Descending
15	27/03/2022	582	91	42513	Slave	Descending
16	08/04/2022	582	91	42688	Slave	Descending
17	20/04/2022	582	91	42863	Slave	Descending

Data Processing

In this study, the SNAP software is utilized to generate interferograms and coherence images, while StaMPS software is employed to create deformation maps. Figure 3 depicts how the PS-InSAR technique is processed using SNAP and StaMPS software.

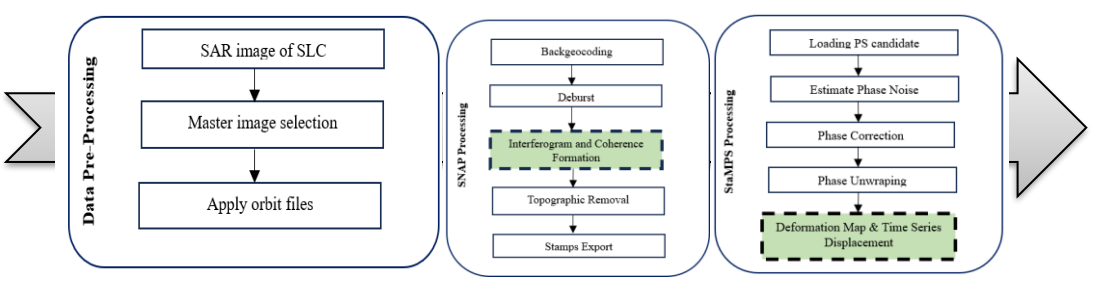

Figure 3. Flowchart of Data Processing Using SNAP and Stamps

First, the satellite images are prepared through pre-processing; master and slave images are selected at this stage. After pre-processing, an orbit file was applied to obtain precise orbits of each image in SNAP processing, which offers the exact satellite position when each image was taken, helping to reduce any positioning errors. Correspondingly, the images were co-registered to compute the interferogram and coherence images. Subsequently, all the interferograms were exported to StaMPS software, where the PS points were identified. The phase contributions from orbital, topographic, and Atmospheric Phase Screen (APS) errors have been minimized, allowing the focus to shift to phase changes caused by deformation.

RESULT AND DISCUSSION

Coherence Images

In coherence images, colors and values indicate the stability of the ground surface between two satellite image captures. Coherence values range from 0 to 1, where a value close to 1, often represented as white or lighter colors, indicates high coherence, suggesting there has been little or no change in the ground surface. While values near 0 are usually displayed as black or darker colors, they represent low coherence and suggest significant changes in the surface, such as ground movement, vegetation growth, or other disturbances. The result of a coherent image can be observed through the intensity of the image.

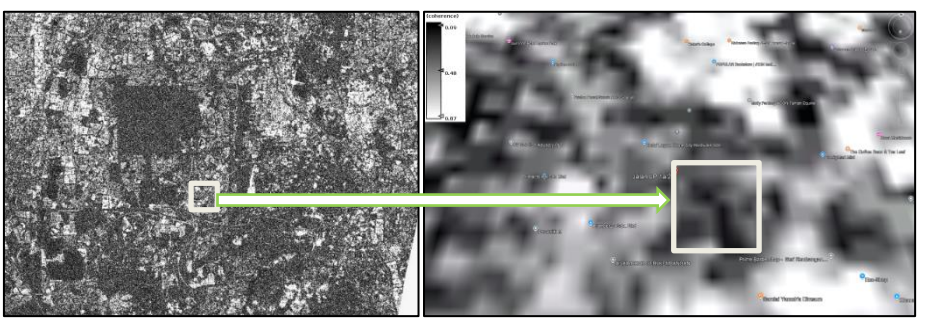

Figure 4. Coherence Images Before Subsidence Occur

Figure 4 displays the coherence image prior to the occurrence of subsidence. The image appears mostly white, indicating high coherence indicating there has not been much change between image captures.

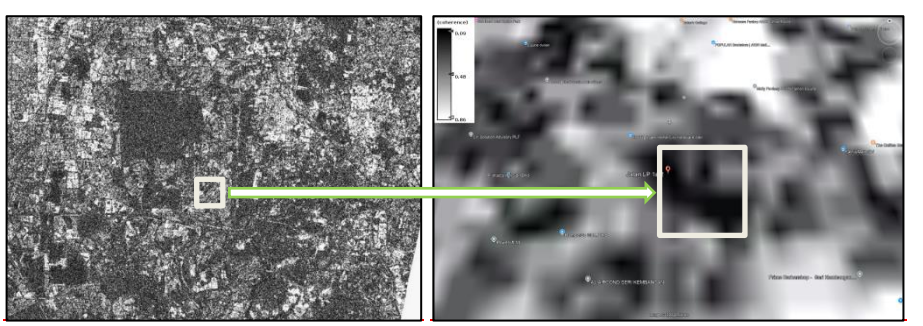

Figure 5. Coherence Images for After Subsidence Occur

Figure 5 depicts the image after subsidence, where the same area appears mostly black, indicating low coherence. This black shading usually implies that the ground has shifted or collapsed significantly. We can observe where the ground has become unstable by comparing the color differences in the coherence images before and after subsidence. These black areas mark zones of ground movement, making coherence images a useful tool for spotting changes and tracking areas at risk of further movement. However, in areas with noticeable movement, such as where cars are moving on the road or in regions with large-scale displacement, there are no identifiable PS points, as selecting PS points requires consistent scatterers. In the PS-InSAR technique, InSAR is unable to detect large movements exceeding a 2π phase shift between two image acquisitions, as well as changes in highly dynamic environments, which

can result in phase unwrapping errors or phase de-correlation. To improve accuracy, nearby buildings with the same object and consistent scatterer characteristics can be used as reference PS points. Figure 6 illustrates the green marker indicating the building, while the purple marker highlights the affected area.

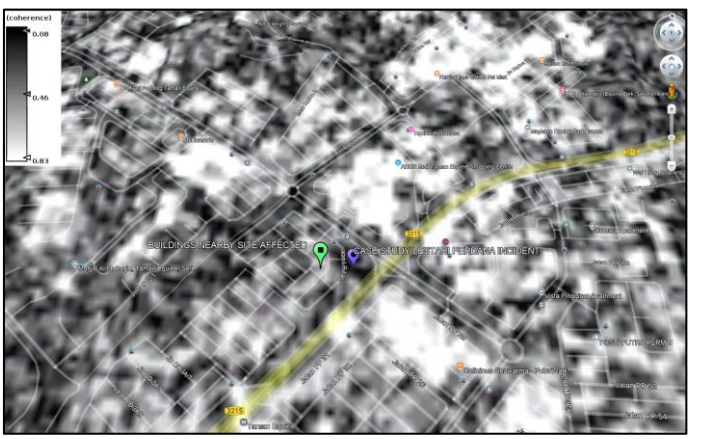

Figure 6. Coherence Images of The Selected PS-Point

Deformation Map

Figure 7 presents a deformation map that provides an overview of ground movement across the area, with different colors representing various types of displacement. The deformation map uses colors to demonstrate ground changes in the affected area. Each color indicates a different type of movement: blue suggests the ground has uplifted, green suggests that the ground is stable with no significant changes, and red indicates that the ground has subsided. Figure 7 highlights the area outlined with a square, as illustrated in Figure 4, displaying subtle color changes following the incident. The deformation map indicates that the monitored buildings have experienced a slight uplift, although certain sections remain stable. This suggests that the ground movement was localized, leaving nearby structures intact.

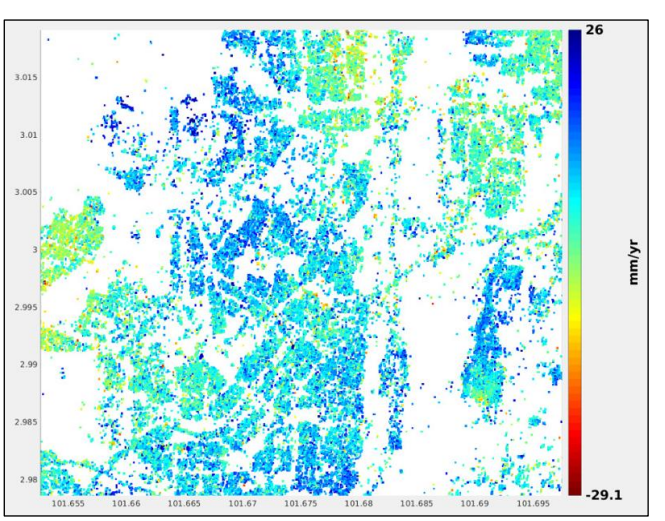

Figure 7. Deformation Map

Displacement Time Series

The time-series graph adds more detail by focusing on specific PS points on the map and demonstrating how the ground has moved at each point over a period. The x-axis represents time, while the y-axis indicates the amount of deformation. The time series data indicates that the building is stable, as the trend remains consistently around 0, with a straight line.

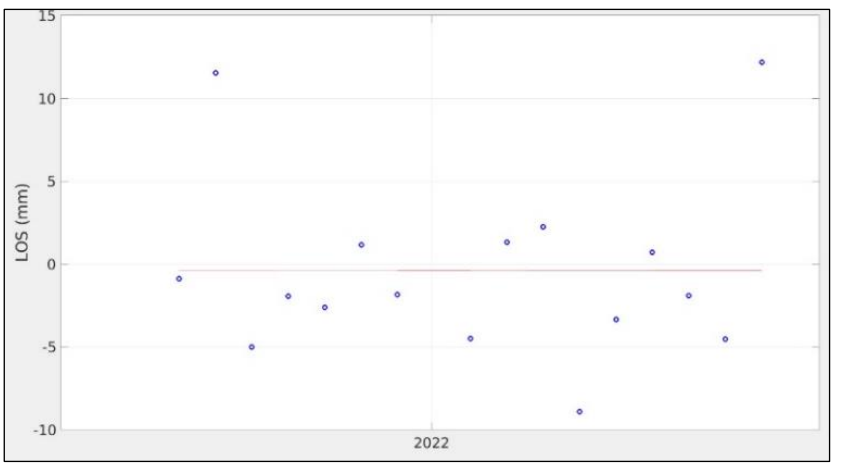

Figure 8. Displacement Time Series

CONCLUSION

The coherence image after the subsidence reveals significant ground movement, particularly in areas of low coherence, indicating substantial displacement. The deformation map offers a clear overview of the spatial distribution of ground movement, highlighting localized subsidence, with the monitored buildings remaining stable. Furthermore, the time-series data further confirms the stability of the buildings, exhibiting no significant deformation over time. As such, these findings emphasize the effectiveness of PS-InSAR techniques in monitoring ground movement, making them useful tools for assessing affected regions. However, the limitation of the PS-InSAR technique lies in its inability to detect large-scale movements and effectively monitor dynamic environments, as there are no PSs in such areas.

ACKNOWLEDGEMENT

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REVOLUTIONIZING FACILITY MANAGEMENT (FM): ADDRESSING INTERNET OF THINGS (IOT) ADOPTION CHALLENGES IN KLANG VALLEY

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Abstract
In the digital era, industries globally are rapidly adopting technologies like the Internet of Things (IoT) and Big Data to drive innovation and improve operational efficiency, with Facility Management (FM) following suit. Despite the excellent growth of the FM industry in Malaysia, the adoption of digital technologies, particularly the IoT, remains low, impacting the quality of FM services. This paper explores the challenges and strategies for enhancing the adoption of IoT technologies in the FM industry, focusing on Klang Valley, Malaysia. A quantitative approach was employed, incorporating quantitative data from questionnaires. The findings reveal that significant challenges include security and privacy concerns, a limited number of experts, high costs of IoT deployment, and a lack of skills and knowledge about new technologies and complexity. To address these issues, the study suggests strategies such as developing more IoT experts, providing training on IoT solutions, enhancing collaboration between government, industry, and academia, and offering financial assistance and subsidies. These insights provide a foundation for FM stakeholders to strategically enhance IoT adoption, thereby advancing the FM industry in Malaysia. This research contributes to the digitalization knowledge in FM and serves as a valuable guide for future research and policymaking.

Keywords: *Internet of Things (IoT); Facility Management (FM); FM Challenges; FM Strategies*

INTRODUCTION

In today's globalized and digital era, integrating technological advancements is paramount for industries aiming to maintain competitive edges and enhance operational efficiency. The Facility Management (FM) industry, historically known for its conservative approach, significantly lags in digitalizing operations compared to other sectors that readily embrace technologies like the Internet of Things (IoT) and Big Data for competitive advantage and improved effectiveness (Granberg & He, 2018). FM integrates people, places, processes, and technology to ensure operational efficiency, comfort, security, and productivity in the built environment (IFMA, 2017; IoT Technology Working Group, 2018). Technologies like Building Information Modelling (BIM), IoT, Digital Twin (DT), Artificial Intelligence (AI), and blockchain are pivotal in transforming FM processes (Olimat, Liu, & Abudayyeh, 2023). Among these, IoT is especially significant for connecting users, building components and services, and blending the physical and virtual realms through intelligent digital interfaces (Wong, Ge, & He, 2018).

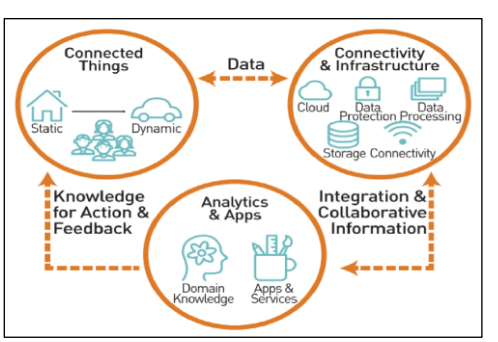
Despite the FM industry's growth in Malaysia, its adoption of digital technologies, particularly the IoT, remains low, impacting service quality (Kamaruzzaman, Myeda, Zawawi, & Ramli, 2018). IoT adoption in FM has seen significant progress globally in countries like China, the Netherlands, and the United States. However, Malaysia's adoption

rate lags and empirical research on IoT in FM is still limited (Abu Bakar & Kamaruzzaman, 2023).

IoT plays a significant role in transforming FM processes by connecting users and building components and services. It enhances building intelligence, safety, and occupant satisfaction (Kawar, 2022). Nonetheless, the rapid evolution of technology, high costs, and lack of expertise continue to pose challenges to IoT adoption in Malaysia's FM industry (Kawar, 2022). Therefore, understanding these challenges is essential for developing strategies to improve IoT integration and ensure operational efficiency in Klang Valley.

INTERNET OF THINGS (IoT) APPLICATION IN FACILITY MANAGEMENT INDUSTRIES

Kamaruzzaman and Zawawi (2010) highlighted that Malaysia's FM has evolved from traditional maintenance to strategic functions driven by technological advancements, management, and business practices. Notably, the adoption of technologies such as mobile applications, data analytics, and the IoT is reshaping FM operations (Atta & Talamo, 2020). Despite these advancements, Abu Bakar and Kamaruzzaman (2023) critiqued the slow adoption of technology in Malaysian FM practices, with workflows remaining labor-intensive and resistant to innovation. Kamaruzzaman et al. (2018) emphasized that improving technology competency is crucial for effective FM. As such, overcoming barriers, such as trust in IoT and understanding technological challenges, is essential to enhancing operational efficiency and strategic decision-making in FM organizations. The IoT is a network of interconnected devices that communicate and share information over the Internet. According to Dahanayake and Sumanarathna (2022), IoT connects devices for communication and data sharing. Meanwhile, Hozdić (2015) described it as a global network of objects exchanging data using standard protocols, with sensors collecting data and connecting devices without human intervention (Erboz, 2017). In FM, IoT plays a key role in maintaining and operating buildings and infrastructure. It uses sensors and devices to monitor facilities, automate processes, and apply data analytics for decision-making. IoT helps FM achieve efficiency, safety, and a conducive environment by offering real-time insights and comprehensive analysis (Aloisio, 2018). Accordingly, IoT comprises three main elements: connected devices, infrastructure and connectivity, and analytics. Malaysia's National IoT Strategic Roadmap highlights the role of intelligent sensors in detecting conditions, transmitting data to the cloud, and generating insights. This data helps stakeholders make more accurate decisions (MIMOS Berhad, 2015).



Source: (MIMOS Berhad, 2015)

Figure 1. The Concept of IoT

The IoT plays a crucial role in FM across various industries by enabling enhanced efficiency, sustainability, and safety through interconnected devices and data exchange. According to Marocco and Garofolo (2021) and Fialho, Codinhoto and Fabricio (2019), key applications of IoT in FM include information management, maintenance management, energy management and emergency management, as summarized in Table 1.

Table 1. Application Fields of FM

	Application Fields of FM	Scope
1.	Information Management	Involves tracking and localizing building components, storing asset information, and using advanced visualization and interaction methods (Marocco & Garofolo, 2021).
2.	Maintenance Management	Maintenance management comprises all the operations that are essential to allowing efficient operation of facilities, including work order administration, decision-making processes for maintenance, identifying defects in building assets and inspecting building assets, along with predictive maintenance (IoT Technology Working Group, 2018; Marocco & Garofolo, 2021).
3.	Energy Management	Observe and analyse the energy consumption of buildings over specified durations, incorporating real-time monitoring, evaluation, and optimization of building energy performance (Marocco & Garofolo, 2021).
4.	Emergency Management	Human-caused emergencies, such as asset failures, chemical spills, and fires, are the most common, but natural disasters, such as tornadoes, can also cause an emergency, including emergency response and path optimization, as well as hazard monitoring (IoT Technology Working Group, 2018; Marocco & Garofolo, 2021).

How Internet of Things (IoT) Shaping The Future of Facility Management

The deployment of IoT in FM offers significant benefits that transform facility operations and enhance user experiences. For instance, IoT reduces costs by providing data-driven insights that help optimize space usage and energy consumption (IoT Technology Working Group, 2018). Thus, by analysing occupancy patterns, FM professionals can make informed decisions about space allocation and energy management, thus avoiding unnecessary expenses. For instance, according to Newton (2024), smart thermostats regulate energy consumption to maintain a consistent temperature, potentially reducing heating and cooling expenses by 8%. This real-time data-driven approach also improves efficiency in systems like heating, ventilation, and air conditioning (HVAC) and water pumps (Newton, 2024). IoT enables predictive maintenance by continuously monitoring asset conditions and forecasting failures before they happen. This system allows assets to self-monitor and alert others of impending issues, preventing broader system failures and improving overall asset performance and durability (IoT Technology Working Group, 2018). Notably, this strategy uses IoT to predict equipment repairs and alert staff, reducing downtime by up to 15% and extending equipment lifespans. As such, it improves efficiency by minimizing emergency fixes and eliminating the need for routine inspections (Newton, 2024).

IoT enhances occupant well-being through continuous monitoring and adjustment of indoor conditions (IoT Technology Working Group, 2018). Sensors track temperature, humidity, and air quality to ensure a comfortable and healthy environment, thereby improving the overall quality of life for occupants (IoT Technology Working Group, 2018). In addition, IoT reduced risk by integrating advanced systems such as cameras and sensors (IoT Technology Working Group, 2018). These technologies detect potential hazards, prevent

unauthorized access, and facilitate quick responses during emergencies, thus reinforcing the safety of the facility. Furthermore, IoT enhances the organizational profile by streamlining operations and improving the overall work environment (IoT Technology Working Group, 2018). For example, IoT can simplify guest registration processes and provide clear navigation within the facility, leading to a more efficient and user-friendly experience. Finally, IoT supports compliance by employing smart tags to verify the authorization and training of employees and using sensors to assist in safe building evacuations during emergencies (IoT Technology Working Group, 2018). Collectively, these advancements demonstrate IoT's pivotal role in enhancing efficiency, safety, and user satisfaction in FM.

Challenges of Internet of Things (IoT) Technology Adoption

The study by Arnold & Voigt (2019) categorized IoT adoption challenges into three (3) aspects; technological, organizational and environmental. A thorough literature review had been done to identified specific challenges in each category, as summarized in Table 2.

Table 2. The Challenges of IoT Adoption

Aspect of Challenges	Specific Challenges	Sources
Technological Challenges	Security and privacy data transactions	(Alenizi & Al-Karawi, 2022; Aloisio, 2018; Badarudin, Din, Prasetyo, Musa, & Kasim, 2018; Ghosh, Hosseini, Edwards, Kassem, & Mateo-Garcia, 2019; Kumar, Tiwari, & Zymbler, 2019; Musfira & Cassim, 2018; Takki, 2019; Tang, Shelden, Eastman, Pishdad-Bozorgi, & Gao, 2019)
	High cost of IoT deployments	(Aloisio, 2018; Badarudin et al., 2018; Fung, Salleh, & Rahim, 2014; Granjal, Monteiro, & Sa Silva, 2015; Ibrahim, Shariff, Esa, & Rahman, 2019; Takki, 2019; Tang et al., 2019)
	Scalability issues	(Alenizi & Al-Karawi, 2022; Kumar et al., 2019; Musfira & Cassim, 2018; Takki, 2019)
	Interoperability/standard issues	(Alenizi & Al-Karawi, 2022; Ibrahim et al., 2019; Kumar et al., 2019)
	Limited network infrastructures & connectivity	(Alenizi & Al-Karawi, 2022; Bedekar, 2017; Botta, De Donato, Persico, & Pescapé, 2016; Ibrahim et al., 2019; Maru, Pitroda, & Raval, 2020; Takki, 2019; Tang et al., 2019)
	Complexity of IoT technologies	(Alenizi & Al-Karawi, 2022; Musfira & Cassim, 2018; Takki, 2019)
	Compatibility issues	(Aamer, Al-Awlaqi, Affia, Arumsari, & Mandahawi, 2021; Ghosh et al., 2019)
Organizational Challenges	Limited number of experts	(Fung et al., 2014; Ibrahim et al., 2019; Maru et al., 2020)
	Resistance to change in the FM profession	(Aloisio, 2018; Ibrahim et al., 2019; Takki, 2019)
	Lack of skills and knowledge about new technologies	(Aloisio, 2018; Bedekar, 2017; Maru et al., 2020; Takki, 2019; Tang et al., 2019)
	Changes in the business model	(Ghosh et al., 2019; Takki, 2019)
	Lack of top management support	(Ibrahim et al., 2019; Rad & Ahmada, 2017)
	Lack of collaboration & information sharing	(Maru et al., 2020; Takki, 2019)
Environmental Challenges	Lack of government policy	(Badarudin et al., 2018; Ghosh et al., 2019; Maru et al., 2020)
	Technological Uncertainty	(Aloisio, 2018; Tu, 2018)
	Lack of partners & stakeholder collaboration	(Gamil, Abdullah, Abd Rahman, & Asad, 2020; Oke, Arowoiya, & Akomolafe, 2022)

Technological Aspect: IoT adoption faces several technological hurdles, notably security and privacy concerns, high deployment costs, scalability issues, interoperability standards, poor internet connectivity, complexity, and device compatibility. Security threats and privacy breaches are significant barriers due to vulnerabilities in data transactions (Alenizi & Al-Karawi, 2022; Ghosh et al., 2019). Furthermore, the high initial costs of integrating IoT solutions in many organizations are compounded by ongoing maintenance expenses (Ibrahim et al., 2019). Scalability challenges arise from the diversity of IoT devices and their varying capabilities, impacting system performance (Rejeb, Rejeb, Zailani, Treiblmaier, & Hand, 2021). Meanwhile, interoperability issues stem from the lack of unified standards across IoT devices and platforms, hindering seamless communication and data exchange (Kumar et al., 2019). At the same time, poor internet connectivity in many regions' further limits IoT deployment potential (Maru et al., 2020), while the complexity of IoT technologies and compatibility issues between devices add layers of difficulty (Musfira & Cassim, 2018).

Organizational Aspect: Within organizations, challenges include a shortage of skilled experts, resistance to technological change, knowledge gaps, business model adjustments, lack of top management support, and insufficient collaboration. The demand for IoT expertise surpasses availability, making it challenging to deploy and manage IoT solutions effectively (Lee & Lee, 2015). Moreover, resistance to change among employees and stakeholders impedes the adoption despite potential benefits (Ibrahim et al., 2019). In addition, insufficient skills and knowledge hinder IoT implementation, requiring investments in workforce training and development (Tang et al., 2019). Businesses often need help with adapting their existing business models to accommodate IoT technologies, fearing disruptions and additional costs (Birkel & Hartmann, 2019). Lack of support from top management further complicates adoption efforts, affecting funding and strategic alignment (Arnold & Voigt, 2019). Lastly, inadequate collaboration and information sharing within organizations create silos and inefficiencies, impacting decision-making and project outcomes (Maru et al., 2020).

Environmental Aspect: External factors such as government policies, technological uncertainties, and stakeholder collaboration pose environmental challenges to IoT adoption. The absence of clear regulations around IoT usage limits standardization and complicates legal and security frameworks (Ibrahim et al., 2019). Technological uncertainties in the market and rapid advancements present risks and uncertainties for long-term IoT investments (Aloisio, 2018). Additionally, inadequate collaboration among stakeholders and partners hampers the development of cohesive IoT ecosystems, where disparate systems and conflicting interests prevent seamless integration and innovation (Oke et al., 2022).

Overcoming Challenges in Adoption of Internet of Things (IoT) Technology

The IoT plays a crucial role in driving digital transformation across industries. Alongside the various challenges faced by the industry players, several strategies are being implemented to promote successful IoT adoption. These strategies aim to mitigate barriers and foster more efficient integration of IoT solutions. Table 3 categorizes IoT adoption strategies into three main areas; technology, organization, and environment at the same time providing a brief overview of the approaches to addressing the challenges in each aspect.

Technological Aspect: Technological advancements form the backbone of successful IoT deployments. Establishing robust and secure network infrastructures, coupled with reliable

internet connectivity, is paramount. Technologies like 5G and satellite systems are pivotal in providing the bandwidth and low latency required by various IoT applications (Jiang & Liu, 2017). In addition, financial assistance in the form of subsidies and tax incentives further supports the deployment of IoT infrastructure, particularly benefiting small and medium-sized enterprises (SMEs) in creative industries struggling with initial investment costs (Sen, 2023). Thus, middleware solutions are critical in integrating disparate IoT systems, ensuring seamless communication and interoperability across different platforms (Silva et al., 2023). Robust data management frameworks are essential for handling the vast amounts of data generated by IoT devices, ensuring data quality and reliability for informed decision-making (Bohli et al., 2015). Pre-rigorous studies before deployment help anticipate integration challenges and optimize system design for scalability and efficiency (Moeuf et al., 2019). Comprehensive security measures, including encryption and regular audits, are essential to safeguard IoT ecosystems from potential cyber threats (Haddud et al., 2017).

Table 3. Overcoming Challenges in Adoption of IoT

Aspect of Strategies	Specific Strategies	Sources
Technological Strategies	Establish robust and secure network infrastructure & internet connectivity	(Jiang & Liu, 2017)
	Provision of financial assistance & subsidies	(Lee & Lee, 2015; Sen, 2023)
	Invest in middleware solutions	(Silva et al., 2023)
	Implementation of data management & quality framework	(Bohli, Skarmeta, Moreno, García, & Langendörfer, 2015)
	Conducted a pre-rigorous study for smooth integration	(Moeuf et al., 2019)
	Implementing comprehensive security procedure	(Ancarani, Di Mauro, Legenvre, & Cardella, 2020; Haddud, DeSouza, Khare, & Lee, 2017; Kamble, Gunasekaran, Parekh, & Joshi, 2019)
Organizational Strategies	Training for employees on IoT solution	(Andersen, 2018; Fantini, Pinzone, & Taisch, 2020; Fernandez, Renukappa, & Suresh, 2019; Moeuf et al., 2019)
	Developing more experts in the IoT field and knowledge	(Badarudin et al., 2018)
	Awareness campaigns and programs	(Badarudin et al., 2018)
	Sponsorship from top or senior manager	(Eaves, Kumar, White, & Loonam, 2018; Fernandez et al., 2019)
	Enhancing organizational communication and collaboration	(Andersen, 2018; Eaves et al., 2018; Moeuf et al., 2019)
Environmental Strategies	Enhanced collaboration between government industry and academia	(Abu Bakar, Z. & Kamaruzzaman, S. N., 2023)

Organizational Aspect: Organizational readiness and support are crucial for the successful implementation of IoT initiatives. Training programs tailored to IoT solutions are essential to equip employees with the necessary skills and knowledge to effectively utilize IoT technologies (Moeuf et al., 2019). Academic partnerships are vital in nurturing IoT expertise and fostering organizational innovation (Badarudin et al., 2018). Moreover, awareness campaigns and sponsorship from senior management are pivotal in garnering organizational buy-in and commitment to IoT projects (Fernandez et al., 2019). Enhancing cross-functional communication and collaboration ensures the smooth integration of IoT technologies across various departments and functions and aligning organizational goals with technological advancements (Eaves et al., 2018). Creating a supportive organizational culture

that values technological innovation, and collaboration further enhances the adoption and acceptance of IoT solutions (Andersen, 2018).

Environmental Aspect: Environmental factors encompass collaborative efforts between government, industry, and academia to create an enabling ecosystem for IoT adoption. National IoT strategies and policy frameworks provide a structured approach to incentivize investment and innovation in IoT technologies (Abbas, 2023). Collaboration with industries facilitates developing and deploying IoT solutions tailored to specific sectoral needs, fostering economic growth and technological advancement (Abbas, 2023). Systematic engagement and collaboration between academic institutions, research organizations, and industry stakeholders promote the co-creation of cutting-edge IoT technologies and solutions (Abbas, 2023). These partnerships facilitate the development of scalable and sustainable IoT applications that address societal challenges and drive economic development through enhanced connectivity and data utilization.

METHOD

This study employed a quantitative approach to collecting and analyzing data. An online survey was conducted, and a questionnaire was distributed to FM organizations in Klang Valley. The quantitative data collected focused on identifying challenges and strategies for enhancing IoT adoption. The questionnaire was structured into three sections to address the study's objectives. Table 4 below summarizes the content and purpose of each section.

The sampling method for this study is non-probability sampling, which is cost-effective and efficient. Specifically, purposive sampling was employed, allowing the selection of respondents based on their expertise and knowledge. The target population consists of FM organizations' stakeholders in the Klang Valley, known for its high level of innovation. Respondents included individuals from FM organizations and firms involved in related services throughout the region. The sampling frame was constructed using data from the official website of the Construction Industry Development Board (CIDB) Malaysia (Table 5).

Table 4. Summary of Sections in The Questionnaire

Section	Content	Type of Question Rating	Purpose
A	Respondent Background	Close-ended	To retrieve demographic information of the respondents
B	To investigate the challenges of the adoption of IoT technologies in the Facility Management sector	5-points Likert scale	To achieve the objective: Challenges of IoT adoption
C	To provide strategies for enhancing IoT technology adoption in the Facility Management sector	5-points Likert scale	To achieve the objective: Strategies enhancing IoT adoption

Table 5. Number of Population (FM Organizations in Klang Valley Area)

Firm	Area of Specialization	Number
Facility Management	F01 (Building Facilities & Infrastructures)	585
	F02 (Healthcare Building Facilities)	89
Total		674

To calculate the sample size, Yamane's (1973) formula was applied, with a 90% confidence level and an acceptable error margin of 0.10. The formula yielded a sample size of 87 respondents, representative of the FM organizations. The questionnaire was distributed online to 100 targeted respondents via WhatsApp and email. As a result, a total of 90 responses were received. The data collected through the questionnaire were analysed using IBM Statistical Practices for Social Sciences (SPSS) version 28. Descriptive analysis was performed, and the reliability of the questionnaire was assessed using Cronbach's Alpha Reliability Test.

RESULTS AND DISCUSSION

Respondent's Demographic

Based on Table 6, the gender distribution indicates that 55.6% of the respondents are male and 44.4% are female. The age distribution reveals that 42.2% of the respondents are between 26 and 35 years old, 33.3% are between 36 and 45 years old, 17.8% are between 18 and 25 years old, and 6.7% are 46 years old and above.

Regarding education, most respondents (71.1%) hold a degree, 17.8% have a diploma, 7.8% have a master's degree, 2.2% have a PhD, and 1.1% completed secondary school. The respondents' roles within their organizations vary, with 58.9% belonging to the Executive Core (operational level), 36.7% to the Middle Management and Support Group (tactical level), and 4.4% to Top Management (strategic level).

In terms of experience with IoT, 37.8% of the respondents have one to two years of experience, 23.3% have three to five years, 20.0% have less than one year, and 18.9% have five to ten years. This demographic data provides a well-rounded view of the respondents' backgrounds and engagement with IoT in the FM sector, highlighting their substantial experience and expertise.

Table 6. Quantitative Method – Demographic Information

Variables	Value	Frequency	%
Gender	Male	50	55.60%
	Female	40	44.40%
Age	18-25	16	17.80%
	26-35	38	42.20%
	36-45	30	33.30%
	46 and above	6	6.70%
Education Level	Secondary School	1	1.10%
	Diploma	16	17.80%
	Degree	64	71.10%
	Master	7	7.80%
	PhD	2	2.20%
Management Group	Top Management (Strategic Level)	4	4.40%
	Middle Management & Support Group (Tactical Level)	33	36.70%
	Executive Core (Operational Level)	53	58.90%
Internet of Things (IoT) Experience	Less than 1 Year	18	20.00%
	1-2 Years	34	37.80%
	3-5 Years	21	23.30%
	5-10 Years	17	18.90%

The Challenges of Adoption of IoT Technologies

Findings presented in this section were collected from the participant responses to Section B of the questionnaire. Table 7 tabulated the mean score ranking of each challenge.

Security and privacy data transactions are the primary technological challenges in IoT adoption, with a mean value of 4.91 and a standard deviation of 0.441. Organizations are hesitant to fully adopt IoT technologies due to the perceived risks of data security breaches and privacy violations. The high mean score reflects widespread recognition of these issues, aligning with findings from Palak and Gaur (2023), who also noted that IoT's potential for data breaches could deter adoption. This underscores a significant challenge: organizations are likely to be cautious about IoT due to fears of data security breaches and privacy violations, directly related to the research objective of identifying barriers to IoT adoption in FM.

Table 7. Mean Score Ranking for The Challenges in The Adoption of IoT Technologies

Item	Challenges	Aspect	N	Mean	Standard Deviation	Level of Agreement	Mean Rank
1	Security and privacy data transactions	Technology	90	4.91	0.441	Strongly Agree	1
2	Limited number of experts	Organization	90	4.86	0.412	Strongly Agree	2
3	High cost of IoT deployments	Technology	90	4.6	0.557	Strongly Agree	3
4	Lack of skills and knowledge about new technologies	Organization	90	4.57	0.562	Strongly Agree	4
5	Complexity of IoT technologies	Technology	90	4.52	0.585	Strongly Agree	5
6	Limited network infrastructures & connectivity	Technology	90	4.49	0.674	Strongly Agree	6
7	Lack of government policy	Environment	90	4.11	0.529	Agree	7
8	Lack of partners & stakeholder collaboration	Environment	90	4.08	0.403	Agree	8
9	Lack of collaboration & information sharing	Organization	90	4.06	0.483	Agree	9
10	Interoperability/standard issues	Technology	90	4.03	0.461	Agree	10
11	Lack of top management support	Organization	90	3.71	0.768	Agree	11
12	Changes in the business model	Organization	90	3.71	0.64	Agree	12
13	Compatibility issues	Technology	90	3.66	0.603	Agree	13
14	Scalability issues	Technology	90	3.63	0.841	Agree	14
15	Resistance to change in the FM profession	Organization	90	3.62	0.728	Agree	15
16	Technological uncertainty	Environment	90	3.02	0.948	Quite Agree	16

The analysis identified the limited number of experts as the second significant organizational challenge, with a mean value of 4.86 and a standard deviation of 0.412. Respondents strongly agreed that this is a significant barrier to IoT adoption in the FM sector. This finding aligns with previous research by Maru et al. (2020), Ibrahim et al. (2019), and Fung et al. (2014), who also highlighted the scarcity of skilled professionals capable of efficiently operating IoT devices.

The research highlights that the high cost of IoT deployments is a significant challenge, ranking third among respondents' concerns, with a mean value of 4.60 and a standard deviation of 0.557. This indicates strong support from respondents regarding the difficulties organizations and stakeholders in the FM industry face when adopting IoT. The

transformation to new technology necessitates procuring technical equipment and specific skills, leading to high allocation costs, particularly affecting small and medium enterprises. Zainon, Mohd-Rahim, Aziz, Kamaruzzaman and Puidin (2018) also noted that financial constraints often prevent firms from utilizing digital technology, posing substantial obstacles to integrating IoT into operations.

The fourth challenge, a lack of skills and knowledge about new technologies, obtained a mean value of 4.57 and a standard deviation of 0.562. This finding supports Rosman (2016) and Maru et al. (2020), who emphasized the significance of knowledge and skills in adopting new technologies. The necessity for both theoretical knowledge and practical training highlights the need for educational initiatives and training programs as part of our strategies to enhance IoT adoption.

The complexity of IoT technologies scored 4.52 with a standard deviation of 0.585, ranking fifth among challenges. This complexity, requiring a deep understanding of interconnected devices and networks, is consistent with Khanna and Kaur (2019), who discussed the challenges of integrating diverse IoT devices. Accordingly, simplifying IoT technologies and providing user-friendly solutions could mitigate this challenge, contributing to more effective adoption strategies.

The Strategies for Enhancing IoT Technologies Adoption

Findings presented in this section were collected from the participant responses to Section C of the questionnaire. Table 8. tabulated the mean score ranking of each strategy.

Table 8. Mean Score Ranking for Strategies Enhancing IoT Technologies Adoption

Item	Challenges	Aspect	N	Mean	Standard Deviation	Level of Agreement	Mean Rank
1	Developing more experts in the IoT field & knowledge	Organization	90	4.90	0.369	Strongly Agree	1
2	Training for employees on IoT solutions	Organization	90	4.89	0.436	Strongly Agree	2
3	Enhanced collaboration between government, industry & academia	Environment	90	4.74	0.572	Strongly Agree	3
4	Provision of financial assistance & subsidies	Technology	90	4.60	0.557	Strongly Agree	4
5	Enhancing organizational communication and collaboration	Organization	90	4.52	0.545	Strongly Agree	5
6	Conducted a pre-rigorous study for smooth integration	Technology	90	4.24	0.865	Strongly Agree	6
7	Establish robust and secure network infrastructure & internet connectivity	Technology	90	4.22	0.514	Strongly Agree	7
8	Implementing comprehensive security procedure	Technology	90	4.19	0.959	Agree	8
9	Implementation of data management & quality framework	Technology	90	3.89	0.57	Agree	9
10	Awareness campaigns and programs	Organization	90	3.81	0.652	Agree	10
11	Investing in middleware solutions	Technology	90	3.81	0.634	Agree	11
12	Sponsorship from top or senior managers	Organization	90	3.14	0.855	Agree	12

The study identifies the development of expertise in the IoT field as the top strategy for enhancing IoT adoption, with a mean score of 4.90 and a standard deviation of 0.369. This finding underscores the need for skilled professionals to advance IoT technologies, as Badarudin et al. (2018) supported. Academia's role in providing relevant education is crucial for creating a proficient workforce, addressing expertise gaps, and fostering IoT innovation, which aligns with the research objective of overcoming barriers to IoT adoption.

The second strategy, training employees on IoT solutions, scored 4.89 with a standard deviation of 0.436. This strategy highlights the importance of comprehensive training, echoing (Hong, Sepasgozar, Ahmadian, & Akbarnezhad, 2016). Hence, effective training should integrate formal and situational elements, with adequate support tailored to individual needs (Andersen, 2018; Moeuf et al., 2019). Ensuring user-friendly technology and simplifying its use can ease adoption (Fernandez et al., 2019). Moreover, comprehensive training plans are crucial to addressing perceived complexities and accelerating the mastery of IoT systems (Fantini et al., 2020). Addressing these training needs aligns with mitigating complexities in IoT adoption.

Enhanced collaboration between government, industry, and academia ranks third, with a mean score of 4.74 and a standard deviation of 0.572. This strategy aims to foster a supportive environment for IoT adoption, exemplified by Malaysia's National IoT Strategic Roadmap (Abbas, 2023). By combining resources and expertise, such partnerships can address regulatory and technological barriers and drive innovation. This strategy underscores the importance of a tri-sector partnership in fostering IoT integration and advancing technological solutions, addressing key barriers identified in our research.

The fourth strategy is providing financial assistance and subsidies, scoring 4.60 with a standard deviation of 0.557. Respondents support government subsidies as essential for overcoming financial barriers to IoT adoption, reflecting Chan, Olawumi and Ho (2019). Financial aid, cost reductions, and tax incentives enable stakeholders to leverage IoT technologies and stimulate industry competition. This strategy addresses financial constraints and enhances the attractiveness of IoT investments, contributing to broader adoption.

Enhancing organizational communication and collaboration ranks fifth, with a mean score of 4.52 and a standard deviation of 0.545. Improving communication across functions can facilitate IoT adoption by aligning duties and training, as Andersen (2018) noted. Targeting tech-savvy employees and gradually involving others can ease adoption (Fernandez et al., 2019). Organizing feedback events and promoting continuous improvement (Eaves et al., 2018; Moeuf et al., 2019) can foster a collaborative environment that supports smoother technology integra00tion and addresses the research objective of enhancing organizational practices.

CONCLUSION

This study highlights that despite widespread awareness of IoT benefits in the FM industry in Klang Valley, adoption remains slow, hindered by security concerns, high costs, and a lack of expertise. A total of 16 challenges were identified, with 12 strategies proposed to address them, such as enhancing training, providing financial support, and fostering collaboration between stakeholders. Notably, these findings offer valuable insights for

organizations and policymakers looking to overcome adoption barriers, with potential implications for boosting innovation, efficiency, and competitiveness in the FM sector. Therefore, future research should explore IoT adoption across a broader geographical scope and investigate differences among FM roles to further understand the industry's challenges and opportunities. Nevertheless, this study contributes to the growing knowledge of IoT adoption in FM and offers a foundation for future research and policy development.

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THE INFLUENCE OF KNOWLEDGE SHARING DETERMINANTS IN IMPROVING THE PERFORMANCE OF OUTSOURCED FACILITIES MANAGEMENT DELIVERABLES

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Abstract

Government assets represent a substantial financial investment of public funds, which has gained growing attention since the mismanagement of the government's assets has been featured in the Auditor General Report for several years. The rising demand for the government sector to be fiscally lean is challenging for Facilities Management (FM) service providers. Despite numerous challenges and issues with outsourcing, there is a need of a holistic Knowledge Management (KM) approach. Knowledge Sharing (KS) is the most vital process of KM in organisational operations. It is influenced by individuals' interaction that affects job efficiency by exchanging of relevant knowledge, best practices and lessons, hence improving organisational performance and knowledge competence. Nevertheless, the impact of KS towards the performance of Outsourced FM (OFM) is ambiguous, leading to this study, which aims to assess the influence of KS determinants on the performance improvement of OFM in government buildings. The study employs a deductive theoretical approach with a cross-sectional time horizon. Using the Theory of Planned Behaviour (TPB) as the foundational framework and a questionnaire survey as the data collection method, findings from 112 OFM personnel in government buildings revealed that Self-Attitude (SA) and the Nature of Knowledge (NK) significantly influence OFM performance. Nonetheless, Motivation to Share (MS), Organization Culture (OC) and Opportunity to Share (OS) demonstrated insignificant influence. The outcome of the study can help outsourcers strategically enhance KS initiatives and address weaker areas for the improvement of the OFM-government context. However, the study is limited to the context of OFM under the administration of the Malaysia Public Work Department (PWD) with a small sample size. Further research is suggested to consider the prior research conceptual model consisting of the five proposed determinants. This study accordingly has proposed a KS model to improve the performance of OFM deliverables in government buildings.

Keywords: *Government buildings; Knowledge sharing; Performance improvement; Outsourced facilities management; Theory of Planned Behaviour*

INTRODUCTION

In contrast with other advanced markets such as the USA, UK, Australia and Japan, Facilities Management (FM) in Malaysia has been driven by the government sector through the Public Works Department (PWD) since 1974 (Myeda & Pitt, 2014; Abdullah et al., 2017). Consequently, the focus then was on the maintaining public roads, buildings, and sewerage systems (Kamaruzzaman & Zawawi, 2010). Being the longest stage in a property asset life cycle, the operational and maintenance stage is indeed is a critical phase that consumes more than two-thirds of the total building cost, many times more than the original construction costs

(Hauashdh et al., 2021). Following the major privatisation of non-clinical services of public hospital services all over Malaysia in 1996, outsourcing FM has been the most opted choice not only in the government sector but also in the private sector. Notably, FM service providers or vendors are hired through total or phased outsourcing to reduce scale and expenditure in the operation and management of support services (Lok et al., 2021). By employing this, the client could relieve its financial burden while relying on outsourcers' technical expertise, and, at the same time, could concentrate on its core activities.

FM of public buildings and facilities has gained much attention due to its significant representation of government financial investments, making the management more expensive than private sector services (Hopland et al., 2019). Furthermore, the community is also attracted to the issues as they involve public funds and reflect the credibility of the government civil service in managing these assets (Ismail et al., 2019). As highlighted by Ashok (2021), the increasing demand for the public sector to be financially lean and address the needs of diverse stakeholders insists that the government adopt Knowledge Management (KM) practices for agile, technologically advanced and responsive administration. Effective KM efforts and programmes are essential for managing these assets, besides ongoing cost reduction exercises in the public sector (Haile et al., 2020). KM, as defined by Sadat (2021), is a strategy to enhance the delivery of government services by managing its intellectual assets, such as existing knowledge and expertise. The main key component of KM is Knowledge Sharing (KS), a process where individuals reciprocally exchange knowledge and collaboratively create new knowledge (Fullwood & Rowley, 2017). Notably, KS involves shared beliefs or behavioural practices related to exchanging worker knowledge, experiences, and skills across a department or organisation (Farooq, 2018).

Previous studies have highlighted that KS can significantly affect organisational performance. As a central process in KM, KS connects and integrates various other KM processes and practices, facilitating the exchange of knowledge, experiences, and skills throughout an organisation (Abdelwhab et al., 2019). Characterised by profound human interactions, KS is a dynamic social process (Kucharska, 2018). Numerous studies have affirmed that robust KS implementation can improve social networks (Xin et al., 2021), promote innovation (Fattah et al., 2020), increase job satisfaction (Yun et al., 2021) and life gratification (Ahmad & Karim, 2019), also improve work-life balance (Amber et al., 2021). These beyond work-related impacts are profoundly crucial to indirectly enhance organisational performance.

Nevertheless, Martins et al. (2019) claimed that authoritative stakeholders do not use proper KS practices. Evidence from several case studies indicates that expected sourcing outcomes, such as service delivery quality and cost reduction, are unmet when service providers and clients fail to adequately share relevant knowledge (Zimmermann et al., 2018). Furthermore, the in-house staff are hesitant to cooperate and be involved with the service provider's activities due to the difference in overseeing the services process (Sridarran & Fernando, 2016). This lack of KS leads to unnecessary expenses for maintenance and remedial work, as the different cultures and work processes of the various parties involved in an outsourced project hinder mutual understanding among team members.

Poor building conditions could leave various speculations, such as giving the impression that the current government is not performing, mismanaging public funds (Ismail et al., 2019)

and presence of disputes in the present government's administration. Over the years, the government has spent massive amounts of money managing its assets. However, problems still occur, such as poor maintenance, changes of contractors and major breakdowns, leading to poor FM performance (Awang et al., 2017; Hauashdh et al., 2020). Kamaruzzaman et al. (2018) highlighted that in 2007, six incidents alone were reported to take place at government buildings involving hospitals, such as the collapse of a ceiling, floods due to leaking and various other defects worth millions of construction value.

Although previous studies have revealed various advantages of knowledge, the awareness of KS in the area of FM is very low. Zaidi et al. (2021) highlighted that the main obstacle to KS sustainability is the willingness of individuals to be involved in KS activities, as individuals and groups lack the Motivation to Share (MS) (Farooq, 2018). On the other hand, tacit knowledge that is not documented is at risk of being lost or forgotten (Swain, 2020). The industry is experiencing a high turnover rate by losing valuable skills and an experienced workforce (Kamaruzzaman et al., 2016). At the same time, the experienced FM personnel are retiring, while the young ones are under-experienced yet forced to manage vendors of higher experience and knowledge (Kashiwagi & Rivera, 2020). The outsourced services, in turn, are utilising the same FM professionals. As a result, the agility of the public service will decrease as the organisation needs to repeatedly realign its policies and strategies (Sulistyaningsih et al., 2021).

In light of the above, this research necessarily is intended to assess KS determinant factors that influence OFM performance improvement in government buildings.

RESEARCH CONCEPTUAL MODEL

A conceptual model was developed for this research founded on the Theory of Planned Behaviour (TPB). Note that TPB was expanded from the Theory of Reason Action (TRA) developed by Fishbein and Ajzen (1975). TRA undertakes the significance of the intention to perform a specific behaviour and supports the idea that the harder the efforts, the more possible it is for the behaviour to occur (Fullwood & Rowley, 2017). Ajzen (1991) later extended TRA to TPB, which, according to TPB, an individual's behavioural action primary determinants are intention and perceived behavioural control. Intention is impacted by a person's behavioural, normative, and control beliefs. Furthermore, Azjen's (1991) theory assumes that every element is totalled as part of actual behaviour (Tohidinia & Mosakhani, 2010).

The TPB is selected in this study as it is regarded as the most influential and popular model for explaining and predicting human behaviour in a specific context (Ajzen, I. 2001). The TPB model is recognised to have a robust construct. Thus, the reliability and validity of the variables are already justified (Rahadhi & Suzianti, 2020).

The developed conceptual framework contains 30 independent variables and five dependent variables that are clustered under five KS group factors, namely Self-Attitude (SA), Nature of Knowledge (NK), MS, Organisation Culture (OC) and Opportunities to Share (OS). Accordingly, five (5) hypotheses were recognised for this research based on the research conceptual framework, as displayed in Figure 1.

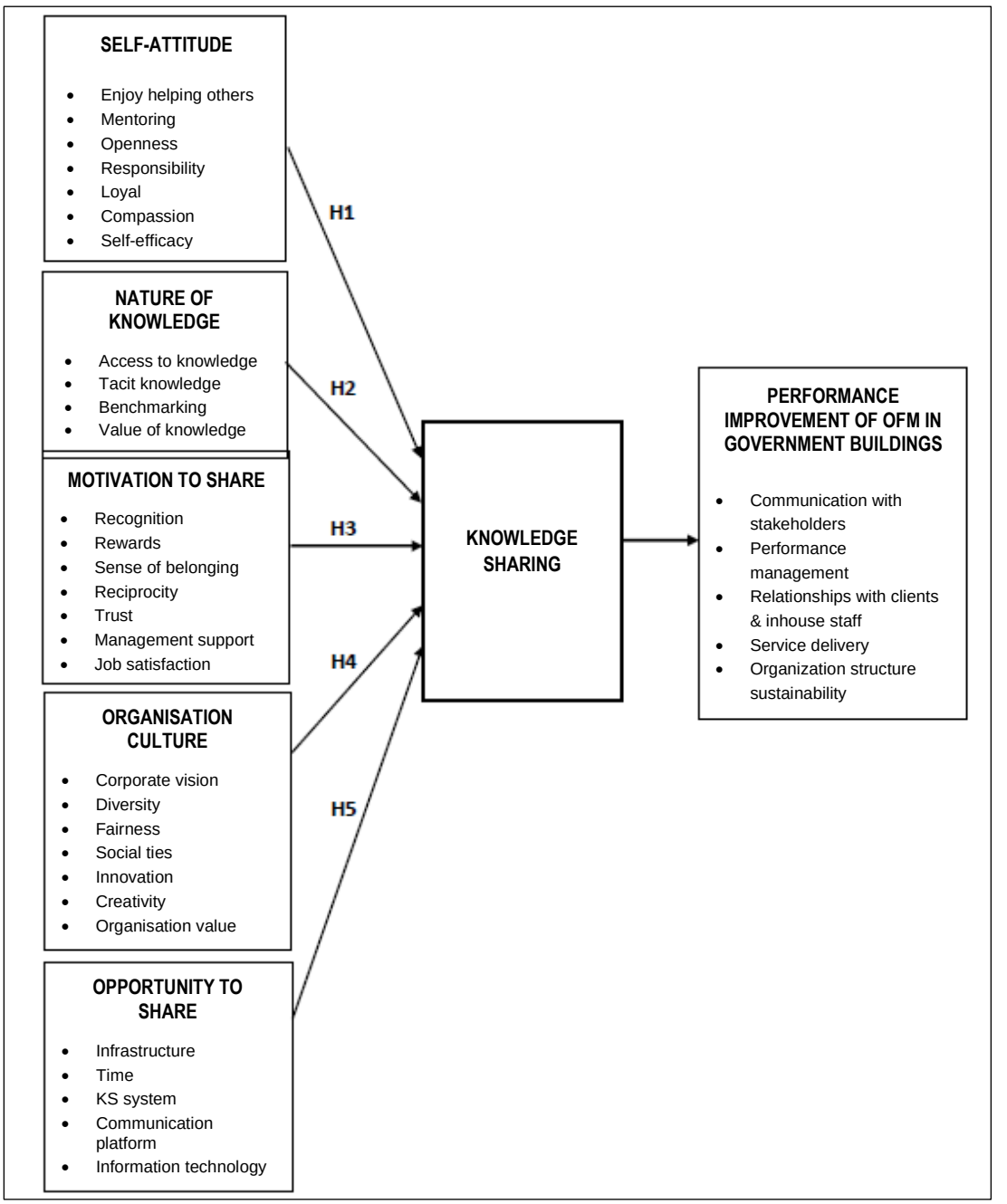

Figure 1. Research Conceptual Model

Below are the hypotheses established from the conceptual model:

Hypothesis 1: There is a significant relationship between the determinants of "SA" and KS towards the performance improvement of OFM in government buildings. This hypothesis consists of enjoying helping others, mentoring, openness, responsibility, loyalty, compassion and self-efficacy.

Hypothesis 2: There is a significant relationship between the determinants of "NK" and KS towards the performance improvement of OFM in government buildings. This hypothesis consists of access to knowledge, tacit knowledge, benchmarking and value of knowledge.

Hypothesis 3: There is a significant relationship between the determinants of "MS" and KS towards the performance improvement of OFM in government buildings. This hypothesis includes recognition, rewards, trust, reciprocity, sense of belonging, job satisfaction and management support.

Hypothesis 4: There is a significant relationship between the determinants of "OC" and KS towards the performance improvement of OFM in government buildings. This hypothesis consists of innovation, creativity, diversity, corporate vision, fairness, organisational value and social ties.

Hypothesis 5: There is a significant relationship between determinants of "OS" with KS towards the performance improvement of OFM in government buildings. This hypothesis comprises infrastructure, time, KS system, communication platform and information technology.

METHODOLOGY

The study aims to examine the influence of KS determinant factors on the improved performance of Outsourced FM (OFM). It employs positivism, philosophical, and deductive approaches that use a questionnaire survey strategy for data collection.

Sample

The study involved 200 population size of Facility Managers and executives representing the Facilities Management and Maintenance (FMMC) and Housekeeping and Pest Control Services Contract (HPCSC) in Peninsular Malaysia and Sabah. These sites are under the administration of PWD, involving 11 Facilities Superintending Officers (FSO) Offices. At the same time, non-probability convenient sampling is applied as the method of sampling, where the respondents are approached through email, WhatsApp applications, and LinkedIn platforms.

Instrumentation

A questionnaire was developed from the research conceptual framework comprising 30 independent variables and five dependent variables. It is mainly divided into two sections. Section A contains six multiple-choice questions on the respondent's backgrounds, while Section B consists of 38 5-point Likert scale questions representing independent and dependent constructs. Google Form is used to collect and self-administered the responses received.

Data Analysis

The data set was analysed using Structural Equation Modelling (SEM) via SmartPLS 4.0 software. SEM is a technique of multivariate analysis that works on the regression analysis

principle, a preferred choice from the traditional methods in dealing with substantial and statistical problems. The analysis involves two stages: measurement model assessment to examine the validity and reliability of the scales and structural model assessment to investigate the relationship between the determinant factors and KS through path coefficient.

FINDINGS

The analysis results are explained further in the following sub-sections.

Respondents' Profile

From the 200 questionnaires distributed, only 112 responses were returned and valid for analysis, making up 56% of the response rate. According to Wu et al. (2022), the average response rate for online surveys is 44%. Table 1 below summarises the detailed distribution of the respondents' profiles.

Table 1. Profile of Respondents

Profiles	Category	Frequency	Percent	Valid Percent	Cumulative Percent
Working years' experience in the FM industry	2-5	27	24.1	24.1	24.1
	5-8	24	21.4	21.4	45.5
	8-10	17	15.2	15.2	60.7
	Less than 2	5	4.5	4.5	65.2
	More than 10	39	34.8	34.8	100.0
	Total	112	100	100	
Working years' experience in the current organisation	2-5	38	33.9	33.9	33.9
	5-8	19	17	17	50.9
	8-10	10	8.9	8.9	59.8
	Less than 2	39	34.8	34.8	94.6
	More than 10	6	5.4	5.4	100
	Total	112	100	100	
Academic Qualification	Bachelor	90	80.4	80.4	80.4
	Certificate	1	0.9	0.9	81.3
	Diploma	6	5.4	5.4	86.6
	Master	13	11.6	11.6	98.2
	Others	1	0.9	0.9	99.1
	SPM	1	0.9	0.9	100.0
	Total	112	100	100	
Job Position	CEO/ Director	3	2.7	2.7	2.7
	Facility Manager	61	54.4	54.4	57.1
	Assistant Facility Manager	2	1.8	1.8	58.9
	Facility Executive	16	14.3	14.3	73.2
	Engineer	20	17.9	17.9	91.1
	Assistant Engineer	3	2.7	2.7	93.8
	Quality Officer	5	4.4	4.4	98.2
	Health and Safety Officer	2	1.8	1.8	100.0
	Total	112	100	100	

The respondents mostly have over ten years of working experience in the FM industry (34.8%), followed by two to five years (24.1%) and five to eight (21.4) years of experience. This suggests that the respondents are experienced working in FM and understand the industry relatively well. However, regarding working experience in the current organisation, most participants have less than two years' experience (34.8%), and 33.9% have two to five years of experience. The lowest number is over 10 (5.4), and 8.9% have eight to ten years of working experience in the present organisation. Therefore, it is apparent that FM is undergoing a high employment turnover rate. The duration of an FMMC contract is between three to five years, based on the nature of the contract. Hence, reorganisation and displacement of personnel nearing the end of the contract period is not uncommon as the employment is mostly on a contract basis. In terms of academic qualification, respondents with bachelor's degrees outnumbered the rest with 80.4%, followed by master's degrees (11.6%) and diploma degrees (5.4%). Bachelor's degrees are the qualification for managerial and executive-level positions in FMMC. Accordingly, 54.4% are facilities managers, 17.9% are engineers, and 14.3% are facilities executives. In addition, there are other positions, namely quality officers (4.4%), Chief Executive Officers (CEO) and directors (2.7%), assistant engineers (2.7%) and Health and Safety officers (1.8%). A typical FMMC staff is comprised of a facility manager, facility executives, engineers (electrical, mechanical, and civil), quality officers, safety officers, energy officers, supervisors, and technicians. The analysis was subsequently conducted further with SEM, and the results are revealed in the following sections.

Measurement Model Assessment

The validity of items used in the instrument is evaluated by examining whether they accurately measure the intended items according to the theoretical expectations. Several steps are employed to measure the measurement model, including both independent and dependent constructs' convergent validity and discriminant validity. Consequently, convergent validity is performed to confirm the correlation of the scale with the concept of other known measures (Hair, 2014) where i) factor loadings should be above 0.50 (Hair, 2010) and ii) Average Variance Extracted (AVE) should be above 0.50 (Fornell & Larker, 1981). The results of these criteria are tabulated in Table 2.

Table 2. Convergent Validity

Determinant Factor	AVE	Cronbach's Alpha	Composite Reliability
Self-Attitude	0.553	0.893	0.903
Nature of Knowledge	0.533	0.811	0.829
Motivation to Share	0.791	0.870	0.967
Organisation Culture	0.583	0.876	0.931
Opportunity to Share	0.597	0.883	0.892
Knowledge Sharing	0.707	0.923	0.920

The result confirms that the scale is interrelated with the concept of other known measures, such as the value of factor loadings for all constructs, which achieved the threshold value, with most loadings exceeding 0.70. The factor loadings are ranged from 0.524 to 1.006. Similarly, the AVE value exceeds the minimum value of 0.50, ranging between 0.533 to 0.791.

The final step in Measurement Model Assessment is discriminant validity. It reflects the extent to which the measure is unique and not simply a reflection of other constructs (Peter & Churchill, 1986). Discriminant validity is assessed by analysing the cross-loadings of each item within the constructs and the square root of the AVE calculated for each construct, as presented in Table 3. Note that each item should exhibit higher loading on its corresponding construct compared to its loadings on other constructs within the model. Additionally, the square root of the AVE for each factor should exceed the correlations between that construct and all other constructs.

Table 3. Discriminant Validity

	AVE	Knowledge Sharing	Motivation to Share	Nature of knowledge	Opportunity to Share	Self-Attitude	Organisation Culture
Knowledge Sharing	0.707	**0.841***					
Motivation to Share	0.791	0.409	**0.889***				
Nature of knowledge	0.533	0.799	0.416	**0.730***			
Opportunity to Share	0.597	0.339	0.675	0.304	**0.773***		
Self-Attitude	0.553	0.751	0.340	0.957	0.287	**0.744***	
Organisation Culture	0.583	0.659	0.566	0.774	0.503	0.709	**0.764***

Note: *The values of diagonal AVE are greater than the off-diagonal AVE; where diagonal values present the AVE values

The result above demonstrates that the AVE diagonal values in bold are more than the off-diagonal AVE. Hereby, the test has affirmed the discriminant validity.

Structural Model Assessment

For structural model assessment, the path coefficient that denotes hypothesised relationships of all KS determinants is assessed by comparing beta (β) values amongst all the paths. The greatest β value signifies the strongest impacts of KS determinants towards improving the performance of OFM in government buildings. The acceptable level of path coefficient is above 0.10 based on Hair et al. (2013). Nonetheless, the value of β should be assessed for its significance through p-value and t-value as suggested by Ramayah et al. (2018) below:

p-value < 0.01, t-value >2.58 (two-tailed), t-value >2.33 (one-tailed)
p-value < 0.05, t-value >1.96 (two-tailed), t-value >1.645 (one-tailed)
p-value < 0.10, t-value >1.645 (two-tailed), t-value >1.28 (one-tailed)

Table 4. The Results of Hypotheses Testing

Hypothesis	Relationship	Path Coefficient (β)	p-value	t-value	Decision
H1	Self-Attitude > KS towards performance improvement in Government Buildings	*0.298*	*0.029*	*2.185***	*Significant*
H2	Nature of Knowledge > KS towards performance improvement in Government Buildings	0.325	*0.016*	*2.409***	*Significant*
H3	Motivation to Share > KS towards performance improvement in Government Buildings	0.070	*0.499*	*0.676***	*Not Significant*
H4	Organisation Culture > KS towards performance improvement in Government Buildings	0.139	*0.261*	*1.125***	*Not Significant*
H5	Opportunity to Share > KS towards performance improvement in Government Buildings	0.041	*0.632*	*0.478***	*Not Significant*

The research hypotheses are evaluated with the extracted data of Standard Beta for path coefficient, t-value and p-value, as summarised in Table 4.

The results above demonstrate that β values for SA, NK and OC achieved the minimum value of 0.10. Meanwhile, NK has the highest value (β = 0.325), which represents the most significant relationship with KS, followed by SA (β = 0.298) and OC (β = 0.139). Despite that, when assessed with p-value and t-value, only NK and SA achieved the cut-off significant value with a p-value less than 0.05 (0.016 and 0.029, respectively), while t-values above 1.96 for two-tailed (2.409 and 2.185, respectively). This designates that SA and NK have significant impacts in this study. In contrast, MS, OC, and OS have no significant impacts on KS in improving the performance of OFM in government buildings.

Results and Discussion

Self-Attitude

H01: There is no significant relationship between the determinants of SA and KS towards the performance improvement of OFM in government buildings.

H1: There is a significant relationship between the determinants of SA and KS towards the performance improvement of OFM in government buildings.

The analysis result suggests that the path coefficient of "SA" towards KS in OFM in government buildings is significant (β = 0.298; t-value = 2.185**, p-value = 0.029**). Thus, the alternate hypothesis H1 is accepted and the null hypothesis H01 is not accepted. SA is a built-in personality that influences a person's behaviour naturally without any force or motivational support. An employee with extra positive SA enjoys helping others and finds pleasure and comfort in sharing knowledge. At the same time, a person with self-efficacy always thinks that they have something knowledgeable to share. Aside from that, mentoring, openness and compassion are the characteristics that make an individual more inclined to share knowledge sincerely without any second thoughts. These intrinsic personalities are driven by the emotions that they have towards others. Responsibility and loyalty, on the other hand, are the positive attitudes necessitated by any employee in an organisation. These attitudes make employees attached to the company and influence them to share knowledge as part of their duty to serve their best.

Nature of Knowledge

H02: There is no significant relationship between the determinants of NK and KS towards the performance improvement of OFM in government buildings.

H2: There is a significant relationship between the determinants of NK and KS towards the performance improvement of OFM in government buildings.

The result reveals that the path coefficient of "NK" towards KS in OFM in government buildings is significant (β = 0.325; t-value = 2.409**, p-value = 0.016**). Thus, the alternate hypothesis H2 is accepted, and the null hypothesis H02 is not accepted. The NK describes how knowledge is presented and generated inside a person or organisation, influencing the

behavioural belief to share knowledge. Note that staff are determined to share knowledge when it is accessible, and they recognise the value of knowledge. The accessibility of knowledge is vital in any organisation to ensure that the knowledge is readily available at all times without any hindrances to facilitate the working process. A highly valued knowledge is always appreciated and treated well when shared. As such, tacit knowledge is a valuable knowledge area that is more recognised amongst OFM staff than explicit knowledge. This knowledge is priceless as it resides in a person's mind and is developed through years of experience and practice, which is not found in any documentation. Another determinant of KS is benchmarking. With benchmarking, an organisation can continuously improve its performance by learning from others and adopting the best performance standard.

Motivation to Share

H03: There is no significant relationship between the determinants of MS and KS towards the performance improvement of OFM in government buildings.

H3: There is a significant relationship between the determinants of MS and KS towards performance improvement of OFM in government buildings.

It is reported that the path coefficient of "MS" towards KS in OFM in government buildings is not significant (β = 0.070; t-value = 0.676**, p-value = 0.499**). Thus, the null hypothesis H03 is accepted and the alternate hypothesis H03 is not accepted. MS is an individual dimension but different, as it needs a driving factor to encourage KS behaviour. Motivation factors can be present in the form of tangible and intangible. Tangible factors such as recognition and rewards give credit to employees who participated in KS and make them feel appreciated. This personal appreciation motivates them to be involved more in KS and influence others to do the same as they witness the benefits. Meanwhile, intangible factors such as reciprocity, sense of belonging, management support, trust, and job satisfaction motivate individuals to engage in KS behaviour, which is driven by their belief in the existence of these factors. For instance, in reciprocity, a person is willing to share knowledge with his colleague since he believes that there is a return of favour from his colleague for doing the same. Similarly, an employee who feels a sense of belonging is satisfied with his job, trusts and perceives good management support, and will eventually be involved in KS. Nevertheless, in this study, MS is discovered to have no influence on KS in improving the performance of OFM in government buildings.

Organisation Culture

H04: There is no significant relationship between the determinants of OC and KS towards performance improvement of OFM in government buildings.

H4: There is a significant relationship between the determinants of OC and KS towards performance improvement of OFM in government buildings.

The path coefficient result of "OC" towards KS in OFM in government buildings is insignificant (β = 0.139; t-value = 1.125**, p-value = 0.261**). Thus, the null hypothesis H04 is accepted and the alternate hypothesis H4 is not accepted. OS is the normative belief that refers to a person's perception of a specific group and adaptation to the norms with a set of

shared assumptions and values in fostering KS behaviour. A company that uses KS as part of its practice will definitely ensure the implementation of KS throughout the organisation. It starts with strategising the corporate vision that employs KS in its activities. This will indirectly promote creativity to inspire new solutions or processes, creating innovation within the staff with KS involvement. Notably, a company that compliments diversity in all aspects and practices fairness could reduce bias, improving KS participation. The strong social ties that form through company activities and positive work culture could boost the exchange of knowledge among co-workers and between workers and the management. In addition, the final attribute that cultivates KS in OC is organisation value. Understanding and respecting the company values encourage employees' behaviour towards KS. The value that establishes a company includes its intellectual, resource, and market value. The study, though, discovers that OC has no significant influence on KS in improving the OFM in government buildings.

Opportunity to Share

H05: There is no significant relationship between the determinants of OS and KS towards performance improvement of OFM in government buildings.

H5: There is a significant relationship between the determinants of OS and KS towards performance improvement of OFM in government buildings.

The result presents that the path coefficient of "OS" towards KS in OFM in government buildings is not significant (β = 0.041; t-value = 0.478**, p-value = 0.632**). Thus, the null hypothesis H05 is accepted and the alternate hypothesis H5 is not accepted. OS signifies control belief, the perceived external or technical factors that help to enable KS. Undoubtedly, a company with well-equipped infrastructure and information technology will facilitate the whole KS process across the organisation. Moreover, with an appropriate KS system, the dissemination of knowledge will become smooth, and staff will have a better way to connect through a designated communication platform. Another critical attribute of KS is time, where the availability and flexibility of time could encourage higher KS engagement in the company. However, the finding indicates that OS has the highest insignificant influence on KS in improving OFM in the context of government buildings.

CONCLUSION

Outsourcing of FM in government assets has to be effectively managed with more holistic KM measures to overcome performance inadequacies and ensure the sustainability of knowledge. Hence, adopting KS within the organisation is the most fundamental process in KM to improve the performance of OFM. In summary, it is demonstrated that OFM personnel KS behaviour is solely influenced by behavioural belief, dominated by their volitional control, determined by SA and NK. Conversely, normative belief and control belief also demonstrate positive relationships. However, they are not statistically significant in this analysis and are temporarily rejected within the context of this research. Nevertheless, all three KS-related determinants, MS, OC, and OS, might still be relevant in different research circumstances, as several studies have indicated that they substantially influence KS in enhancing organisational performance. Thus, it is recommended that future research deploy the prior proposed research conceptual model in different research settings with a larger sample size. Furthermore, understanding the influence of KS towards the OFM performance will assist outsourcers in

manoeuvring the initiatives that could empower KS and recover the less influential areas for the enhancement of OFM-government context performance. This study is among the first to employ TPB in examining the KS behaviour within the FM setting, and the next succeeding step is to validate the findings with the experts to finally confirm the research model.

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TYPES AND CAUSES OF DEFECTS IN TERRACE HOUSING CONSTRUCTION PROJECTS DURING THE DEFECTS LIABILITY PERIOD (DLP)

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Abstract
Defect management in construction projects is critical to ensure that structural building components are safe and durable throughout the building's lifespan. Newly constructed building projects should be free from latent or patent defects since there is minimal usage by end-users that occurred during the Defects Liability Period (DLP). Failure to maintain the specified quality and workmanship standards determined in the construction contract could result in numerous defect issues, directly impacting time, cost, and other project aspects. This study focused on Seremban, Negeri Sembilan, aiming to identify key factors leading to building defects. Data was collected through a questionnaire survey targeting major construction industry participants, specifically project team members who worked under the G7 contractors registered with the Construction Industry Development Board (CIDB), Malaysia. The gathered data and information were analysed using the Statistical Package for the Social Sciences (SPSS) software to evaluate the responses. Results and findings revealed that poor workmanship was ranked first as the most prevalent cause of defects, followed by low-quality construction materials in second place. Notably, a significant concern was raised regarding inadequate quality compliance outlined in the contract specifications, which could potentially decrease the property's market value. This study suggests that contractors should engage in proactive measures such as adopting working processes such as QLASSIC and PQP as guidelines for defects management at the outset of construction processes to enhance quality performance after project completion. The insights derived from this research could be instrumental in guiding building contractors towards strategies to minimise defects in their future projects.

Keywords: *Defects Liability Period (DLP); types and causes of defects; building; terrace housing projects.*

INTRODUCTION

A Defects Liability Period (DLP) is the duration for which the contractor performing the construction work is responsible for repairing and correcting any defects caused by their poor workmanship. In accordance with Clause 48 of the Public Works Department (PWD) 203A REV.1/2010 standard form of construction contract, the DLP will end 12 months after a Certification of Practical Completion (CPC) is issued to the main contractor. During this period, the property owner should appoint an inspection team to check and inspect the building components to search for any latent or patent defects after CPC issuance. Any defects or damage discovered in the building must be reported to the client so that further instruction via written notice can be issued to the contractor for rectification and remedial works.

Recent studies indicated that the most frequent building defects in new houses are caused by poor workmanship by the contractor who completed the project (Ismail, 2015; Lambers et al., 2023). Besides, it appeared that wall cracks (Loke, 2022) and water leakage (Hong, 2016) are the common defects typically found in new terrace housing projects during the DLP. Some

pertinent contributing factors to these situations include the design errors made by the architect, inappropriate construction materials, an improper installation method, and unsuitable construction sequences (Hassan et al., 2016). Thus, these issues have raised many dissatisfactions, including developers' concerns about their reputation and expectations of the end-products they invested in earlier stages when launching and selling the properties.

In an attempt to address these issues, the present study investigates the causes of defects in construction projects, particularly terrace housing projects in Malaysia. The outcomes from this study are significant in protecting the buyer's interest and simultaneously helping minimise defect occurrences, particularly in the Malaysian construction industry.

LITERATURE REVIEW

Defects Liability Period (DLP)

Various standard forms of Malaysian construction contracts define the DLP as the contractual duration for carrying out the maintenance works on the completed buildings against any defects and imperfections (refer to Table 1). In the *Pertubuhan Akitek Malaysia* (PAM) Contract 2018, Clause 15.3 explains that the architect shall report any defects that occur during the DLP at any time to the contractor involved with the condition not later than 14 days after the expiration of the said defects period. After receiving the architect's defect report, the contractor must consequently begin corrective action or make good on the defects within 28 days.

Table 1. Defect Clauses in The Malaysian Standard Form of Contract

Item	Standard Form of Contract	Clause
1	PAM Contract 2018 (With Quantities)	Clause 15; Practical Completion and Defects Liability
2	PWD Form 203A (Rev.1/2010)	Clause 48; Defects After Completion
3	CIDB Standard Form of Contract for Building Works 2022	Clause 27; Defects Liability After Completion

Meanwhile, the government construction contract, PWD Form 203A Rev.1/2010, determined in Clause 48.1(a) that all defects such as imperfection, shrinkages or any fault in the buildings during the DLP shall be under contractors' responsibility. The same consideration is mentioned in Clause 27.1 of the CIDB Standard Form of Contract (2022), whereby the obligation to remedy and rectify any defects during the DLP shall be under the contractor's obligation starting from the issuance of the CPC until the end of the said maintenance period. Therefore, the contractor must rectify all minor or major defects at his own costs until he is finally released from the obligation and the Certificate of Making Good Defects (CMGD) is issued to him.

Sufficient time is imperative when considering the rectification period (Kariya, 2016) to avoid any distress due to receiving poor quality building works (Yarnold et al., 2023) that could lead to adversarial effects between various stakeholders involved in the construction projects (Paton et al., 2021). To avoid being subjected to a breach of contract, the contractor must fulfil his obligation successfully within the stipulated time given in the contract. The client has the right to appoint third parties to make good defects as identified in the project. However, the contractor will still be held liable for paying the additional costs arising from the third parties' engagement (Nouh et al., 2023; Shwan, 2011). Subsequently, the presence

of defects during the DLP can significantly diminish the performance of the buildings, resulting in a negative impact on the quality of life for occupants and the reputation of the contractor, as well as the sustainability of the building.

Building Defects

For the past decade, scholars in construction-related fields have elaborated the term "defect" as a failure to perform works following contracts, drawings and specifications (Hassan et al., 2016; Lambers et al., 2023), whereby the direct consequence of these failures could shorten the building's lifespan. Besides, the impacts could also affect the owner's safety and health due to poor building performance from its intended purposes. This problem cannot be ignored as it will create a negative perspective (Hassan et al., 2016) towards the image of the Malaysian construction industry. The building defects in construction projects commonly occurring during the DLP are discussed next.

Substructure Defects

A substructure defect is a defect that occurs at the part of the building below the ground level. Unstable foundations, sedimentation, and clogging are some examples of substructure defects. According to Hong (2016), the foundation system is an essential component of any building because it supports the building structure and helps transfer the load imposed on the earth below. Foundation failure is one of the structural failures that can occur in any construction project. Soil sedimentation usually affects the lower or ground floor of the building as it usually happens at the lower bases of the building (Ismail, 2015). Additionally, vegetation could occur when fast-growing trees are planted near the building. Empirical evidence demonstrates that the pipe system could be partially or fully clogged when the plumbing selection is not according to the suitable size (Ghane, 2022). When sand or any other particles enter the pipe, they could remain at the entry point, which will then build up over time, resulting in the clogging of the pipe. Other than that, leakage in a sanitary pipe can also be one of the reasons why the wastewater does not flow away smoothly, and it could sometimes present a bad appearance to structural and architectural building elements.

Superstructure Defects

A superstructure defect is any improperness at the part of the building above ground level. Crack appearance is one of the signals showing corroded reinforcement in the structure, and cracks commonly occur on plastered walls, wall ceilings, columns, and beams (Hong, 2016). It could be indicated that corrosion of reinforced steel is a critical issue that must be addressed because it contributes significantly to the overall life cycle of ageing concrete structures (Yu et al., 2021). One of the side effects that could happen if there is any corrosion in the reinforced steel is structural failure, which could lead to costly maintenance work that needs to be done.

From an architectural standpoint, peeling paint is one of the most frequent defects in components such as plastered walls, ceilings, columns, and beams. Peeling paints usually happen at those components as they are consistently exposed to sunlight, rain, wind, and dampness (Mydin et al., 2014). Paint peeling can also result from the amount or layer of paint applied on the building surfaces (Hong, 2016). Othman et al. (2015) further criticised that the

causes of moisture problems in other architectural components, such as roof leakages, can be influenced by environmental factors, such as heavy rain, windy season, groundwater level, and temperature of the area itself. Additionally, roof leakage (Hong et al., 2016) is mostly caused by unsealed penetration, improper installation of waterproofing, and the lack of roof tiles applied to the roof structure.

Construction scholars criticise that electrical defects can be classified as rare defects in building projects (Shahrir and Rahman et al., 2014). A specific study by Ganisen et al. (2015) discovered that hazardous electricity components not installed properly could become dangerous to the building's condition, as electrocution produced from electrical defects could cause harmful situations to humans. Moreover, some examples of electrical defects are exposed wires, electrical insulation breakdowns, and faulty appliances. Exposed plugs in open spaces and wet locations can also cause short circuits and electrical shocks to the body (Hassanain et al., 2016), especially when touched with wet skin.

In summary, building defects are issues that arise in a completed new building and can affect its functionality, safety, and appearance. Some common building defects include substructure, structural, architectural, and electrical defects. These kinds of defects can range in severity from minor cosmetic issues to major structural problems, which it is believed can threaten the occupants' safety.

Common Causes of Defects in Terrace Housing Projects

Many young people prefer to live in landed housing compared to high-rise housing development, meaning they are most likely to live in more spacious houses with land. Nonetheless, past literature has demonstrated that various causes of defects happened in this category of landed property due to faulty design and other factors. Design errors can come from misjudgement, leading to inappropriate decisions that cause the design to fail. Besides, frequently faulty design in construction projects (Olenrewaju et al., 2021) reduces initial construction costs that might be expensive at the beginning of the planning stage (Ahzahar et al., 2011). For example, reducing the size of reinforcement bars is a common design error, which results in the structure being unable to withstand the imposed load and finally cracking and collapsing.

Poor workmanship is one of the reasons newly constructed residential buildings face several issues with defects. It is agreed that the main cause of building defects is poor workmanship made by the construction team (Ahzahar et al., 2011; Lambers et al., 2023). In addition, Hong (2016) emphasised that poor workmanship is influenced by insufficient expert supervision, unskilled and inexperienced labourers, poor communication skills, and language barriers. In certain situations, irresponsible parties, such as the main contractor or subcontractor, feel compelled to use low-quality construction materials to reduce the cost of purchasing materials and thus increase their profits (Hong, 2016; Yarnold et al., 2023). It is vital for the parties involved in selecting building materials to be more familiar with and have better knowledge regarding the quality of each element to ensure that each material is capable of functioning well (Ahzahar et al., 2011).

From a different perspective, it is necessary to include climatic weather conditions as one factor leading to building defects, as Malaysia usually experiences heavy rainfall or a year-round dry season (Ahzahar et al., 2011). As a result of rapid exposure to heavy rain, defects such as fungal stains, peeling paint, defective plastered rendering, and mortar joint erosion can occur. Other than that, a dry season with extreme weather affects labour productivity, leading to poor workmanship and building defects. Moreover, hot temperatures over an extended period can create a wall crack as all the moisture and water needed in the concrete evaporate (Dai et al., 2009).

The lack of professional or skilled labour in a construction project is another critical factor that could lead to poor supervision among the on-site workers (Dalibi, 2016). Due to insufficient supervision of the labourers' work, numerous building flaws were discovered in the finished project (Isa et al., 2016). Moreover, a decent quality of work can be achieved with adequate supervision, requiring extra cost to achieve the goals (Nouh et al., 2023). From another viewpoint, poor communication could lead to poor quality end products, such as project failure, contractual disputes, and cost overruns (Gamil et al., 2017). These failures will result in an inadequate quality of work (Hussain et al., 2018), which could result in unsatisfactory feedback from the clients due to massive reworks, which will require extra time and cost, particularly for the contractor. This situation could lead to disputes in the relationship between the various parties involved in the project execution.

Summarily, building defects can occur for various reasons, including faulty design, poor workmanship, low-quality materials, a lack of supervision, and poor communication among the parties involved in the construction projects. Climatic weather conditions such as heavy rainfall or dry season over an extended period can further lead to building defects. Hence, identifying the root cause of building defects is crucial to effectively addressing them and preventing them from occurring.

RESEARCH METHODOLOGY

Several stages have been undertaken to derive the findings and achieve the aim of this study. The first stage involved extensive reading through secondary data such as journals, books and standard forms of contract to understand the current body of knowledge and determine problems that led to the aim of this study. The second stage focused on data collection, where the identified causes of building defects were surveyed with the construction players involved in construction projects. The third stage involved data analysis, whereby answers obtained from the surveys were analysed using the Statistical Package for the Social Sciences (SPSS) software to disclose the results and findings. The final stage of this study summarised the conclusion and recommendations for future improvements.

The primary data in this research consists of questionnaires, which can be labelled as quantitative methods. The questionnaires were distributed to the parties involved in terrace housing construction projects, mainly contractors and their construction team members, including managers and others. The sampling method involved G7 contractors registered with the Construction Industry Development Board (CIDB) as respondents in the survey. In conducting this study, the specific location of Seremban was selected because the site areas were accessible for data collection. Moreover, urban developments in this locality were also ideal for assessing contractors' current defect management practices during the DLP. Thus,

from the total population of 240 G7 contractors in Negeri Sembilan, 110 contractors were involved in building construction projects in Seremban. Hence, the questionnaire surveys were sent to contractors in Seremban areas who focused on constructing terrace housing projects using Google Forms, face-to-face, and other electronic devices (refer to Figure 1).

(Source: Google Maps, 2024)

Figure 1. Sampling for Data Collection Located at Seremban, Negeri Sembilan

The data obtained from the questionnaire survey was analysed using the SPSS software. For example, for the multiple-choice questions in the survey, the data was analysed by identifying their percentage, which was then transformed into tables or outline diagrams such as pie charts and bar charts. The questionnaire is intended to help gain as much information as possible regarding the common causes of building defects in terrace housing projects during the DLP. Additionally, this research utilised different data analysis methods for evaluating Likert scale questions. This analysis was conducted using SPSS software, calculating each variable's mean and standard deviation. These calculations were then used to rank the variables, with the highest mean placing a variable at the top of the list.

RESULTS AND FINDINGS

Respondents' Background and Experiences

The first part of the questionnaire specified information on the background and experiences of the respondents. Table 2 presents the respondents' particulars. Based on the frequency and percentage of the respondents' profiles, 100% were G7 contractors registered with CIDB in Seremban. The second segmentation highlighted the roles of the professionals. The highest role of those who answered the questionnaire was that of the main contractors (41.94%), followed by the quantity surveyors (38.72%), and the least were those who worked as project managers (19.35%). The results indicated that mixed professional backgrounds were involved as the respondents.

Table 2. Background and Experience of The Respondents (N=31)

Item	Information	Number of Respondents	Percentage (%)
Grade	G7 contractors in Seremban	31	100%
Roles	Contractor	13	41.94%
	Project Manager	6	19.35%
	Others (i.e., engineers and site supervisors)	12	38.72%
Experience in The Construction Industry	Less than 5 years	6	19.35%
	5 years - 15 years	13	41.94%
	16 years – 25 years	4	12.90%
	Above 26 years	8	25.81%
Types of Terrace Housing Project Involved	Single-storey	17	27.90%
	Double-storey	27	62.80%
	Three storeys and above	4	9.30%

Regarding the working experience in the construction industry, the highest range was five years to 15 years (41.94%), followed by more than 26 years of experience (25.81%), 16 years to 25 years (12.90%), and only six respondents (19.35%) worked less than five years. It could be observed that much participation came from those with well-established experience managing construction projects. For the question of types of terrace housing projects involved by the respondents, double-storey construction demarcated as the highest percentage project (62.80%) compared to single-storey (27.90%) and three-storey and above (9.30%). This finding strongly suggested that many homeowners were concerned with having private rooms and functional areas other than single-storey houses.

Common Disputes Occurred During The DLP

A few significant findings emerged from Table 3 regarding disputes typically resolved during the DLP.

Table 3. Common Disputes That Occurred During The DLP

Item	Disputes on Defects During DLP	Mean	Standard Deviation	Rank
a.	The client may not be satisfied with the quality of work done by the contractor.	4.26	0.445	1
b.	Clients consider themselves immune from any liability for construction defects or failures.	4.26	1.182	2
c.	Increasing project costs due to the wastage of valuable resources and energy.	3.90	0.700	3
d.	The contractor demands payment for the work done, but the client refuses to pay due to the contractor's unsatisfactory work.	3.90	0.790	4
f.	The client raised concerns regarding safety issues, like faulty wiring, which can cause harm to the building's occupants.	3.90	0.870	5
g.	The client alleges that the materials used by the contractor did not follow the agreed-upon specifications.	3.74	0.773	6
h.	The owner and contractor may not agree on the cost of rectifying the defects.	3.65	0.755	7
i.	The owner and contractor may disagree on who is responsible for correcting the defects.	3.58	0.923	8
j.	The contractor failed to complete the work within the agreed-upon timeline.	3.52	0.626	9
k.	The contractor overlooks the quality of the completed project because they might think their work is already done.	3.35	1.112	10

The client's dissatisfaction with the contractor's work quality was ranked highest (mean score = 4.26). Clients who believed they were immune from liability for construction defects or failures ranked second, with a mean score of 4.26. The third-ranked concern, with a mean of 3.90, was the rising costs of the undertaking due to the waste of valuable resources and energy. This result emphasised the significance of efficient resource utilisation in preventing unnecessary expenses. After that, a dispute involving the contractor demanding payment for unsatisfactory work and the client's refusal to pay received a mean score of 3.90 and a fourth place, indicating a common disagreement over payment terms.

Furthermore, safety issues reported by clients, such as faulty wiring, ranked fifth with a mean of 3.90, demonstrating the importance of addressing potential risks that can injure building occupants. Disagreements over materials failing to meet agreed-upon standards placed sixth with a mean of 3.74, highlighting the importance of specification adherence and quality control. Aside from that, arguments between owners and contractors about the expense of repairing faults and responsibility for defect correction ranked seventh and eighth, with averages of 3.65 and 3.58, respectively. These disagreements highlight the significance of effective communication and agreement on cost and responsibility sharing during the DLP. On top of that, with a mean of 3.52, delays in finishing the work within the agreed-upon deadline placed ninth. The result proved that timely completion is critical. Finally, with a mean of 3.35, the contractor overlooking the quality of the completed project scored lowest, indicating that this issue is less widespread throughout the DLP.

Based on the above analysis, the top two challenges are quality of work and clients claiming they are free from responsibility, implying a probable lack of awareness or understanding of liability (Yarnold et al., 2023) among some clients. As a result, clients should not assume they are free from accountability for potential building defects or failures, as some may arise from their faults (Shafiq, 2020). Contractors and clients should prioritise excellent communication, deadline adherence, and contractual clarity to minimise conflicts and ensure a smoother project completion process.

Types of Defects which Cause Inconveniences to Homeowners

As presented in Table 4, the analysis revealed some findings about the defects commonly occurring during the DLP.

Table 4. Types of Defects That Commonly Occur During The DLP

Item	Types of Defects	Mean	Standard Deviation	Rank
	STRUCTURAL DEFECTS			
a.	Cracking (walls, beams, columns)	4.77	0.947	1
b.	Sagging and uneven floor	3.58	1.205	2
c.	Corrosion of reinforced steel	3.48	1.313	3
d.	Leaning walls	2.71	1.101	4
	ARCHITECTURAL DEFECTS			
a.	Peeling of paint	4.42	0.720	1
b.	Roof leakages	4.06	0.892	2
c.	Mould growth	2.84	1.036	3
d.	Poor ventilation	2.45	1.150	4
	ELECTRICAL DEFECTS			
a.	Exposed wire	4.16	1.128	1
b.	Short circuit	3.81	0.946	2
c.	Electrical insulation breakdowns	3.61	1.054	3

For the Structural Defects category, with a mean of 4.77, cracking (walls, beams, columns) came in first. This suggests that the most frequent structural defect homeowners notice during the DLP is cracking, which might impact the property's stability and appearance. With a mean of 3.58, sagging and uneven floors came in second. For homeowners, this problem may present inconveniences and safety risks. Furthermore, with a mean of 3.48, corrosion of reinforced steel came in third place. This flaw needs immediate attention because it could jeopardise the building's structural integrity. The analysis indicates that cracking is the most frequent problem that typically appears (Yarnold et al., 2023). It could be demonstrated that cracks occurring on plastered walls, wall ceilings, columns, and beams indicate the corrosion of the reinforced steel in the building structures (Hong, 2016).

For the Architectural Defects category, paint peeling was the most frequent problem, with a mean of 4.42. Although it might not have a direct impact on the building's structural stability, it could have a substantial impact on how appealing the property looks. Next, with a mean of 4.06, roof leakages came in second. If not fixed immediately, this issue may result in water damage, the formation of mould, and potential structural problems. After that, mould expansion came in third with a mean of 2.84. If mould is not safely removed, it can harm people's health and cause property damage. Additionally, with a mean of 2.45, insufficient ventilation ranked fourth. Even though inadequate ventilation came in fourth, this problem still needs to be addressed seriously because it can result in excessive moisture inside the building (Yarnold et al., 2023), which can lead to discomfort, moisture buildup, and even the growth of mould (Mydin et al., 2014).

For the Electrical Defects category, exposed wires were rated first with a mean of 4.16. The defect presents serious safety hazards, including electrical shocks or fire hazards. Short circuits came in second with a mean of 3.81. If not remedied promptly, this problem can cause electrical equipment damage and represent a fire risk. Electrical insulation breakdowns came in third place with a mean of 3.61. If this fault is not corrected quickly, it can cause electrical failures and associated safety issues. Thus, a study by Ganisen et al. (2015) criticised electricity as one of the most harmful components in a building. Electrical defects are a form of defect that should be considered dangerous since they can cause electrocution, which can result in the death of a person.

Common Causes of Defects During The DLP

The respondents were asked to determine the common causes of defects during DLP, specifically during the construction of terrace housing projects in Seremban.

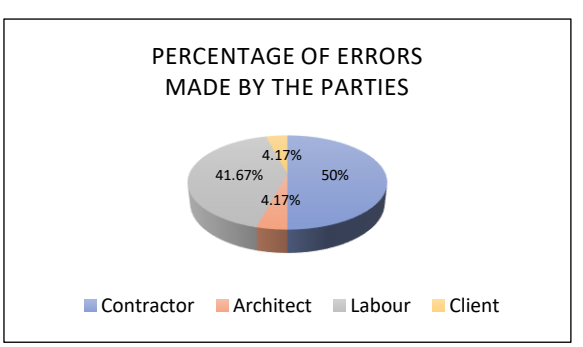

Figure 2. Percentage of Errors Made by The Parties That Frequently Result in Building Defects

As depicted in Figure 2, contractors were responsible for most of the 48 answers, with 24 problems accounting for 50% of the total. This high percentage shows that the contractor plays a substantial role in the occurrence of faults inside the project. Following that, labour-related errors had a significant impact, with 20 errors accounting for 41.67% of the total. This discovery indicates that labour-related factors, such as workmanship, coordination, and skill levels, contributed to building defects. With only two errors, or 4.17% of the total, the architect's contribution to errors was minimal, emphasising that architectural errors had a diminished impact compared to the contractor and labour-related mistakes. However, it is essential to note that even a small number of architectural errors can significantly affect the quality and functionality of the entire project. Additionally, clients were culpable for two errors, accounting for 4.17 % of the total. Although the percentage is comparatively low, it demonstrates that clients' actions and decisions can contribute to construction project errors. This situation may entail alterations to project requirements, inadequate communication, or omission of essential information.

The above analysis highlights the importance of effective coordination and communication among all parties involved in a construction project to minimise errors. While contractor and labour-related errors dominate the list, it is crucial for all parties, including the architect and the client, to collaborate closely and take initiative-taking measures to prevent and address errors. This finding is supported by Ahzahar (2011), who stressed that poor workmanship by the construction team is the leading cause of construction defects. Incompetent and inexperienced workers, a language barrier, inadequate communication skills, and a lack of professional supervision are all contributing causes of substandard workmanship (Hong, 2016). Doing so reduces the likelihood of errors, improving project outcomes and client satisfaction.

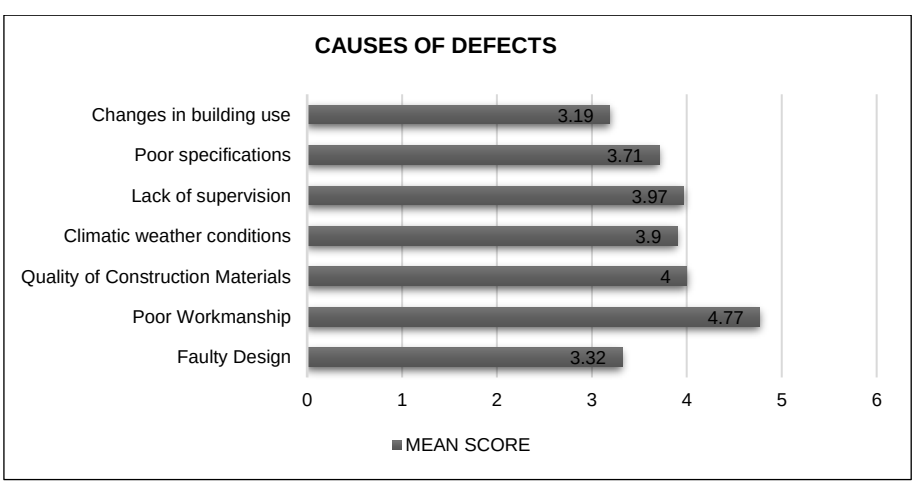

Figure 3. Causes of Defects During The DLP

The findings obtained from the analysis, as presented in Figure 3, discovered that "poor workmanship" has the highest average score (4.77), making it the most common cause of faults. With an average score of 4.00, "quality of construction materials" is the second most crucial factor. Considering this, it is clear that utilising materials of suitable quality is vital. Defects such as material degradation, premature failure, or decreased durability can result from using poor materials in construction.

After that, with a mean of 3.97 and a standard deviation of 0.752, "lack of supervision" comes in at number three. This result shows that faults can result from insufficient supervision during construction. Design or construction process flaws may go undetected if there is supervision or the specifications are not followed correctly. In addition, "climatic weather conditions", with a mean value of 3.90, rank as the fourth most crucial factor. This suggests that adverse weather conditions, such as hot temperatures, high humidity, or heavy rainfall, can have an undesirable effect on a building project and contribute to problems. Material expansion, contraction, or degradation brought on by weather-related causes can weaken structures or allow water intrusion.

Furthermore, with a mean value of 3.71 and a standard deviation of 0.864, "poor specifications" ranks fifth. Poorly stated or imprecise project specifications can lead to defects. Inadequately specified or confusing specifications can lead to misinterpretations or wrong execution of construction activities, resulting in defects. "faulty design" is the sixth most common cause, with a mean value of 3.32 and a standard deviation of 0.60. It could be implied that mistakes or errors in design can contribute to defects during the construction phase. Inadequate structural calculations or poor consideration of functional needs during the design phase might result in defects that jeopardise the building's safety and performance. Finally, with a mean value of 3.19 and a standard deviation of 0.833, "Changes in building use" ranks eighth. This shows that additions or modifications to the building's intended function can contribute to defects. Changes in building usage may necessitate changes to the original design or construction processes, which, if not performed effectively, might result in defects or functional concerns.

This research exposed that the quality of workmanship during construction plays a critical role in the occurrence of defects. Defects, particularly those stemming from substandard workmanship (Anthony, 2013), are closely linked to contractors' or client-developers' failures. Insufficient expert oversight, unskilled and inexperienced labour use, and inadequate communication skills significantly contribute to poor workmanship (Hong, 2016). Hence, improvements in the workmanship should be made by carrying out more inspections from the supervision team. Errors made by construction teams, such as improper installation, inadequate skills, or lack of diligence, can result in defects that affect the structural integrity and functionality of the building. These aspects are critical to consider for future improvements.

CONCLUSION

This research demonstrated that the contractor knows their responsibilities for repairing defects during the DLP period. The study revealed that many disputes between clients and contractors frequently lead to unnecessary expenditures for repairs. The client's dissatisfaction with the contractor's work quality is among the most commonly observed disputes. Besides, the analysis revealed that several types of building defects typically occur during DLP and have caused homeowners significant inconveniences. For instance, superstructure defects include multiple defects, such as cracking, uneven floors, and roof leakages.

This prevalent occurrence of defects has indirectly caused many inconveniences for homeowners. Safety concerns, disruptions to homeowners' daily lives, and tenants' inability to effectively utilise the new facility are among the top three inconveniences homeowners

have encountered. Poor workmanship was ranked first as the most prevalent cause of defects, followed by low-quality construction materials in second place. In a word, the risk of defects can be decreased during the DLP period by addressing these concerns proactively and applying ways to tackle the root causes of the identified issues.

Initiative-taking efforts should be implemented to address these concerns, address poor workmanship, and improve construction material quality, lowering the likelihood of faults during the DLP. It is advised that adequate mechanisms be established for homeowners to report and fix defects during the DLP time. Contractors should be proactive by employing the Quality Assessment System for Building Construction Works (QLASSIC) and Project Quality Plan (PQP) as guidelines for defect management at the outset of construction processes to enhance quality performance before project completion. Developing a structured procedure for defect reporting and guaranteeing fast response and resolution by contractors can improve homeowner satisfaction and minimise disruption.

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CHALLENGES OF ADOPTING DIGITALIZATION OF FACILITIES MANAGEMENT IN UNIVERSITY

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Abstract
The development of digital implementation grew rapidly according to the achievement of the Industry 4.0 goal. Every organization needs to adopt digitalization in management and not be left behind, and Facility Management (FM) also requires digitization to manage and control facilities. In educational management, especially for the higher educational level, it is important to implement digitalization to manage facilities at the university. This study aims to enhance the use of digitalization in university FM. To determine the challenges, a semi-structured interview with the competent person who has been serving to manage the digitalization of facilities must be conducted. The study was conducted at the Infrastructure Development Department at University A. This study has used descriptive analysis. The study employed several challenges, especially budget constraints, infrastructure limitations, and unclear vision and mission, to name a few. This study contributes to offering enhancements to the usage of digitalization of FM in the university that can support the university's vision and mission.

Keywords: *Facilities Management; Digitalization; University; Challenges; Budget Constraints*

INTRODUCTION

Facilities Management (FM) today is undergoing a transformative shift, embracing technology, sustainability, and adaptability. According to International Facility Management Association (IFMA), to enhance people's quality of life and the efficiency of the primary business, FM is an organizational function that integrates people, location, and processes within the physical environment. As such, FM is an integrated approach to managing the workplace, encompassing various components such as service, support, and maintenance to ensure that the building, its systems, and services align with the organization's strategic objectives (Norsyazwana Jenuwa et al., 2023). It involves the management of the entire built environment, including people, processes, place, and technology, to optimize the functionality of the built environment system. Meanwhile, digitalization in FM also extends to emergency management, where digital technologies can be utilized to improve building and asset information models, particularly for emergency management in buildings (Mousharbash Nabih et al., 2022). Notably, the use of digital technologies such as Computer-Aided Facility Management (CAFM), Building Information Systems (BISs), and Building Information Modeling (BIM) has been introduced into facility operation functions to address issues around real-time information collection and processing (Zhan et al., 2019).

FM in educational institutions is vital for creating an environment conducive to learning and academic achievement (Zurainan et al., 2021). In particular, FM ensures that spaces like classrooms and libraries are safe, comfortable, and functional for learning, either in public or private universities. Public universities often rely on government funding for research, while private universities may seek third-party funding and industry partnerships to support their

research endeavors (Muscio et al., 2013). Despite its potential advantages, implementing digitalization in FM presents many challenges. Moreover, organizations face challenges ranging from workforce resistance to technological integration issues as they increasingly implement digital technologies to improve efficiency and streamline operations (Araszkiewicz, 2017). Therefore, this study aims to explore the challenges of adopting the digitalization of FM in University A.

Digitalization refers to the process of using digital technologies to transform and improve various aspects of business, society, and everyday life. Significant changes and transformations have been brought about by digitalization in several sectors, including factories, institutions, professions, education, finance, security, and health (Sahin, 2017). Refer to Table 1.0, which explains the definition of digitalization.

Table 1. Definition of Digitalization

Author(s)	Definition(s)
Srai and Lorentz, 2019	The term "digitalization" refers to the restructuring of numerous areas of social life around digital media and communication infrastructures. Clarify it straightforwardly: digitalization is the application of digital technologies.
Gobble, 2018	Digitalization is the process of producing and obtaining value through fresh methods by means of digital technology and, most likely, digital information.
Lenka et al., 2017 Learch and Gotsch, 2015 Parida et al. 2015	According to research on industrial management, digitalization is the phenomenon of intelligent, networked machines powered by data and digital technologies.
Ringenson et al., 2018	The reorganization of social life around digital media and communication infrastructures is known as digitalization.
Crittenden et al., 2019 Hansen et al., 2011	Digitalization unlocks new channels for communication between businesses and consumers.

There are various obstacles to the digitalization of FM in higher education. The modern digitalization of the FM system aims to improve decision-making and transform operations. Furthermore, digital technology has demonstrated promising results in FM as well as other building phases. Hence, it may enhance complicated FM decision-making for renovation and general FM (Mousharbash Nabih et al., 2022). One of the main problems is that staff and students lack digital knowledge skills and educational technologies (Popova et al., 2020). Additionally, the administration of facilities at public institutions faces considerable issues, from poor conditions, overcrowding, inadequate skills and competencies of FM departments, and lack of financial resources (Chikafalimani et al., 2021).

While investigating the challenges of implementation of digitalization of FM from the literature review, it has been conducted that budget considerations and management evaluation both have an impact on how well information systems are implemented in facilities and infrastructure management when there are financial constraints (Gibranamar Giandatenaya, 2024). According to Katurura and Cilliers (2018), public institutions may find it more affordable and practical to implement digital systems if they set aside a specific budget for this purpose. However, the necessity to increase efficiency, productivity, and profitability with constrained resources and condensed schedules exacerbates the difficulties of FM under financial constraints (Cao et al., 2014). Moreover, according to Birkel et al. (2019), risks can be linked to technical risks like standards and technical integration, Information Technology related risks like data security, and legal and political risks like unclear legal precedents regarding data possession. Accordingly, it is a constant struggle to strike a balance between

the advantages of data collection and analysis and facility users' privacy concerns (Xu et al., 2018). For that reason, effective use of digital systems is hampered by issues with data storage, data interchange protocols, and data interoperability (Ahmed, 2023; Wong et al., 2020).

Furthermore, there are challenges in implementing digitalization, such as unclear vision and mission. To effectively utilize cutting-edge technologies, FM is at the forefront of ensuring optimal physical space functioning that needs a clear vision. In the context of education administration management, the absence of a clear legal basis, vision, mission, and goals poses obstacles to digital libraries in high schools (Sunu, 2022). One of the greatest challenges to implementing digitalization in university FM is the lack of qualified personnel. The body of research emphasizes how critical having qualified staff is to the success of digital transformation projects (Chiu & Lai, 2020). Thus, a worldwide obstacle to accomplishing successful digital records management has been recognized as a lack of knowledge and abilities (Tsvuura, 2022).

On the other hand, resistance to change poses a significant challenge in the implementation of digitalization in FM. The reluctance of instructors and learners due to the lack of proper digital facilities can hinder the successful implementation of digital entrepreneurship programs (Gunaseelan et al., 2022). Furthermore, the employment of numerous staff members to handle large quantities of data in FM drives up operational expenditures (Marzouk & Zaher, 2020). Moreover, challenges in implementing BIM technologies in FM include a lack of knowledge among personnel, data management quality issues, lower data management standards, and inadequate data provision for maintenance (Chioma et al., 2020). One of the biggest challenges to digitalization in FM is infrastructure constraints. The digital divide may be made worse by inadequate infrastructure, such as inadequate electrical and network infrastructure. This would leave facilities in underdeveloped areas behind (Were et al., 2021). In addition, the difficulties in preserving digital records also include inadequate hardware, a lack of IT support, and a lack of management commitment to improving infrastructure capabilities. This, ultimately, underscores the significance of infrastructure in digital initiatives (Daniel & Ndumbaro, 2022).

Compatibility issues with existing systems pose a significant challenge when implementing digitalization in FM. This challenge is especially important when switching from analog to digital systems since digital systems have many functional benefits and might not work well with the current infrastructure (Bao et al., 2019). One challenge in information management for FM and maintenance is the absence of structured frameworks that can efficiently deliver information models (Patacas et al., 2020). Digital systems frequently do not update modifications made after the design phase, necessitating expensive surveys by maintenance contractors to gather precise data (Ahmed, 2023; Wong et al., 2020). Furthermore, industrial organizations typically have mechanistic traditional organizational structures. However, digital transformation calls for more organic and flexible structures that can effectively keep up with technological advancements (Faisal et al., 2022). Additionally, since digital transformation cuts across established hierarchies and cultures and upends organizational structures and employee behavior, it presents a challenging task for managers (Carlsson et al., 2022). For FM digital transformation projects to be successful, a shift towards more adaptive and flexible organizational structures is required to handle digital changes

(Anna Karin Olsson et al., 2024). Moreover, to ensure the success of digital initiatives, local organizational structures that are out of alignment with the requirements of digital transformation must be recognized and transformed (Badasjane et al., 2022).

Implementing digitalization in FM is fraught with significant challenges due to a lack of awareness and understanding. Araszkiewicz (2017) highlighted several challenges to the advancement of FM, such as improving data integration and interoperability, improving knowledge management, and providing facility managers with better training and competency development. Other than that, the implementation of Industry 4.0 is influenced by strategic, operational, environmental, and social opportunities, while challenges related to competitiveness, future viability, organizational fit, and production hinder its progress (Muller et al., 2018). Managers encounter specific challenges in implementing Industry 4.0, but strategic approaches offer opportunities to overcome these challenges (Bajic et al., 2020). In addition, implementing digitalization in FM presents significant challenges due to limited awareness and understanding. According to Linkov et al. (2018), adaptive governance strategies for addressing the problems of social and economic sustainability have an impact on various forms of digitalization. There is a chance that digital technology use, management, and integration within the company will not align with the goals and objectives of the company if there are no clear guidelines in place (Muinga et al., 2020). To manage data as a business asset, ensure cybersecurity, collaborate with others, draw in digital talent, and build robust IT systems architecture, it is imperative to have clear governance policies together (Machado et al., 2021).

METHOD

The overall objective of this study is to identify the current challenges faced by implementing the digitalization of FM at University A. The outcome of the preliminary research on the FM-related practitioner resulted in the digitalization approach being applied in the FM department in a university building. The complexity and scale of University A's FM needs are unparalleled in the context of higher education institutions in Malaysia. This complexity offers a rich source of data and insight into the practical challenges and opportunities related to the digitalization of FM. Hence, this leads to choosing University A as the case study to drive this study approach. The method used for the data collection is semi-structured interviews.

Two interviewees were selected from the Infrastructure Development Office (*Pejabat Pembangunan Infrastruktur*, PPI) at University A. These interviewees are currently managing the FM and digitalization of the operation, and the questions are solicited from the challenges of implementing the digitalization of FM on their site. Interviewee 1 works as deputy director for the policy division; his division expert on managing digitalization on FM in the University A system. Meanwhile, Interviewee 2 works as head of FM at University A and is currently in charge of the process of FM work at University A. Accordingly, these two interviewees can fulfill these research findings.

Table 2. Interviewees Details

Interviewee	Designation	Work Experience	Gender	Interview Duration
R1	Deputy Director of Policy Division	22 years	Male	1 hour
R2	Head of Facilities Management	23 years	Female	45 minutes

RESULTS AND DISCUSSION

Table 3. The Responds of Interviewees on Challenges of Implementation of Digitalization of FM

Characteristics	Code	Quotations
Budget Constraints	R1	"...For a **budget, of course, constraints**, but we planned for every activity or improvement phase by phase. Sometimes, this system management must provide enough budget because of upgrading, but it is according to the budget itself."
	R2	"...The major challenge that has been faced is **budget constraints.** When it has budget constraints**,** we can't digitalize all the things at one time. So, there is a need for phase activities. It comes for the priority of FM needs."
Data Privacy and Security Concerns	R1	"...We **have a cyber secure unit that can secure the data information,** so it will not leak."
	R2	"...Currently, **we're not having a face on the data privacy and security** because our department is good at managing and controlling the data information".
Unclear Vision and Mission	R1	"...For my side, for **vision and mission, all the departments are clear on what University A needs**. So, if they are not unclear, maybe it can be one of the challenges that we have to face, but for now, we do not face it."
	R2	"...Of course, **unclear vision and mission can be one of the challenges in the digitalization of FM.** Strategic level need to know the direction of the university that can be achieved and always give some awareness of the digitalization for public users".
Lack of Skilled Professional	R1	"...**for in-house, we do not have any issue regarding the lack of expertise staff because we provide training**, so for now, they are experts on digitalization. For new staff, they will be coached by the experts."
	R2	"...Yes, **when we're outsourcing FM, we're having a lack of skilled professionals**, so we're monitoring the contractor using FMS. However, in-house staff, we provide training to improve the knowledge".
Resistance to Change	R1	"...so far, **early stage when implementing digitalization, we face resistance**, but **for now, every staff can tackle and adapt** for the better digitalization."
	R2	"...it is **not resistance anymore**; however, when we're implementing the new digitalization, **not everyone can adapt fast**. It takes a few times to work efficiently".
Infrastructure Limitations	R1	"...everything was perfect, **no issue for limitation**".
	R2	"...Maybe i**nternet, but internet coverage is provided for all space** in the University A".
Compatibility Issues with An Existing System	R1	"...In terms of changing data information, sometimes data in the site is different, in a system different. When updating, it does not give information, but **now we are not having this challenge**".
	R2	"...**no issue regarding the existing system**, but the new system needs to improve by phase, one by one, and prioritize the important activities".
Organizational Culture	R1	"...the **organization can adapt to digitalization,** so no issue regarding it."
	R2	"...the **organizational can be adapt** on the digitalization FM".
Limited Awareness and Understanding	R1	"...the **digitalization well-known by staff**. Everybody can adapt because they get full training."
	R2	"...not agree that our country is still early to enhance the digitalization, so **everyone aware and understanding why need to digitalize**".
Unclear Government Policy	R1	"...there **is no issue with the government policy** because the government is fully supporting digitalization."
	R2	"…not a challenge, **because of management are welcoming to digitalize facilities management**, they're fully supported. In this era, everyone accepts the digitalization".

This section provides the findings that highlight the aim of the research, which is to enhance the usage of the digitalization of FM in public universities. This study will discuss the challenges of implementing the digitalization of FM in University A. The challenges that

influence the implementation of the digitalization of FM are that this study has not been concluded and will be extended when a more comprehensive analysis is conducted. Below is the analysis of the challenges that gained from this study.

Based on Table 3, overall, all the participants can explicitly explain the questions related to the study, which are the challenges that have been faced when implementing the digitalization of FM. From that, we can observe the respondents' responses on which major challenges have been addressed when implementing digitalization.

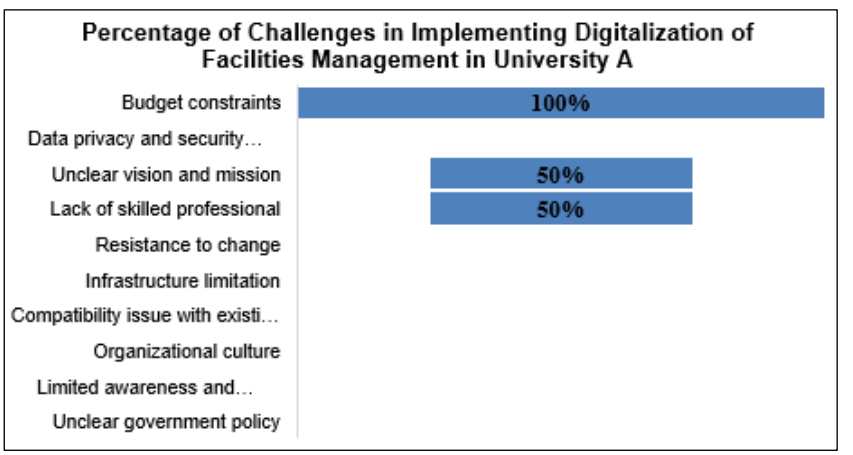

Figure 1. Respondent Percentage of Challenges Implementation Digitalization of Facilities Management

Figure 1 illustrates the analysis of the challenges of implementing the digitalization of FM. The scoring percentage agreed upon by the respondents is budget constraints, which are respectively 100%. This is attributable to the fact that implementing digitalization requires a huge budget allocation. Meanwhile, R2 responded that there was an unclear vision and mission and a lack of skilled professionals with 50%. This proves that budget constraints are the biggest challenges during the implementation of digitalization.

The data from this study is presented in Figure 1, displaying the percentage of challenges in implementing digitalization of FM. From that, we can conclude that budget constraints are the major challenges in implementing the digitalization of FM. According to the response, the activities plan needs to be planned phase by phase. Thus, it will take a long time to implement digitalization in all areas. Nevertheless, tight budget constraints and the absence of strategic planning can indeed present challenges in FM (Hou et al., 2016). Therefore, it is crucial to consider budget limitations when evaluating auction mechanisms for the preservation of digital objects in digital preservation systems (El Fakdi & de la Rosa, 2021). Accordingly, budget constraints are one of the significant challenges in implementing the digitalization of FM. Although in University A, the stakeholders strongly support the digitalization of FM, there is still a challenge to budget constraints in implementing digitalization.

On the other hand, an unclear vision and mission is one of the challenges in implementing the digitalization of FM, notably having a clear vision and mission that can drive the organization to implement digitalization. In the context of digital transformation, a clear vision and mission statement are fundamental for driving change and innovation (Li et al.,

2019). In the context of Table 3, R2 mentioned that she agrees that an unclear vision and mission can be one of the challenges of implementing digitalization. This is due to the fact that not everyone in the university management is clear on the direction of the university. However, this can be improved by raising awareness among all users. Hence, it is vital to understand the digitalization of FM.

Furthermore, there is also a lack of skilled professionals to manage and control the digitalization of FM at University A. In the context of higher education and industry, the shortage of professionals with digital competencies poses challenges to digital transformation and the economy (Konovalova et al., 2023). For this reason, having expert personnel who can manage the FM is essential. There are two understandings of the lack of professionals: firstly, there is a lack of professionals for IT experts, and secondly, with digitalization, the number of recent FM staff is limited. Since every work process can be conducted for a small group of staff, having more workers who can oversee FM is not essential. In conclusion, three challenges are being faced when implementing the digitalization of FM in University A, which has been interpreted at the strategic level. This can be attributed to the fact that the understanding of challenges between the strategic and operational levels is slightly different when facing one. Therefore, it can be summarized that budget constraints can be the biggest challenges when implementing digitalization since all the needs to develop and maintain digitalization is having substantial financial support.

CONCLUSION

The conclusion highlights the key challenges faced by University A in adopting digitalization within FM. These challenges include budget limitations, a lack of a clear vision and mission, data privacy and security concerns, resistance to change, infrastructure limitation, compatibility issues with existing systems, organizational culture, limited awareness and understanding, unclear government policy, and a shortage of skilled professionals. Furthermore, the study emphasizes that by implementing these strategies, the process of digitalization in FM can be made more effective. Additionally, the study opens the door for future researchers to explore these challenges further, fostering the exchange of ideas, opinions, and knowledge in this area.

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THE PERCEPTION OF MALAYSIAN CONSTRUCTION EXPERTS TOWARDS THE ACCESSIBILITY OF GREEN ROOFS AS PUBLIC SPACE

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Abstract

Green roofs offer significant environmental, social, and economic benefits; however, their potential as accessible public spaces are still inadequately examined in Malaysia. The urgent matter of accelerated urban sprawl prompts apprehension regarding the capacity of green roofs to increase green space within urban areas for recreational purposes among residents. This study examines the perceptions of Malaysian construction professionals regarding the accessibility strategies of green roofs as public spaces. This study utilises focused group discussions (FGDs) to assemble multidisciplinary local construction experts, including architects, town planners, developers, and construction specialists, to identify the challenges and opportunities in implementing accessible green roof strategies that are conducive to public use. Initial findings indicate that the advantages of green roofs, alongside various accessibility impediments such as location, safety considerations, community involvement, and other technical constraints, can be strategically addressed by incorporating best practices and innovative approaches from global examples, tailored to the Malaysian demographic and tropical climate conditions. This research proposes practical strategies to improve the accessibility of green roofs for sustainable urban development and enhanced urban quality of life in Malaysia, by incorporating expert insights and universal design principles.

Keywords: *Green Roof; Public Space; Accessibility; Urban Sprawl; Focused Group Discussion*

INTRODUCTION

Green roofs, defined by vegetated flat roofs with slight incline have recently emerged as an innovative solution to diverse urban challenges (Cappello, Giuffrida, Trovato and Ventura, 2022). These green infrastructures offer a myriad of environmental, economic, and social advantages. From an environmental standpoint, green roofs positively influence air quality, biodiversity, and stormwater management by reducing runoff (Alim et al., 2022). From an economic perspective, the implementation of green roofs yields energy savings via enhanced insulation and prolongs the durability of roofing materials by shielding them from environmental factors (Bevilacqua, 2021). From a social standpoint, green roofs enhance aesthetics and facilitate leisure activities and community involvement (Lee et al., 2024).

In the context of rapid urban expansion, green roofs are essential in alleviating the negative impacts of urbanisation, including the urban heat island effect and the rise of surface runoff (Joshi & Teller, 2021). They integrate natural elements into urban settings, improving the sustainability and quality of life in cities (Leal Filho et al., 2021; Alim et al., 2022).

Moreover, when green roofs are designed and implemented for public accessibility, they can transform neglected urban spaces into vibrant communal areas that enhance the overall urban living experience (Sörensen & Emilsson, 2020; Ip, 2023).

The integration of green roofs as public spaces introduces innovative dimensions to their utility. Besides their environmental and economic advantages, accessible green roofs provide urban residents with spaces for recreation, relaxation, and social interaction (Mamajonova et al., 2024). Green roofs serve a dual purpose, rendering them significant resources in urban planning aimed at attaining sustainable development.

PROBLEM STATEMENT

Despite the recognised benefits of green roofs, their implementation in Malaysia remains limited (Zaid, Zaid, Esfandiari & Abu Hasan, 2022). The widespread adoption of green roofs in Malaysian cities faces some notable constraints, such as architectural, social aspects and technical difficulties (Zhang & He, 2021). Moreover, the existing green roofs are often not designed or utilised as readily accessible public spaces, thereby limiting their potential impact on urban communities (Ariff, Zawawi, Yunus & Kwong, 2023).

The lack of accessible public spaces in Malaysia's urban areas is a pressing issue and critical concern, as urban inhabitants faces the shortage of green areas for recreation and social engagement, thereby impacting their quality of life. Green roofs present a viable practical solution to this problem by creating extra green spaces without necessitating substantial alteration in land use (Joshi & Teller, 2021). To materialise this potential, it is essential to understand the perceptions of parties responsible during the design phase through to the implementation stage.

AIM AND OBJECTIVES

This study aims to formulate strategies to improve the accessibility and usability of green roofs as public spaces in Malaysia, utilising insights obtained from construction experts via focused group discussions. The goals are to identify the primary obstacles to the implementation of green roofs and to propose feasible solutions for their incorporation into urban settings. The study focuses on the practical implementation of strategies to offer guidance on overcoming obstacles and facilitating the adoption of green roofs as accessible public spaces in Malaysia.

Green Roofs: Definitions and Types

Green roofs, also known as vegetated roofs, are roofing systems that support the growth of plants on the roof of building (Capello et al., 2022). They are primarily classified into two types: extensive and intensive green roofs. Extensive green roofs are characterised by shallow substrate layers with lightweight, low maintenance needs (Nektarios, Kokkinou & Ntoulas, 2021). Conversely, intensive green roofs possess deeper substrate layers, facilitating a broader array of plant species, including shrubs and small trees (Kotze et al., 2020). Intensive green roofs are designed for accessibility and serve as recreational areas, similar to conventional gardens.

Benefits of Green Roofs

Green roofs offer numerous benefits, particularly in urban settings. From a societal standpoint, green spaces provide substantial recreational opportunities that enhance the overall well-being of urban inhabitants (Jabbar, Yusoff & Shafie, 2022; Enssle & Kabisch, 2020). Green roofs can be constructed as communal gardens, providing residents with a space to unwind, socialise, and participate in physical activities (Mouratidis, 2021). These spaces enhance the aesthetic allure of urban landscapes, converting desolate rooftops into verdant areas that elevate the visual environment (Jeffs, 2024). Furthermore, green roofs serve as educational tools, enhancing awareness and understanding of sustainability and environmental conservation (Pacini, Edelmann, Großschedl & Schlüter, 2022). These systems can be integrated into educational institutions and community facilities, offering practical learning opportunities centred on ecology and urban agriculture.

Green Roofs as Public Spaces

The impact of green roofs on urban public spaces in Malaysia presents significant exploration opportunities. The recent trend of rapid urban sprawl in Malaysia has led to a reduction in urban green spaces; thus, green roofs can serve as an effective solution to increase public recreational areas (Ariff et al., 2023). The integration of green roofs in urban planning enables Malaysian cities to improve environmental quality, create new social spaces, and promote sustainable development.

Various examples of successful green roof public spaces demonstrate the potential of these structures worldwide. The High Line in New York City, an elevated railway converted into a linear park, serves as a significant model that has become a prominent urban attraction (Mahmoodabadi Arani, 2020). Namba Parks in Osaka, Japan, seamlessly combines cascading green terraces with retail and office spaces, resulting in a multifunctional urban oasis (Yan, 2022). These examples illustrate the design of green roofs to create accessible and stimulating public spaces that enrich urban living.

The impact of green roofs on urban public spaces in Malaysia presents significant potential for investigation. The recent trend of rapid urban expansion in Malaysia has led to a reduction in urban green spaces; thus, green roofs offer a viable solution to enhance public recreational areas (Ariff et al., 2023). By integrating green roofs into urban planning, Malaysian cities have the potential to improve environmental quality, create new social spaces, and promote sustainable development.

Challenges in Implementing Green Roofs

According to Zhang & He (2021), the implementation of green roofs poses various challenges. Establishing accessible green roofs for public utilisation in Malaysia includes addressing various architectural, social, and technical obstacles. In the architectural design of green roofs for public access, various factors must be considered, including prime location (Dvorak & Rottle, 2021), effective signage (Azis & Zulkifli, 2021), points of entry and exit (Ariff et al., 2023), available amenities (Jim & Hui, 2022), and capacity (Phoomirat et al.,

2020; Pardela et al., 2020) to ensure that the green roof functions as an additional recreational space in urban environments, particularly for retrofitting existing structures (Zhang & He, 2021). Securing community support and engagement is crucial yet may prove difficult due to differing levels of public awareness and interest in green infrastructure (Venkataramanan et al., 2020). Involving various community stakeholders in the planning and continuous management of green roofs is essential for their success and acceptance. Maintaining green roofs necessitates specialised expertise and consistent maintenance to mitigate safety hazards (Zaid et al., 2022). Moreover, the incorporation of accessibility elements like ramps, handrails, and clear signage necessitates careful planning and compliance with universal design principles (Nasir, Ahmad, Aziz, Mohamad & Razali, 2024). The amalgamation of these challenges demands a collaborative endeavour among architects, urban planners, developers, and the community to establish functional, secure, and inclusive green roofs.

Accessibility of The Green Roofs

Strategic location planning, visibility, unobstructed access, and urban signage are essential for enhancing the accessibility of green roofs in Malaysia. Community utilisation and involvement rise with an accessible green roof (Zhang & He, 2021; Jim & Hui, 2022). It must be reachable by foot, bicycle, public transportation, and automobile (Patil, 2021). Green roofs situated in proximity to pedestrian pathways, bicycle lanes (Mansoor, Kashifi, Safi & Rahman, 2022), and public transit stops can facilitate non-motorized transportation and enhance accessibility for a broader demographic (Benoliel, Manso, Ferreira, Silva & Cruz, 2021; Magrinya, Mercadé-Aloy & Ruiz-Apilánez, 2023; Hsiao, 2022).

Similar to other green public spaces, clear signage, maps, and directional arrows are important to direct visitors from street level to the green roof (Ryan & Hill, 2022). Visitor access to the green roof must be indicated by clear signage at various entry points (Ariff et al., 2023) along with relevant information to ensure safe and enjoyable (Donnelly, 2020) utilisation of the green roof. To cater to Malaysia's diverse population, signage must be provided in various languages to facilitate navigation for non-native speakers and tourists (Astawa & Wijaya, 2024). Effectively designed, multilingual signage can enhance the accessibility and appeal of green roofs, thereby increasing public engagement and their value as urban public spaces.

The safety and convenience of visitors rely on entrances and exits that are clearly marked and adequately illuminated (Ndewin, 2022). Wide entryways and exits should accommodate wheelchair users and others with mobility issues at these points (Hasan, 2024). This design consideration removes barriers to green roof enjoyment for some. To reduce accidents, these entrances and exit points should be smooth and level with no tripping hazards. Handrails and non-slip surfaces can assist visitors with mobility challenges (Nasir et al., 2024). These initiatives enhance the safety and accessibility of Malaysian green roofs, promoting community engagement.

To ensure safe walking on the green roof, non-slip surfaces must be installed consistently, particularly during wet weather (Waluś, Warguła, Wieczorek, & Krawiec, 2022). Guardrails or barriers should be strategically positioned along roof edges to prevent accidental falls and enable children and individuals with mobility challenges to utilise the space safely (Mwanik, 2022). Fire escape routes must be distinctly indicated to facilitate prompt and secure

evacuation during an emergency. These pathways must be unobstructed and easily navigable, equipped with signage and illumination for visibility in low-light conditions (Han, Feng, Liu, Zhang & Han, 2024). In Malaysia, the safety and accessibility of green roofs can be enhanced by emphasising surveillance and safety features, encouraging public utilisation, and augmenting urban green spaces.

In Malaysia, green roof accessibility requires clearly defining and posting the maximum capacity to ensure visitor safety and comfort. The dimensions and structural integrity of the green roof should sufficiently support anticipated public usage without resulting in overcrowding (Sattler, Zluwa & Österreicher, 2020). Entry control systems and timed ticketing can effectively reduce crowd sizes and enhance visitor satisfaction (Feliciani, Shimura & Nishinari, 2022). To foster an inclusive and inviting environment, the green roof must be accessible to all visitors during operational hours and cater to individuals with disabilities. These factors enable Malaysian green roofs to harmonise safety, accessibility, and stimulation, rendering them valuable urban public spaces.

Providing thoughtful amenities improves visitors' comfort and experience. The green roof must provide sufficient seating for visitors to relax and appreciate the views, promoting extended and more pleasurable visits (Gibson, 2024). Shade structures or umbrellas are essential for maintaining visitor comfort in the tropical sun (Klemm, van Hove, Lenzholzer & Kramer, 2017). Visitors must have access to drinking fountains or alternative water sources to maintain hydration and health (Heusinkveld, 2020). Furthermore, restrooms located on or adjacent to the green roof are crucial for fulfilling fundamental needs and enhancing accessibility. In Malaysia, green roofs can transform into inviting and accessible areas that cater to the varied needs of all visitors by incorporating these amenities, thereby enhancing their value as urban public spaces.

Malaysian green roof requires regular maintenance to ensure safety and cleanliness. To welcome visitors and keep the space clean, scheduled upkeep should include trash removal (Zaid et al., 2022). To prevent accidents and ensure safe use, broken handrails, loose paving stones, and deteriorated plantings must be identified and repaired immediately (Cevallos, 2020). Adequate lighting influences nighttime security and low-light visibility (Casciani & Casciani, 2020). Illuminated pathways and entrances mitigate slips and falls while fostering a sense of safety and accessibility, thereby promoting the utilisation of green roofs. Regular and prompt maintenance ensures that Malaysian green roofs remain functional, aesthetically pleasing, and usable, thereby establishing them as dependable and appealing urban public spaces.

Accessibility of green roofs in Malaysia must be inclusive and functional for individuals of all ages and abilities. The design must incorporate wheelchair ramps or lifts to ensure accessibility of the green roof for wheelchair users and strollers (Kiss et al., 2022). To prevent accidents and enhance accessibility, pathways must be free from tripping hazards (Waluś et al., 2022). To aid visually impaired visitors, Braille signage and tactile pathways must be incorporated (Zajadacz & Lubarska, 2020). These initiatives render the green roof accessible to all community members, demonstrating a commitment to inclusivity and equity in urban public spaces.

Community involvement enhances the sustainability and accessibility of green roofs in

Malaysia. Engaging the community in the design and planning process allows the green roof to be customised to local requirements and preferences, thereby enhancing its value as a relevant public asset (Zhang & He, 2021). Community engagement in green roof management and programming fosters ownership and stewardship, promoting active participation and support (Kiss et al., 2022). This inclusive strategy guarantees that the green roof embodies and caters to the community's varied interests, offering a venue for recreation, social interaction, and cultural activities. The incorporation of green roofs into urban environments enhances functionality and accessibility, establishing a green oasis that elevates quality of life (Semeraro, Scarano, Buccolieri, Santino & Aarrevaara, 2021). This engagement can convert green roofs into dynamic, multifunctional areas that enhance environmental sustainability, community connections, and urban living.

Educational resources and interpretive exhibits are crucial for enhancing green roof accessibility in Malaysia, aimed at informing visitors about the environmental advantages and principles of sustainable urban design. Educational resources can highlight stormwater management, urban heat island mitigation, and biodiversity enhancement, positioning the green roof as a model for environmental experimentation (Cole, Priscilla, Zangori, Kania-Gosche & Burken, 2024). The green roof can serve as a model for other urban developments by exemplifying sustainable practices. Workshops, tours, and educational programs on the green roof involve the community and enhance their relationship with nature (Baird et al., 2022). The green roof can enhance awareness of sustainability and environmental concerns, motivating urban residents to adopt more sustainable practices through these initiatives.

METHOD

This study employs a qualitative research methodology, facilitating a comprehensive understanding of complicated issues, thereby rendering it suitable for investigating the accessibility of green roofs as public spaces. The principal method of data collection is focused group discussions (FGDs). Focus Group Discussions promote interactive dialogue among participants, fostering the exchange of varied perspectives and producing comprehensive, refined data. This approach is especially effective in documenting expert perspectives and insights from professionals in the built environment.

Selection of Participants

The selection of participants for the FGDs is predicated on specific criteria to guarantee a diverse and informed cohort. Participants chosen from built environment specialists include architects, urban planners, developers, and construction professionals. These professionals are selected for their proficiency and experience in the design, implementation, and regulation of urban spaces and infrastructure, as well as their understanding of the end user. The recruitment process involves identifying prospective participants via professional networks, industry associations, and academic institutions. Invitations are issued to individuals who have exhibited substantial engagement in projects pertaining to green roofs or urban sustainability.

Data Collection

The data collection process is focused on the organised format of the FGDs. The focus

group discussion was conducted over a two-hour period and involved eight participants to promote effective interaction and efficient data collection. The discussions are directed by a series of fundamental themes and enquiries designed to investigate perceptions of accessibility, challenges, and opportunities associated with green roofs as public spaces. The focus group discussions are held in a supportive setting, facilitating face-to-face interactions to elicit more authentic dialogue. All discussions are audio-recorded and supplemented with video recordings, contingent upon participants' consent, to guarantee precise data collection for future analysis.

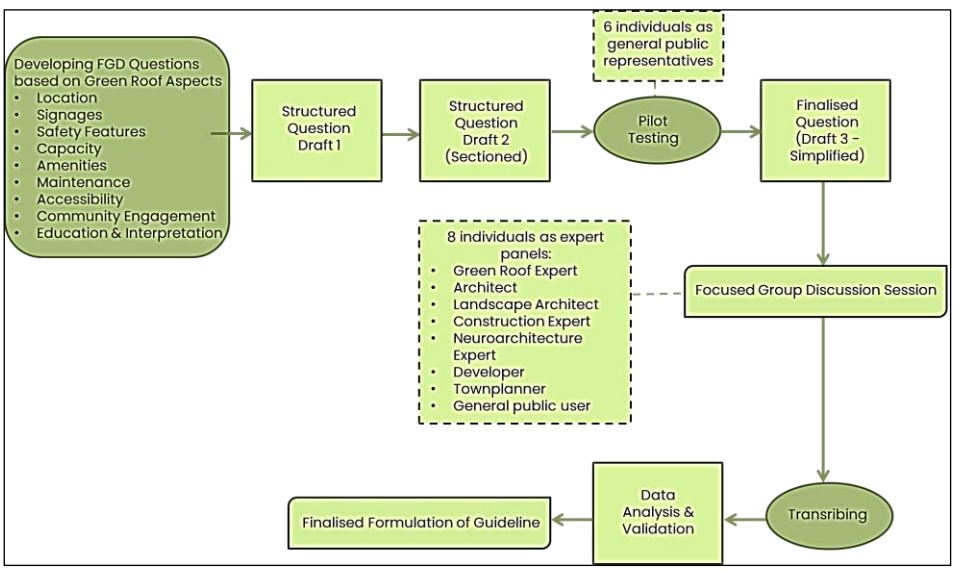

Figure 1. The Flow of Conducting Focused Group Discussion

The process involved formulating FGD questions regarding green roof accessibility derived from a literature review, draughting structured enquiries in formal, comprehensible language adhering to research ethics, conducting pilot testing, simplifying the questions, executing the actual FGD session, and transcribing the audio recording prior to data analysis and validation to attain finalised findings from the FGD.

Data Analysis

The data analysis employs a methodical process for transcribing and coding the FGD data. Transcriptions are conducted verbatim to accurately capture the diverse range of participant responses. Thematic analysis is utilised to discern and interpret patterns and themes within the data derived from frequently used keywords by expert panels. This procedure includes several readings of the transcripts, coding text segments, and categorising these codes into overarching themes. Thematic analysis facilitates the extraction of essential insights and the synthesis of findings into cohesive narratives that respond to the research questions.

RESULTS AND DISCUSSION

The literature review findings are analysed and categorised into various themes that summarise the overall parameters and criteria of an optimally accessible green roof. The thematic analysis is derived from the recurrent occurrence of keywords, which are identified

through coding and subsequently translated into the themes presented in Figure 2 below.

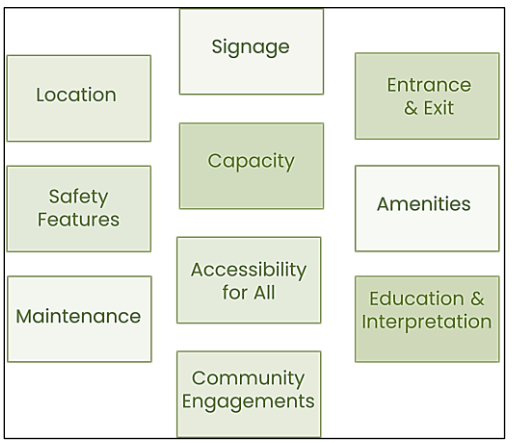

Figure 2. Green Roof Accessibility Themes

These themes are elaborated through a literature review to establish a set of design criteria for green roof accessibility. Themes and criteria for green roof accessibility design are the central focus of the FGD. The findings from the focused group discussion are compiled with design criteria, analysed, and categorised based on identified themes to emphasise perceptions regarding design criteria, including additional considerations or the exclusion of irrelevant points. Table 2 illustrates that the design criteria for green roof accessibility are being rigorously examined to confirm their validity. The points highlighted in yellow represent new additions to the criteria, established through mutual agreement among the experts, while the crossed-out points indicate irrelevant criteria that requires omission.

Table 2. Revised Design Criteria of Green Roof Accessibility from FGD Session

Accessibility Theme	Green Roof Accessibility Design Criteria
Location	• The green roof is easily accessible by foot, bicycle, public transit, or car • It is located in a prominent and visible location, easily identifiable from the ground • There are no significant obstacles or barriers to accessing the green roof • Terraced intermediate stops & nodes connecting ground level and green roof as recommended access towards green roof • There is adequate signage or wayfinding to guide visitors to the green roof • Initial design planning including wind tunnel study for high level green roof
Signage	• Clear, contrast colour-coded and visible infographic directory signage, with indicates the green roof's accessibility, zoning and usage guidelines • Signage provides information on opening hours, the location of the green roof, safety rules and regulations with information of imposed fine/penalty and any other relevant information • There is adequate strategically placed signage to guide visitors to the green roof (entry point, intermediate, rooftop) • Signage is available in multiple languages, including Braille
Safety Features	• Non-slip surfaces are in place to prevent slips and falls • Demarcation of tactile for assisted wayfinding • Recessed guardrails or barriers of minimum 1200mm height from green roof floor level are in place at perimeter to prevent falls from the roof • Fire safety measure is in place with provision of clear fire escape routes and alternative exit in compliance with maximum travel distance • Provision of ramp of 1:12 gradient in lieu of stairs directly towards assembly point during fire breakout • Diagonal pathway layout plan of green roof with more intersections and nodes promoting social interaction for natural surveillance from crowd traffic

Accessibility Theme	Green Roof Accessibility Design Criteria
	• Strategically placed emergency button • Adequate lighting is in place to ensure visitor safety during opening hours • Provision for obstruction lights for high level green roofs
Capacity	• The maximum capacity of the green roof is clearly determined by structural expert, defined and posted • The maximum capacity is sufficient to accommodate expected public use, in reference to amount of green space with occupancy per person • There are measures in place to manage the number of visitors and prevent overcrowding by imposing limit on reserved time slots and monitoring devices of entry and exit • The green roof is accessible to all visitors during opening hours
Amenities	• Seating is available for visitors to rest and enjoy the view • Shade structures or umbrellas are available to protect visitors from the sun • Prohibition of loose furniture use for high level green roofs • Drinking fountains or other sources of water are available for visitors • Restrooms are available on or near the green roof • Back of house with utilities such as janitor room, storage • Cycling track as recommended recreational amenity
Maintenance	• Regular maintenance is performed to ensure the safety and cleanliness of the green roof, including trimming, fertilizing, and brooming • Provision of maintenance access for green roof services • Proper seamless covered drainage and irrigation system to prevent water stagnant • Compulsory waterproofing for all green roof area coverage • Choice of less maintenance and self-sustaining landscaping • Provision for proper management of waste disposal and channel such as automated waste collection system (AWCS) for heavily landscaped green roof • Debris and litter are promptly removed from the green roof • Any damage or safety hazards are repaired promptly • Adequate lighting is in place to ensure visitor safety during opening hours
Accessibility for All	• Green roofs to designed in accordance with universal design is to be made accessible to people of all ages and abilities, including those with disabilities • Wheelchair ramps or lifts following barrier-free design provisions are in place to provide access to the green roof • There are no tripping hazards, abrupt curbs or other obstacles that would make the green roof inaccessible • Braille signage or other accommodations are available for visitors with visual impairments • Ergonomic consideration of facilities catering for kids • Special provision for intermediate stops as resting points for elderly in long-span green roofs • Provision of zoning for different parts of green roof, such as active zone and relaxation zone
Community Engagements	• Balanced involvement of stakeholders and community has been involved in the design and planning stage of the green roof • The community is involved in the ongoing management and programming of the green roof • The green roof serves the needs and interests of the surrounding community, such as urban community farming, activities that supports healthy lifestyle • The green roof is integrated into the surrounding urban landscape and contributes to the community's quality of life such as reflexology, yoga, light exercise activities, brisk walk and passive activities for night time operation
Education and Interpretations	• Educational materials or interpretive displays are available to inform visitors about the green roof's environmental benefits and the importance of sustainable urban design • Informative signage such as viewing from different altitude level, appreciation of view and identification of city skyline with binoculars as recommended facilities • Kid's playground for sensorial experience, extended as outdoor classroom as recommended facilities for informal learning • The green roof serves as a demonstration project or model for sustainable urban design, such as study on solar panels • The green roof provides opportunities for environmental education and outreach, through close experience with nature • The green roof contributes to public awareness and understanding of sustainability and environmental issues.

(Source: Authors, 2024)

The focused group discussion on green roofs as public spaces in Malaysia highlighted consistent key recommendations derived from literature aimed at enhancing accessibility (Nasir et al., 2024; Magrinya et al., 2023; Hsiao, 2022; Ryan & Hill, 2022; Donnelly, 2020; Ndewin, 2022; Dropkin & Smith, 2021; Kiss et al., 2022), safety (Zaid et al., 2022; Waluś et al., 2022), community engagement (Ip, 2023; Zhang & He, 2021; Azis et al., 2021; Baird et al., 2022), and education (Pacini et al., 2022; Kiss et al., 2022). In addition to being easily accessible by foot, bicycle, public transit, or car, experts emphasised that the initial design planning of green roofs should incorporate wind tunnel studies for elevated green roofs. It was recommended to enhance wayfinding through strategically positioned contrast colour-coded infographic signage directories and clear, multilingual signage, including Braille. Safety protocols, including non-slip surfaces, tactile indicators, and guardrails with a minimum height of 1200mm, must be implemented, alongside clearly marked fire escape routes and strategically positioned emergency buttons and lighting.

To facilitate expected public usage, the panel experts advised establishing the maximum capacity through structural evaluations and instituting measures such as reserved time slots to avert overcrowding. Amenities, including back-of-house utilities such as a janitor room, storage, and a cycling track, should complement existing facilities like seating, shade structures, restrooms, and water sources, as well as maintenance provisions, including adequate drainage and automated waste collection systems.

Panel experts emphasised the importance of community involvement in achieving balanced stakeholder engagement for the planning and management of the green roof, incorporating activities such as urban farming and exercise to improve the community's quality of life. The green roof must include educational resources and amenities, including interpretive displays, a viewing platform, and an outdoor classroom to enhance environmental education. Integrating these elements allows the green roof to function as a sustainable urban design model, enhancing public awareness of environmental issues and providing significant educational opportunities. Well-planned and executed green roofs, which are easily accessible to the public, have substantial potential as restorative communal spaces (Lee et al., 2024; Jabbar et al., 2022).

CONCLUSION

Malaysian construction experts consider accessible green roofs is important towards sustainable urban development, in tackling the issue of green space shrinkage due to urban sprawl. Insights from diverse expert stakeholders during the design phase, extending to actual implementation, are crucial for establishing validated criteria to achieve highly accessible green roofs for the public. According to expert panels, the placement of green roofs must be strategic, seamlessly integrated into the urban landscape, accessible via various modes of transportation, and devoid of barriers. Green roofs should incorporate clear, multilingual signage, expansive, hazard-free access points, and extensive safety measures to accommodate a more diverse audience. Consistent maintenance guarantees safety and cleanliness, while capacity management and considerate amenities enhance user experience and foster public confidence in utilising green roof facilities. Ramps and Braille signage exemplify inclusive design for all community members. Community engagement in the design, management, and programming of green roofs cultivates a sense of ownership and significance, rendering them essential public assets that address local requirements. Educational programs on green roofs

should foster sustainability and environmental consciousness through innovative and engaging methods that resonate with the public, encompassing all age groups from children to seniors. In Malaysia, green roofs can transform into dynamic, multifunctional areas that enhance urban living and environmental sustainability by following specific design criteria, supported by a balance between theoretical frameworks and practical applications in the built environment, as assessed by construction experts' perceptions.

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DEEP LEARNING-BASED GIS FRAMEWORK FOR AUTOMATED MULTIPLE OBJECT DETECTION IN SCANNED TOPOGRAPHIC MAP: A COMPREHENSIVE CONCEPTUAL GROUNDWORK

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Abstract
Automatic object detection in image analysis has seen extensive development in recent years, particularly for satellite imagery and scanned topographic maps. However, there is a noticeable gap in research with regards to topographic maps. Topographic maps present unique challenges due to the abundance of multiple object requirements. There is also a lack of an established integrated framework for the automated multiple detection technique of vectorization. This study focuses on developing a conceptual framework for automated multiple object detection in scanned topographic maps by emphasizing GIS and deep learning techniques. Through an extensive literature review, various methodologies for automated object detection, particularly in scanned topographic maps, were examined, with an emphasis on the incorporation of deep learning approaches. This comprehensive review identifies common methodologies, trends, strengths, and limitations in the field, guiding the research direction. Key findings encompass discussions on map vectorization processes, existing frameworks for automated systems, the role of deep learning in vectorization, and its integration with object detection techniques in the geospatial domain. The research model adopted introduces unique components to enhance the geospatial data structure, resulting in a novel dataset technique. These findings contribute significantly to advancing automated object detection techniques in geospatial analysis, addressing previous study gaps, and enhancing existing methodologies.

Keywords: *Automated Multiple Object Detection; Convolutional Neural Network; Deep Learning; Geospatial Artificial Intelligence; Hardcopy Map*

INTRODUCTION

Preserving hardcopy maps through digitization is essential, yet challenges persist due to issues such as the lack of map expertise, undefined procedures, and redundant or unused maps. While scanning is common, conflicts arise in defining it as a digitization process. From a geomatic perspective, true digitization involves vectorization, which converts raster images to vector data. Vectorization enriches spatial data, enabling diverse applications. However, manual digitization is time-consuming and prone to errors, necessitating automation (Anuar & Rauf, 2022).

Given these challenges, the development of an integrated framework becomes imperative to address existing issues. One of the main issues involve the lack of expertise and defined procedures. Library institutions, such as the Perpustakaan Tun Abdul Razak (PTAR) from UiTM Shah Alam, often lack specialized expertise in managing maps and defined standard operating procedures (SOP) for map management. Without clear guidelines and knowledgeable staff, the process of preserving and digitizing hardcopy maps becomes

challenging and prone to errors. An integrated framework can therefore help streamline the digitization process by providing standardized procedures and guidelines that reduces dependency on individual expertise and ensures consistent quality across digitization efforts (Anuar & Rauf, 2021).

A second challenge involves redundant or unused hardcopy maps. PTAR, like many other libraries, faces the challenge of managing a large volume of unused hardcopy maps due to the existence of digital maps. This is due to the shift usage from hardcopy to digital maps. These maps pose a risk of damage due to age and may ultimately be discarded if not digitized and preserved effectively. An integrated framework can facilitate the systematic digitization of these maps, ensuring their preservation for future reference and research purposes.

A third challenge concerns conflicts in defining digitization, particularly within the context of map preservation. While scanning is commonly perceived as digitization, true digitization involves vectorization, which converts raster images to vector data. From a geomatic perspective, the term digitization involves vectorization, which converts raster images to vector data. Vectorization not only extracts the information of the spatial features in the map but also preserves the map, making it more valuable compared to scanned copies. This conflict can lead to misconceptions and inefficiencies in the digitization process. An integrated framework that emphasizes vectorization can help clarify the digitization process and ensure that the full potential of digital mapping is realized (Jaafar, Abdul Rasam, et al., 2024).

The fourth challenge relates to conventional digitization challenges. The current digitization method for converting hardcopy maps to digital format, is time-consuming, labor-intensive, and prone to errors. With a large number of hardcopy maps to digitize, manual digitization becomes impractical and costly. Prolonged digitization time can also significantly increase costs associated with labor and resources. An integrated framework can incorporate automated techniques such as deep learning to streamline the digitization process, reduce manual effort, and improve accuracy and efficiency.

The identified issues underscore the need for an integrated framework that addresses challenges in map management, streamlines the digitization process, clarifies the definition of digitization, and incorporates automated techniques to enhance efficiency and accuracy while mitigating cost escalation (Jaafar, Abdul Rasam, et al., 2024). Such a framework would not only facilitate the preservation of hardcopy maps but also empower libraries like PTAR to better manage their map collections and make them accessible for research and educational purposes.

To bridge these gaps, the focus of this paper is primarily on the conceptual development and integration of Geographic Information System (GIS) workflows with deep learning techniques. The framework aims to serve as a foundational step toward future empirical research, where the proposed methods can be tested and validated using scanned topographic map datasets. Below are the objectives of the study:

i. To review previous studies on developing a framework for object detection in scanned topographic maps for automated vectorization.
ii. To propose an integrated conceptual framework for multiple object detection in scanned topographic maps for automated vectorization.

LITERATURE REVIEW

Issues and Concern

Malaysian academic libraries have long realized their role as a vast storage of local information. Digitizing documents and materials is one activity to preserve records for archiving purposes. The National Library of Malaysia (NLM) has taken the initiative to update available digitization guidelines to be more comprehensive and usable by all libraries in Malaysia, particularly in implementing digitization projects and activities. However, the digitization workflow practice only applies to materials and library documents such as theses, publications, journals, and other text-based materials and not hardcopy maps. Therefore, a specific workflow and guideline needs to be established as an SOP for digitizing mapping documents (Anuar & Rauf, 2022).

The PTAR library in UiTM Shah Alam focuses on digitizing books and theses rather than hardcopy maps (Yusof, 2020). Documents such as theses, research papers, and reference books are actively scanned using digital techniques such as the Optical Character Recognition (OCR) extraction. For hardcopy maps, PTAR only performs the classification process of cataloguing and storing for customer retrieval. Issues also abound in terms of the limited space available for storing the maps. This calls for the need for a digitization process to convert the hardcopies into digital maps.

From the government's perspective, the Department of Surveying and Mapping Malaysia (DSMM) had performed digitization of topographic hardcopy maps from 1999 to 2000. This contract-based digitization process intended to convert a series of maps that use imperial measurement units (T735) to a series of maps that use metric measurement units (T738). This procedure was necessary as there were no original digital data sources available at the time. Using the R2V method by a third-party company, the DSMM had successfully implemented ISO standards and demonstrated efficient management of their printed maps, and there was no requirement for them to perform vectorization. All maps are meticulously stored at the National Map Library, ensuring their preservation and accessibility. Consequently, the utilization of automated techniques is not necessary within this department (Jaafar, Abdul Rasam et al., 2024).

As previously discussed, focal issues often occur at small institutions like PTAR that have a lack of space to store hardcopy maps. To resolve issues of space for storing hardcopy maps, this study addresses the need to convert hardcopy maps into digital maps to resolve the issues of storage space. In the context of PTAR, the institution responded to this matter by stating that they are currently in process of scanning the hardcopy maps to be stored in their digital directory that could be accessed by users through a portal. These documents are scanned using a plotter and are stored as a portable document file (PDF). However, not much can be done with a PDF map apart from being a references source.

Based on this gap, this study recommends libraries like PTAR to perform vectorization from the scanned map by extracting the raster (PDF) to form a vector format of the map for digital mapping purposes. This would enhance the value of the scanned map by converting it into a digital map that enables data to be manipulated for data management and analysis, such as pattern and historical changes, as scanned maps contain historical spatial data. However,

to perform vectorization, a huge effort and commitment is needed to ensure the conversion process is successful. Time, manpower, and cost are the main constraints that need to be addressed. With the current method of vectorization, as well as the condition and large volume of hardcopy maps, the vectorization process would also be time-consuming.

Due to these issues, this study sees an opportunity to develop an automated vectorization technique to speed up the process of vectorization, and at the same time reduce cost and manpower. To initiate this idea, a conceptual framework for multiple object detection in scanned topographic maps for automated vectorization first needs to be developed that encompasses concept to object detection. In the conventional procedure of vectorization, this process of detecting and classifying the object or features in a scanned map consumes the most hours. Objects such as buildings, roads, rivers, and other features in a map need to be manually classified using human verification. This recognition and identification process could be automated through machine learning, specifically deep learning. Implementing this would speed up the classification process in vectorization.

Importance of Developing an Integrated Framework

The study recognizes the potential of integrating GIS with deep learning as the study seeks to combine two methods, vectorization and deep learning, for multiple object detection. The word 'multiple' is used as hardcopy maps contain various features that need to be classified. The word 'detection' is used to refer to the meaning of recognition and classification. Detection is also relevant to the Convolutional Neural Network (CNN) algorithm, which reflects the meaning of classification and segmentation of object in a map.

The development of an integrated framework for digitizing hardcopy maps is crucial for several reasons. First is for preservation of historical data. Hardcopy maps contain valuable historical data that are at risk of being lost or damaged over time. By digitizing these maps, the framework ensures their long-term preservation, allowing future generations to access and study important geographical information. The framework can also enhance accessibility through digital maps, which will make it easier to be distributed compared to hardcopy versions. An integrated framework can also facilitate the conversion of hardcopy maps into digital format, enabling wider access to geographical data for research, education, and decision-making purposes.

The integrated framework also promotes efficiency and cost-effectiveness. Manual digitization processes are time-consuming and labor-intensive, leading to increased costs. The framework incorporates automated techniques, such as machine learning algorithms, to streamline the digitization process, which reduces the time and resources required while improving accuracy. Through the integrated framework, standardized procedures and guidelines for digitization can be established, ensuring consistency and quality across digitization efforts. This helps maintain data integrity and reliability, which are crucial for the effective utilization of digital maps in various applications. The integrated framework for digital maps can be easily integrated with modern technologies such as GIS, to enable advanced spatial analysis and visualization. The framework will ensure that digitized maps are compatible with these technologies, maximizing their utility and applicability. It can also help address real-world challenges. Library institutions, like PTAR, face challenges in managing hardcopy map collections due to limited expertise, undefined procedures, and

resource constraints. The framework will provide practical solutions to these challenges, empowering institutions to effectively preserve and manage their map collections.

METHODOLOGY

This study is divided into two phases of execution, which are reflected within the study objectives. The first phase relates to the need assessment and framework system. During this phase, preliminary studies were conducted to gather information related to previous related research work. An interview session was also conducted with related departments and government agencies as the primary references. At the same time, visits to PTAR UiTM Shah Alam were made to collect samples of scanned topographic maps. Figure 1 below shows an example of a scanned topographic map that was collected.

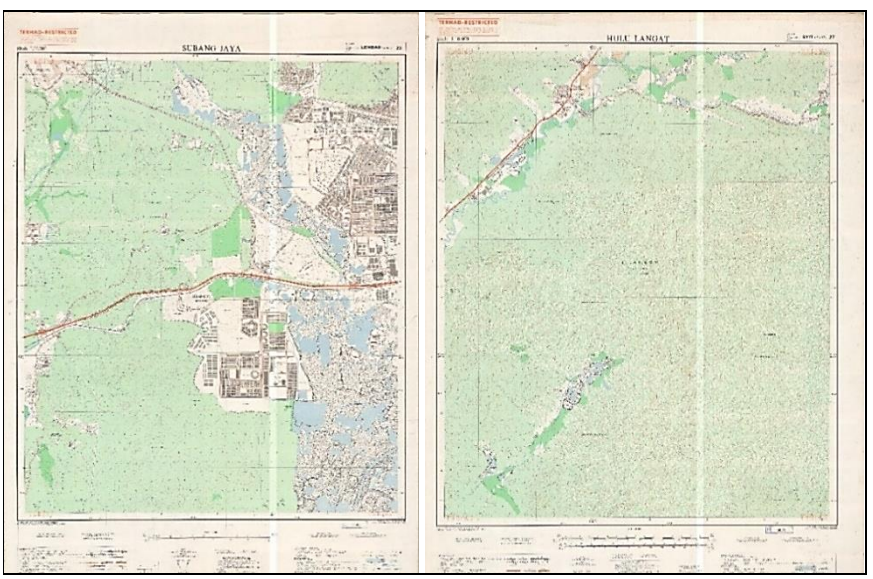

Figure 1. Sample of Scanned Historical Topographic Hardcopy Map, A1 Size

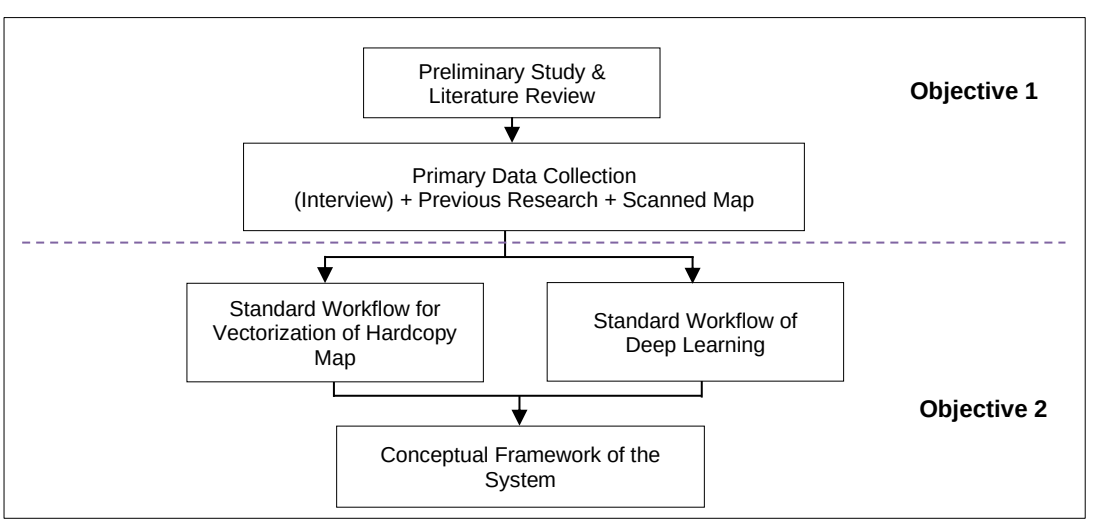

Figure 2. Methodology of Study

During this phase, framework systems were designed to align with the first objective of the study. The findings from the first objective led to the theoretical framework of the standard vectorization of hardcopy map, addressing workflow and deep learning. This output was then used as the input for the second objective in integrating these two conceptual frameworks. These frameworks were referred from previous studies. The integration was done by combining similar workflows for the proposed framework. Figure 2 above shows the method conducted in the study.

RESULTS AND DISCUSSIONS

Previous Studies on Framework Development for Object Detection in Scanned Topographic Maps for Automated Vectorization

Based on the information presented in Table 1, previous studies on automatic vectorization techniques have yielded significant findings. Among the 18 previous research studies that were carefully selected, it is apparent that knowledge-based approaches are frequently employed for the implementation of automatic object detection for vectorization. Knowledge-based techniques play a central role in automating the detection process. Furthermore, the table shows that the primary focus often revolves around image and object detection, with a particular emphasis on identifying objects such as buildings, roads, rivers, and other environmental features commonly found on topographic maps.

The second most commonly utilized approach is "Raster to Vector", encompassing a range of tools, techniques, and methodologies for performing vectorization tasks. When combined with appropriate techniques and a knowledge base, algorithms play a crucial role in enabling automation and achieving automaticity. Additionally, the findings underscore the significance of segmentation techniques as the third essential component in the automatic object detection technique. Segmentation techniques are highlighted as pivotal in executing the automated procedure effectively. From the information presented in the table, it becomes evident that achieving automated vectorization necessitates the use of algorithms capable of enabling the system to autonomously identify, detect, and classify the objects in the map. This is typically accomplished through the utilization of machine learning as the knowledge base for training the system to detect and classify objects present on hardcopy maps. Thus, the usage of deep learning in vectorization significantly highlights the capabilities of detecting objects in a map.

Based on the findings from past research, machine learning emerges as the most accurate and practical solution for achieving automated and applicable techniques. The key strength of machine learning lies in its ability to learn from data and adapt to different scenarios. In the context of this study, this means that machine learning algorithms can be trained to recognize and categorize various objects and features present on hardcopy maps. This adaptability is essential because maps can contain a wide range of objects, from natural features like rivers and forests to man-made structures like buildings and roads.

Machine learning algorithms can be fine-tuned through the training process, where they are exposed to a diverse set of map images with annotated objects. Through this exposure, they learn to identify and delineate these objects accurately. As a result, once trained, these algorithms become highly proficient at self-detecting and classifying objects on new and

unseen maps. This reduces the need for manual intervention, making the automated technique more efficient and less error-prone (Jaafar, Rasam, et al., 2024). This also reveals that the capabilities of deep learning, a subset of machine learning, particularly CNNs, have benefited the GIS field.

Deep learning techniques like CNNs are particularly well-suited for image recognition tasks, which are at the core of vectorization. CNNs are designed to automatically extract intricate patterns and features from images, making them ideal for identifying objects on maps. What sets CNNs apart is their ability to hierarchically analyze images, recognizing simple features like edges and corners before progressively building up to more complex object representations. This hierarchical approach mirrors how humans perceive and interpret visual information, making CNNs highly effective in discerning objects within maps.

In summary, machine learning, with its adaptable and trainable nature, forms the foundation for automated object detection technique for automated vectorization (Jaafar, Rasam, et al., 2024). Deep learning, through techniques like CNN, takes this a step further by offering advanced image recognition capabilities, enabling the system to accurately identify and classify objects on hardcopy maps, ultimately enhancing the overall accuracy and efficiency of the detection process.

Table 1. Previous Technique in Automatic Vectorization

Authors	OCR/text recognition	Object /image recognition	Knowledge Base	Thresholding/ Thinning	Raster to Vector (R2V)	Segmentation
(Liu et al., 2019)	✓				✓	
(Velázquez & Levachkine, 2004)			✓			✓
(Pouderoux et al., 2007)	✓					✓
Lichtner, W. (1985)		✓	✓		✓	
Chiang, Y. Y., & Knoblock, C. A. (2009)	✓					
(Khang et al., 2016)	✓		✓		✓	
(Lee et al., 2000)			✓	✓		
(Wu, 2019)			✓		✓	
(Armenakis et al., 2003)				✓		
(Velázquez & Levachkine, 2004)					✓	
(Miyoshi et al., 2004)		✓				
(Dunshee, 2016)				✓	✓	✓
(Pouderoux et al., 2007)	✓		✓			✓
(H. Chen et al., 2008)						✓
(Szendrei et al., 2011)			✓			
(Taie et al., 2011)	✓	✓			✓	
(Victoria, 2020)				✓		✓
(Liu et al., 2019)						✓
Total	6	3	7	4	7	7

The findings from the Table 1 serve as a guide in highlighting the importance of machine learning techniques in the object detection domain. This crucial finding led to the

investigation of deep learning, with a particular emphasis on CNN, as the primary strategy for the proposed framework. By leveraging the power of deep learning and CNNs, the study seeks to advance the field of automatic object detection and classification technique in the context of topographic maps, revolutionizing the process and enabling more accurate and efficient geospatial data analysis.

Previous Studies on Framework Development for Object Detection in Scanned Topographic Maps for Automated Vectorization

Several applications have utilized CNNs in mapping tasks. Based on Table 2 below, Schlegel (2021) employed CNNs for automatic label extraction, while Jiao, Heitzler, and Hurni (2020) focused on wetland extraction. Vassányi and Gede (2021) used CNNs to enhance image segmentation by predicting symbol locations. Saeedimoghaddam and Stepinski (2020) achieved 90% accuracy in detecting road intersection points using CNNs. Quan et al. (2018) combined point symbol recognition and image segmentation, attaining 98.97% accuracy. Li et al. (2021) employed U-Net, Cascade R-CNN, and Cascade CNN to generate semantic segmentation maps, bounding boxes, and building corners. Their technique achieved high precision, recall, and IoU scores, indicating the production of accurate building footprint polygons.

Another study by Y. Chen, Carlinet, Chazalon, Mallet, Duménieu, et al. (2021) employed CNNs combined with mathematical morphology to improve historical map segmentation. Vassányi and Gede (2021) demonstrated that retraining models using Mask Regional Convolutional Neural Network (MRCNN) and semantic segmentation improved digitization accuracy. ConnNet architecture was found to improve shape detection accuracy (Y. Chen, Carlinet, Chazalon, Mallet, Chen, et al., 2021). The integration of CNN with Optical Character Recognition (OCR) was recommended to enhance text annotations. Egiazarian et al. (2020) achieved promising accuracy by combining deep vectorization models with OCR, while Courtial et al. (2020) utilized U-Net for road and building generalization. The studies mentioned in Table 2 provide a comprehensive analysis and comparison of previous research in terms of techniques and performance. analysis.

Recent advancements in automatic object detection from hardcopy maps have seen significant progress through the application of deep learning techniques. Paula et al. (2023) employed the Segment Anything Model (SAM), leveraging a dataset consisting of 90 GB of random images, including imagery from Unmanned Aerial Vehicles (UAVs), airborne systems, and satellites. This dataset, comprising over 10,000 images and image patches, demonstrated varying levels of accuracy depending on the target class, with the highest Intersection over Union (IoU) scores not exceeding 90%. Similarly, Y. Wang et al. (2023) utilized ResNet50 and SqueezeNet architectures for map image classification. Using a dataset of 92,543 images, split into 73,933 training and 14,787 testing images, they achieved precision, recall, and F1 scores of 92%, demonstrating the effectiveness of these models for classification tasks within the geospatial domain.

Further work by Id et al. (2024) explored a combination of U-Net, Holistically-Nested Edge Detection (HED), and BCDN (Deep Edge Detector) for detecting objects from historical maps. Their dataset, comprising Paris Atlases from the 19th and early 20th centuries, was analyzed at a 1:5,000 scale. While advanced edge detection techniques were applied, the

results indicated that average precision did not exceed 90%, suggesting ongoing challenges in achieving higher accuracy with these methods. Additionally, recent research has highlighted more promising results from models such as YOLOv8, which have demonstrated the potential for superior accuracy in real-time object detection tasks. Collectively, these studies underscore both the progress made in the field and the continued efforts to overcome challenges related to precision and object detection performance.

Table 2. Previous Technique in Object Detection for Hardcopy Maps

Authors	State	Technique	Dataset	Result
(Li et al., 2021)	China	U-Net, Cascade R-CNN & Cascade CNN	**Orthophotos** Area of 78 km^2 in Christchurch, New Zealand.	U-Net 93.2% DLEBFP 94.7%
(Y. Chen, Carlinet, Chazalon, Mallet, Duménieu, et al., 2021)	France	Bi-Directional Cascade Network (BDCN)	**Hardcopy Maps** Multiple map sheets of the collection of Paris atlases, from year 1925	90% of accuracy
(Vassányi & Gede, 2021)	Hungary	Mask Regional Convolutional Neural Network MRCNN	**Hardcopy Maps** Third Military Survey of Austria-Hungary 1: 200 000	Accuracy is 90%, with 94% of symbols
(Delhi & Learning, 2019)	India	Semantic segmentation and standard U-Net architecture	**Satellite Image** 1. Inria aerial dataset 2. Massachusetts building dataset, 3. Indshine's UAV orthomosaic	Model trained on mixed dataset accuracy of 69.62%
(Radne & Forsberg, 2021)	Sweden	PixMax – (ResNet-152)	**Schematic Drawings**	mAP CubiCasa5k training data 97.2% for icon/symbol
(Y. Chen et al., 2021)	France	HED, BDCN, U-Net, or ConnNet standard architectures	**Hardcopy Maps** 1898 map sheet and 1925 map sheet were split into two distinct parts and used as a training and validation set	mAP HED, (70%) BDCN, (90%) U-Net, or ConnNet (90%)
(Egiazarian et al., 2020)	USA	Learnable deep vectorization model (Neural network-based vectorization)	**Floor Plans** PFP vector floor plan dataset ABC vector mechanical parts dataset DLD Degraded line drawings dataset	mAP 87% ABC 77% DLD 80%
(Courtial et al., 2020)	France	U-Net	**Satellite Image** Dataset composed of roads (the French national mapping agency) maps	mAP 65%
(Q. Chen et al., 2020)	China	Polygon CNN	**Satellite Image** Large-scale aerial imagery dataset with 7.5 cm resolution	mAP 88.6%
(Dwivedi & Patil, 2022)	Malaysia	Lightweight CNN	**Satellite Image** UC Merced Land Use consists of 2100 images, each of resolution 256X256	mAP 88.29% without over or underfitting
(Huang et al., 2023)	China	ASPP YOLOv4	2505 images from vectorized maps of different scales. It contained 7471 single symbols cropped to a size of 208 × 208 pixels	mAP of 98.11% and mIoU of 0.876

Authors	State	Technique	Dataset	Result
(G. Wang et al., 2023)	China	UAV-YOLOv8	VisDrone2019 dataset of UAV. Training sets (6471 images), testing sets (1610 images), and validation sets (548 images)	The mAP result was the highest among older versions of YOLO, Faster RCNN, RetinaNet, Cascade RCNN, and ATSS.
(L. Chen et al., 2021)	China	ImYOLOv3	1000 x 1000 sized patches 80% of the images for training, and the remaining 20% for testing	mAP 85.07%
(Paula et al., 2023)	Brazil	Segment Anything Model (SAM)	Random images: 1. Unmanned Aerial Vehicle (UAV); 2. Airborne, and; 3. Satellite 90 Gigabytes and comprises more than 10,000 images and image patches	Different level of accuracy achieves (IoU) depending on target class. Not more than 90% accuracy.
(Y. Wang et al., 2023)	China	Resnet50 and Squeeze Net	92,543 images for map image classification, and then randomly divided 73,933 images into the training set, and 14,787 images into the test set	The accuracy of precision was 92%, similar to the Recall and F1 scores.
(Id et al., 2024)	France	U-Net, HED and BCDN (Deep Edge Detector)	Paris (France) Atlases ("Atlas Municipal") from the 19th and early 20th centuries at 1/5,000 scale	Average precision at not more than 90%

From the above table, the accuracy from the CNN shows a stable achievement of accuracy, which means that this technique in deep learning promises outstanding accuracy achievement, especially in detecting objects through an image. Thus, this research adapted the technique used in CNN and modified it to suit the topographic map as the dataset of the model. These results also prove that CNN produces a promising outcome for image analysis, specifically in performing automatic object detection techniques for topographic hardcopy maps.

Integration of Workflow in GIS Vectorization and Deep Learning

The findings from the previous section had demonstrated the advantages of deep learning in achieving higher accuracy for object detection. In this section, the focus shifts to developing a framework that integrates deep learning techniques with vectorization workflows, aiming to enhance the efficiency and accuracy of map digitization. In practical terms, this integrated framework accelerates the map digitization process by reducing manual effort and time. It is particularly effective in handling complex maps with overlapping features, making it well-suited for large-scale projects, such as digitizing and archiving historical maps. The framework utilizes deep learning techniques, specifically CNNs, to improve and streamline the vectorization procedure. By merging the typical workflow of deep learning with traditional vectorization, the new framework is developed to align with the primary objective of this study: to enhance the accuracy and efficiency of automated map digitization. Figure 2 illustrates the integration process, highlighting key similarities and fundamental aspects of each workflow to ensure alignment with the study's goals. The blue arrow in the figure indicates the critical integration point where the workflows merge to form a cohesive research

framework. Inspired by existing techniques, this model ensures that essential components of vectorization and deep learning are seamlessly incorporated into a single, unified platform.

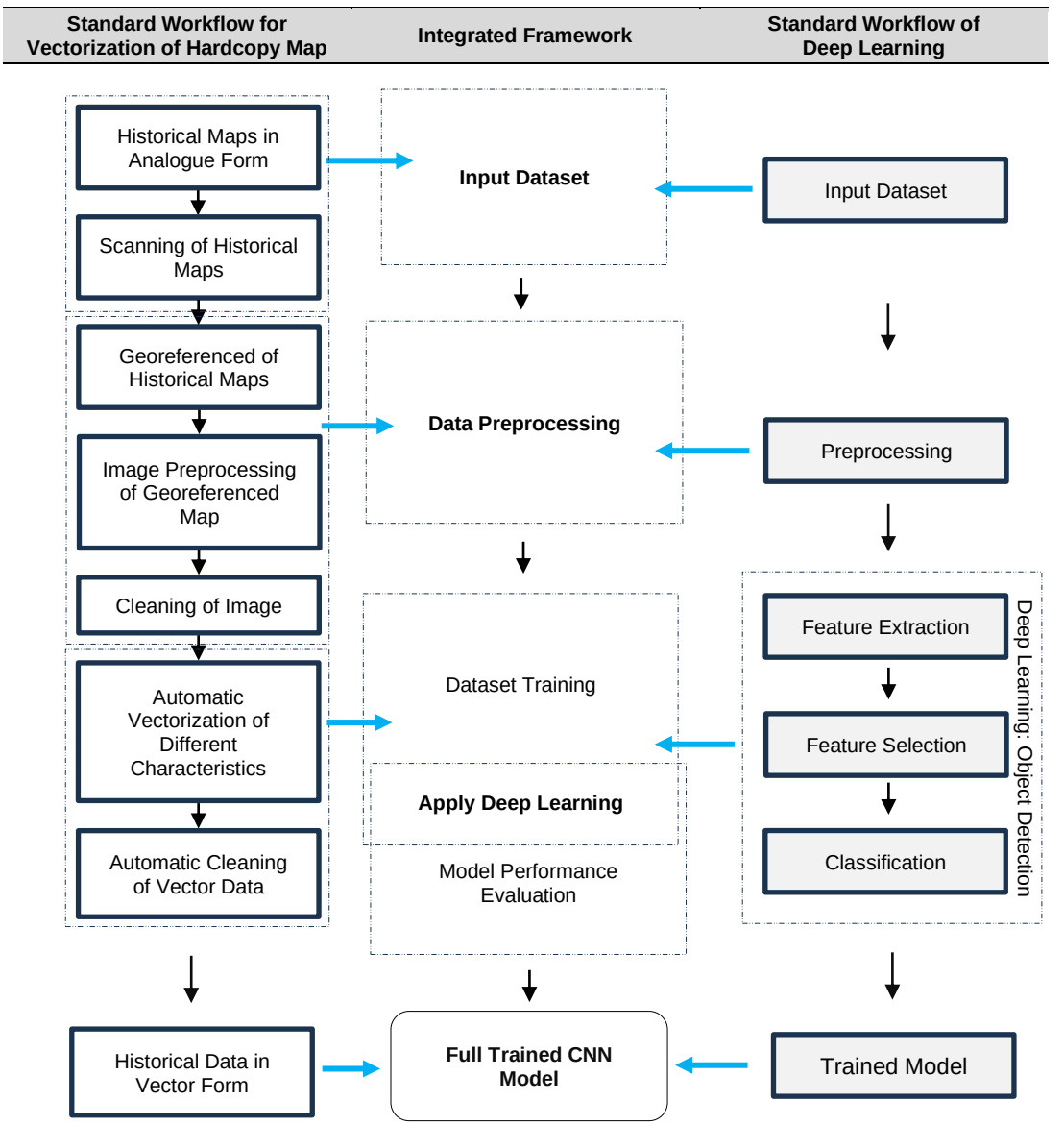

Figure 3. Integration of Workflow for Research Framework

To provide a more thorough analysis, the framework is evaluated by comparing deep learning techniques with traditional image processing methods for vectorization. CNNs deliver higher accuracy and are better equipped to manage complex datasets. Conversely, less precise, traditional vectorization techniques are more computationally efficient and easier to implement for smaller datasets or more straightforward map features. The integrated framework combines the strengths of both approaches, utilizing the precision of CNNs alongside the efficiency of traditional methods. This balance underscores the benefits of deep learning in terms of accuracy and automation, while acknowledging limitations such as high computational demands.

Framework Advantages

The integration of these frameworks highlights the novelty of this paper, which lies in the systematic integration of well-established deep learning techniques, like CNNs, with GIS workflows in performing map vectorization, which has not been extensively explored in previous studies. Key advantages of this framework in the context of geospatial data processing include several important benefits. Utilizing a GeoAI Deep Learning model enables completely automated procedures. This digitalization process not only saves considerable time, but also improves accuracy, providing direct benefits to library institutions, particularly for their cartography departments. A specific application of vectorization to prepare maps for smart mapping by transforming geospatial views into a format that is ready for use and suitable for reference in future research. The library institution can confront numerous obstacles, such as a lack of mapping expertise, limited human resources, and digitization time constraints. To overcome these obstacles, the geospatial domain-specific automated system was devised using artificial intelligence.

Using artificial intelligence techniques, this system seeks to streamline the digitization process and increase productivity (Anuar. S, 2021). Deep learning, particularly employing CNNs, is considered the best solution for multiple object detection techniques for scanned topographic maps. The implementation of this approach involves converting rasterized graphical representations of geographic entities into instance-based geographic data or vector data, which can then be conveniently manipulated using GIS (Chen et al., 2021). This process is achieved through image convolutions, pooling, and fully connected neural network layers. In recent years, Deep CNN has emerged as the most popular and dominating model architecture for image processing and computer vision. The success of CNN can be due to its ability to use convolutions and pooling to extract incredibly fine-grained characteristics from the image.

CONCLUSION

This study presents a comprehensive conceptual framework for an automated map vectorization system. It includes an in-depth analysis of map vectorization procedures, existing frameworks, the role of deep learning, and its integration with geospatial vectorization techniques. The study model incorporates four fundamental components for automated vectorization, effectively combining vectorization operations with deep learning, specifically utilizing CNNs to enhance accuracy and streamline automation. This framework offers benefits such as improved time efficiency, enhanced accuracy, and increased productivity. It addresses limitations often encountered in traditional techniques, facilitating advanced geospatial analysis and applications. Although there are several architectures used in the previous study that show very high accuracy, this study used them as the base foundation for implementing deep learning by experimenting with a new technique in the scope of CNN to find the best architecture for a topographic hardcopy map as the recommendation for the future. Due to the increasing numbers of new models, techniques, and algorithms in CNN, the study also concludes that all the established techniques have specific tasks depending on the model that needs to be applied. While the proposed framework demonstrates the potential for integrating GIS workflows with deep learning, further exploration is necessary to optimize its performance across diverse datasets and applications. As the paper recommends, future research could focus on detection accuracy and efficiency, particularly when handling large-scale geospatial data.

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RESIDENTS' PERSPECTIVES ON HOUSING DEFECTS IN SELANGOR

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Abstract
The prevalence of building defects in residential properties has become a growing concern, impacting the quality of life for residents. The study focuses on investigating the types of defects commonly occurring in residential buildings, determining the causes of defects on residents' quality of life. The study adopts a quantitative research approach to gather data and draw reliable conclusions. This method allows for systematically analysing a large sample of residents' perceptions. A structured questionnaire serves as the primary data collection tool, designed to capture residents' experiences with building defects. The questionnaire addresses various aspects, including the types of defects encountered, their potential causes, and their effects on residents' quality of life. The analysis reveals common defects such as structural issues, plumbing problems, and electrical faults, which stem from factors including poor construction practices and inadequate maintenance. The impact on residents includes safety hazards, health issues, financial strain, disruption of daily activities, emotional stress, and diminished comfort and overall quality of life. The findings of this study can guide policy-makers, developers, and building professionals in implementing effective strategies to reduce the prevalence of building defects in residential buildings in Selangor.

Keywords: *building defects; residential properties; poor construction practices; inadequate maintenance*

INTRODUCTION

The construction sector, including Malaysia, is becoming more contemporary as technology develops and expands daily. Malaysia is a developed nation in the twenty-first century, with several impressive structures that are now being built for various types of industries. Rapid technological and industrial growth has played a significant role in obtaining such an achievement. The building and infrastructure sectors are also critical in achieving developed-country aspirations. Various construction styles have been developed and designed over time to fulfil the demands of customers and the purpose of a building (Yusoff, 2020). A building serves as a space for individuals to live and work (Olanweraju & Abdul-Aziz, 2015). Furthermore, the goal of a building is to offer a comfortable and healthy environment for people to do activities, to provide security, to sustain load, and to provide environmental shelter or control.

However, defects and failures in structures arise as a result of a variety of circumstances. Building defects are a serious issue that the construction sector must address. According to (Keane, 2016), structural defects are defined as any fault in a structural element of a building that may be attributed to defective design, faulty workmanship, defective materials, or any combination of these. For example, honeycombs, hairline cracks at beams, defective design, building materials, structural flaws in walls, reinforcing bars of columns rusted due to exposure to sunshine and moisture, and so on (Hang, 2016). Currently, a large number of

structures have already been constructed, including retail centers, offices, businesses, hospitals, and many more. There must be a structural defect in the building, either after it has been finished being built or while it is being constructed (Soh, 2018). Building defects can be classified as either structural or non-structural from a structural standpoint. A structural defect is defined as a major or critical fault that has an impact on the building's structural integrity, such as settling, fractures, or bowing. On the other hand, a non-structural defect is a less significant or small fault, such as biological moisture or wear and tear.

Defects are categorised as patent and latent defects. During the building phase and the project's Defects Liability Period (DLP), patent defects can be plainly identified. Meanwhile, when a structure is occupied, latent defects normally manifest over time (Isa, 2016). In Malaysia, high-rise structures that are less than ten years old frequently contain structural defects that put both occupants and the public in peril. The reality has proven that every new structure has defects like surface cracks, leaks in electrical risers, or poor workmanship. In addition to these issues, the structures' defects also include rotted wood, honeycomb, roof imperfections, eroding mortar joints, corrosion of reinforced steel, failed foundations, peeling paint, and poor plater rendering (Hang, 2016). Therefore, this research will investigate and explain each type of defect in more depth and determine the factors or causes of building defects.

The occurrence of various types of defects in residential buildings is a significant problem that undermines the quality and safety of living spaces. However, there is a lack of comprehensive knowledge regarding the specific types and their prevalence in residential buildings (Neha Bagdiya, 2015). This knowledge gap hinders effective remediation efforts and preventive measures, leaving residents vulnerable to compromised living conditions. Therefore, there is an urgent need to investigate and document the types of defects occurring in residential buildings to address this critical gap in knowledge and provide the necessary foundation for developing targeted solutions that ensure the quality and safety of residential spaces in the future. Several studies have been conducted to investigate the types of defects occurring in residential buildings. For example, a study analysed defects reported during the warranty period and found that the most common defects included uneven painting, nail marks, poor quality of room and floor finishes, incorrectly fixed handles in doors and windows, and cracks (Plebankiewicz & Malara, 2020).

Several factors contribute to these structural defects. Based on (Ahzahar, 2011), a defect may be caused by a design flaw, faulty materials, incorrect handling or assembly, a contractor's lack of adherence to the design specifications or any combination of these factors. These root causes, which may act separately or in combination, might lead to defects that can be seen in the composition of the materials, the structure itself, the size, shape or weight of the materials or even their outward appearance. Other than that, building defects may result from non-compliance with building codes and deviations from accepted construction practices (Hang, 2016). This might have happened because of poor labour workmanship, lack of skilled supervision, etc. The inadequate quality of the job is frequently the result of insufficient experience and poor direction from the pertinent parties (Soh, 2018). Based on that research gap, the causes that lead to defects in residential buildings will be clarified and covered in this research.

Building defects in residential buildings can have far-reaching and detrimental impacts on the residents. As highlighted by (Neha & Shruti, 2015), these defects can lead to overall dissatisfaction among property owners, eroding the confidence of financiers, buyers, and end-users of construction projects. The presence of defects not only diminishes the perceived value of the property but also undermines the trust and credibility of the construction industry as a whole. Additionally, design faults contribute to a host of issues, such as increased maintenance expenses and a shortened lifespan of the building, as noted by (Ishak, Chohan, & Ramly, 2007). These defects result in financial burdens for residents, who are forced to allocate resources toward repairs and maintenance. Moreover, the compromised structural integrity and functionality of the building pose risks to the safety and health of its inhabitants. Residents may experience a sense of insecurity and face potential hazards due to faulty electrical wiring, plumbing leaks, weakened structures, or inadequate fire safety measures. Collectively, these negative impacts not only disrupt the daily lives and well-being of residents but also create long-term implications for the liveability, financial stability, and overall quality of residential buildings. Therefore, it is imperative to address and rectify building defects promptly to ensure the safety, satisfaction, and confidence of residents in their living environment. Thus, this research will provide a suitable solution to reduce the occurrence of building defects.

LITERATURE REVIEW

Causes of Building Defects

Defects in modern construction have a variety of sources. Inadequate craftsmanship, subpar building materials, defective construction practices, failure to adhere to specifications, etc., are all causes of design and construction defects that result in faults in new structures. In addition, environmental factors such as weather, poor maintenance, exposure to the elements, and a lack of resources might result in defects. If the residents fail to address the problems, all of these factors will ultimately lower the buildings' value, and the expense of fixing them will be high.

Construction Deficiencies

Construction defects are frequently discovered when a home is not built in a sufficiently workmanlike way or when the construction fails to operate as planned by the purchaser. According to the Building Research Establishment (BRE) in the U.K., it was discovered that building errors are caused by poor design, which contributed to 50% of the errors, as well as construction errors, which contributed to 40% of the errors, and product failures, which contributed to 10% of the errors (McDonald, 2017). Poor coordination for the design, confusing or absent paperwork, and subpar execution are the key factors that have an impact on the quality of the design.

Multiple defects may be the result of poor workmanship. Many building defects are out of compliance with codes or might be purposefully hidden by a contractor. A typical illustration is water infiltration through a building's structure, such as around windows, doors or roof holes. Any water incursion might provide a favorable setting for the development of mold. Other structural defects include water leaks, dry rot in wood, electrical and mechanical issues, and foundation fissures (Meyers, 2021).

Poor Workmanship

In the Malaysian construction industry, poor workmanship has always been highlighted in the media due to poor workmanship and low-quality materials being used, which have been identified as major causes of defects occurring in construction projects when developing new buildings. Aside from that, issues that lead to poor craftsmanship include a lack of supervision, experience, and expertise on the part of the labourers, a language barrier, and a lack of communication (Hang, 2016).

The contractor is responsible for ensuring that everything proceeds according to the project's overall quality plan. An independent contractor guarantees the timely completion of the project and prevents resource waste. The contractor guarantees both the quality and safety of the project against any construction defects through ongoing oversight. It's possible for the builders to stumble across a warning sign of impending calamity if there is improper or no monitoring (Sharpe, 2019).

Subcontractor and Labour's Role Ineffectiveness

The subcontractor's participation is responsible for the construction defects. This is due to the fact that subcontractors play an essential role on construction sites since they do the majority of the building labour. At the same time, the primary contractors rely only on the subcontractors to complete the task. Furthermore, the scarcity of competent labour is the key concern for those involved in the building business. Speed and tougher effort cannot increase productivity without better work practices (Hang, 2016).

Additionally, there are significant problems with job coordination and meeting quality requirements brought on by subcontracted labour. This is due to the fact that several types of subcontractors are involved in the same project, which makes it difficult for the principal contractor to manage the work that the subcontractors have completed. Language barriers and a lack of communication will also cause inadequate work execution on the building site. The local and the foreign workers speak different languages, which is why this is the case.

Material Deficiencies

The building's faults and defects are caused by the building materials, whereas the building materials will decide how the structure behaves. Additionally, the behavior will establish whether any future defects will be caused by the current ones. It may take one or two years for the impacts of utilising low-grade materials to become apparent, much like cancer in concrete. For instance, the bricks brought to the site may have faults, or the delivery driver may not have covered the bricks, leaving them exposed to the hot temperature and rainy conditions. The bricks' quality and longevity could be affected by this.

Using lesser-quality building materials might result in serious issues, such as leaky windows or pressure-cracked substandard concrete. Even when placed correctly, inferior items might nevertheless fail to operate and function appropriately. Construction paper or waterproofing membranes that are not up to code, subpar asphalt roofing shingles, or the use of subpar drywall that is not allowed for use in wet or damp places, such as bathrooms and laundry rooms, are just a few examples of common manufacturing problems with building

materials (Meyers, 2021). Occasionally, unethical parties like subcontractors would intend to reduce the value of the materials to reduce the cost of the materials. As a result, materials will eventually be of lower quality, which will hasten the occurrence of problems in new construction.

The majority of structures utilise readily accessible local building materials. Plaster, stone, brick, and wood are examples of such construction materials. Knowing the nature of the building materials and correctly diagnosing faults are of utmost importance in the management of building materials. For the same reason that older individuals are susceptible to certain diseases, so are structures. Therefore, to combat the illnesses, architects, contractors, engineers, and others engaged in building management should be knowledgeable about the typical building materials used and possess a greater grasp of the right ways to maintain the materials and structures (Ahzahar, 2011).

Poor Quality of Materials

The kind of materials utilised should be of excellent quality to construct a construction that is secure and stable. These materials have a longer lifespan and eliminate any possibility of defects. In contrast, subpar building materials result in issues like leaks, concrete fractures, ceilings that drop suddenly, and structures that do not work properly. Toxic mold grows on buildings as a result of leaking drainage lines. Frequently occurring manufacturing issues lead to subpar materials, poor drywall, and failing flashing are a couple of these issues (Sharpe, 2019).

Materials are essential for building, and the quality of the materials is one of the prerequisites for ensuring the quality of the construction. Construction materials include raw materials, finished goods, semi-finished goods, components, and parts (Wai & Cho, 2013). Construction projects that use inferior materials are certain to be poorly installed and have zero longevity. For instance, frames for windows of poor quality may budge during transportation, complicating installation.

Improper Materials Storing

Construction companies are no exception to the need for safe material handling and storage that many businesses face. Additionally, some building materials may become ineffective after being exposed to various weather conditions. Combining certain chemicals and building materials might cause reactions. For example, some are extremely combustible and may interact with one another. The personnel and the actual substance are in danger because of this (Ambegaonkar, 2021).

Variable weather conditions can impact the quality of the majority of building materials. It would be beneficial to store them at room temperature and properly cover them. Make sure your building supplies are not set down on bare ground, which might also be beneficial to material quality. By doing this, they are protected against moisture absorption, which might degrade their quality. Additionally, be careful not to set up your building supplies on uneven surfaces, as some are brittle.

Design Deficiencies

A design defect is defined as the damage suffered when building or constructing a design piece that necessitates replacing the component to fix the problem. An error in a design is typically the result of a failure by the design experts. Normally, in these types of situations, the cost of modifying will be covered by the design experts owing to the design blunder. This is due to the fact that they failed to create construction documentation and drawings that were correct and comprehensive. A design defect is usually referred to as a latent defect (Olanweraju & Abdul-Aziz, 2015). Design defects may be divided into two categories such as design errors and omissions, or both.

An error in design is described as a mistake when the design elements were built or were in the process of being built, and the error has to be corrected by replacing the components. Due to design faults, the design professionals will often cover the expense of modifying under these conditions. The effects of this will result in constructions that are finished but do not adhere to building codes. The roof is a frequent location with poor design. A roof that has been designed improperly may leak, have insufficient drainage or exhibit indicators of weak structural support.

A design omission occurs when a component of the scope of work is either absent or omitted by the designers during the design phase and in the construction papers. Still, it is subsequently discovered and added via a Change Order to the scope of work. In addition, the design omission also includes design elements that were incorrect but were changed before the project was awarded and had a major negative impact on the building process. It is generally accepted that premium fees that are paid for the work that was not competitively priced will be in addition to the real cost of the modified job. The design professional's absence is solely responsible for these extra expenditures (Hang, 2016).

Faulty Design

Design faults are frequently present to reduce the cost of early construction. This is due to the fact that the building's design takes construction costs seriously. If mistakes are made during the design phase, the structure will eventually have defects when construction is finished. A small number of variables influence the building's architecture. For instance, the physical location of the project, the accessibility of construction and building technologies, the accessibility of human resources to manage the process, and the legal framework's limitations (Hang, 2016).

Design mistakes have an adverse effect on the building's residents but also make it impossible to ensure their safety. Typically, design flaws in construction involve poor detailed execution, poor product and material selection, a failure to conduct a design review after a change in the project's scope, and inaccurate structural calculations and loading provisions.

Design Complexity

Architects and designers could create a complicated design. Understanding a complicated design takes time, and it is more difficult to create a building using such designs. One could overlook significant minute aspects like the support of the structure in the course of attempting

to comprehend the design's complexity. Without solid pillars to support it, a building may have fissures that may lead to the structure collapse (Sharpe, 2019).

A difficult design could be given a set amount of time to be finished, but half of that time might be spent revisiting the design to get a better understanding. Only the designer can comprehend complicated designs, which increases the complexity of the construction process. The design should be simple regardless of how complicated it is. According to Okuntade (2014), defects on the job site occur due to the contractor's inability to convey the drawing to the employees owing to his lack of technical knowledge. This will eventually result in poor design and the requirement for rework.

METHOD

This study adopted quantitative research methods, which involved analysing numerical data and using statistical approaches to gain insights into a particular issue or phenomenon. By utilising quantitative research, the study aimed to investigate the residents' perception of residential building defects in Selangor by quantifying the data and drawing conclusions based on questionnaire responses. This method was logical and data-driven, providing a statistical and numerical representation of people's opinions and perspectives. Quantitative research allowed for collecting a large volume of data, which could be analysed and transformed into informative reports. Therefore, given the nature of the study and the need for statistical analysis, quantitative research was the most appropriate approach employed.

Research Area

The state of Selangor served as the focus of the investigation for this research. Selangor was a state in Malaysia located on the west coast of Peninsular Malaysia. It was one of the most populous and developed states in the country, making it an important area of research. Selangor covered an area of approximately 8,000 square kilometres and was known for its diverse landscapes, including urban, suburban, and rural areas. The state was home to the country's capital, Kuala Lumpur, which was a major economic and cultural hub.

In terms of population, Selangor experienced significant growth over the years. According to the latest available data, as of 2020, the estimated population of Selangor was around 6.5 million people. This made Malaysia's most populous state, accounting for a substantial portion of its total population. The population density in Selangor was relatively high, especially in urban areas such as Petaling Jaya, Shah Alam, and Subang Jaya, where there was a concentration of residential, commercial, and industrial activities.

The population of Selangor was diverse, comprising various ethnic groups, including Malays, Chinese, Indians, and other indigenous communities. The state attracted people from different parts of Malaysia and served as a destination for international migrants seeking better economic opportunities and a higher quality of life. The large population of Selangor presented unique challenges and opportunities in terms of urban planning, infrastructure development, housing, and social services. Therefore, studying Selangor provided valuable insights into the dynamics of a rapidly growing and diverse population, making it an important area of research for various disciplines, including social sciences, economics, and urban studies.

Data Analysis

The data analysis for this study involved two methods of data collection: a literature review and quantitative data from questionnaires. The data analysis approach employed was descriptive analysis, which focused on summarising and presenting data in a meaningful way. In the literature review, data was collected from existing sources such as academic papers, books, and reports. The gathered information was then analysed to identify key themes, trends, and relevant findings related to the research topic. This allowed for a comprehensive understanding of the existing knowledge and served as a foundation for the study. The quantitative data collected through the questionnaire was analysed using descriptive analysis techniques. This involved summarising and presenting the data through means, ranks, and frequencies. Mean analysis was used to calculate the average response for each question or dimension. This helped to determine the central tendency of the data and provided insights into the participants' perceptions or experiences.

Rank analysis was employed to assess the relative importance or ranking of different factors or aspects. Participants were asked to rank their responses, and the rankings were analysed to identify the most significant factors or preferences. Frequency analysis involves examining the frequency of responses for each category or option within a question. This provided information on the distribution and prevalence of specific responses or characteristics within the sample. Overall, the data analysis for this study utilised descriptive analysis techniques to summarise and present the findings from the literature review and the quantitative data collected through the questionnaire. This approach allowed for a comprehensive exploration of the research topic and provided valuable insights into the participants' perceptions, preferences, and experiences.

Table 1. Data Collection and Data Analysis

Research Objectives	Method of Data Collection	Data Analysis
To investigate the types of defects that occur in residential buildings	Literature Review	Content Analysis and Descriptive Analysis
To determine the causes of defects in residential buildings	Literature Review and Questionnaire	Descriptive Analysis

RESULTS AND DISCUSSION

The distribution of the questionnaire was done by email and by hand. It is difficult to ask the public to complete the questionnaire since they provided several justifications for doing so. In the meantime, the questionnaire was disseminated via an online survey by blasting the link to potential respondents in Klang Valley, Selangor, Malaysia. A total of 195 participants completed the survey and sent it back. The researcher only managed to collect 195, which is 85% of respondents who completed and returned the survey, which is less than the intended sample size of 230. There were no more respondents willing to complete the questionnaire, preventing the researcher from obtaining a 100% response rate. Despite the fact that the researcher was powerless to make individuals spend the time filling out the questionnaire, she did provide many reminders before cutting off the connection to the survey she had created to boost the response rate.

Table 2. The Occurrence of Each Defect Type

No.	Features	Mean	Ranked
1.	Structural defects	2.41	5
2.	Plumbing defects	3.58	2
3.	Electrical defects	3.23	3
4.	Finishing defects	4.01	1
5.	Roofing defects	3.15	4

Table 2 presents the occurrence of different types of defects, with their respective mean values and rankings. Among the defects, finishing defects have the highest mean of 4.01, placing them at the top rank, while structural defects have the lowest mean of 2.41, ranking them last. This indicates that finishing defects are more frequently observed and reported compared to other types of defects. The reasons behind finishing defects being ranked first could be attributed to their visibility and the subjective nature of assessing their quality. As finishing defects are often noticeable and impact the overall aesthetic appeal, they tend to receive more attention and scrutiny. On the other hand, structural defects being ranked last could be due to their lower occurrence or the fact that they are less visible to the naked eye. Structural defects might require specialised inspection methods or expertise to identify, resulting in fewer reported instances and a lower mean ranking.

The study reveals that finishing defects have the highest mean value and ranking. In contrast, structural defects have the lowest mean value and ranking, which are consistent with the literature on construction defects. According to (Benarroche, 2019), construction defects are common and can range from minor issues to catastrophic collapse with severe human toll. Defects like undersised beams, understrength concrete, and coating failures are usually visible during construction when liability is clear and the cost of correction is minimal. Structural defects, such as premature deterioration, may be less visible and require specialised inspection methods or expertise, leading to fewer reported instances and a lower mean ranking. Additionally, defects can affect completed projects in various ways, from poor aesthetics to catastrophic collapse. Finishing defects, which are noticeable and impact the overall aesthetic appeal, receive more attention and scrutiny, possibly explaining their high mean value and ranking.

Table 3. The Common Defects

No.	Variable	Frequency	Percent (%)	No.
1.	The common defects	Peeling paint	129	66.2
		Wall cracks	136	69.7
		Ceiling cracks	36	18.5
		Floor cracks	30	15.4
		Dampness	83	42.6
		Leakage	159	81.5
		Roof defects	43	22.1
		Growth of fungus	96	49.2
		Broken window	1	0.5

**This question requires the respondent to tick more than one answer*

The questionnaire collected responses from a total of 195 participants regarding common defects in a building. Peeling paint was reported by 129 individuals, accounting for 66.2% of the respondents. Wall cracks were identified by 136 participants, representing 69.7% of the

total. Ceiling cracks were mentioned by 36 individuals, making up 18.5% of the respondents. Floor cracks were reported by 30 people, accounting for 15.4% of the participants. Dampness was identified as an issue by 83 respondents, representing 42.6% of the total. Leakage was the most commonly reported defect, with 159 participants constituting 81.5% of the respondents. Roof defects were mentioned by 43 individuals, making up 22.1% of the participants. Growth of fungus was reported by 96 respondents, representing 49.2% of the total. Broken windows were the least frequently reported defect, with only 1 person (0.5%) mentioning it. In summary, the survey findings indicate that the most prevalent defects were leakage, wall cracks, peeling paint, and fungus growth, while broken windows were the least commonly reported issue.

A literature review titled "Structural Defects in Residential Buildings: A Study of Quetta, Pakistan" (Kasi, Mahar, & Khan, 2018) examines the prevalent structural defects in residential buildings in Quetta, Pakistan. One of the key findings of the study is that the growth of fungus and peeling paint or wallpaper are commonly observed building defects in the region. This finding reinforces the survey results obtained from the study, which indicate that peeling paint and the growth of fungus were among the most frequently reported issues in the buildings. These defects can significantly impact the structural integrity, aesthetic appeal, and overall quality of residential buildings, making them important concerns for homeowners and property managers. Understanding the presence and causes of these defects allows for targeted interventions and preventive measures to mitigate their occurrence and maintain the long-term durability and liveability of residential structures in the area.

Table 4. The Common Causes of Defects

No.		Variable	Frequency	Percent (%)
1.	The common causes of defects	Poor workmanship	184	94.4
		Subcontractor and labour's role ineffectiveness	165	84.6
		Poor quality of materials	125	64.1
		Improper materials storing	57	29.2
		Faulty design	34	17.4
		Design complexity	20	10.3

**This question requires the respondent to tick more than one answer*

Table 4 reveals that poor workmanship is the primary cause of defects, accounting for 94.4% of the total. This is due to inadequate skills, negligence, or lack of attention during the construction process, which directly impacts the quality of the final product. Subcontractor and labour's role ineffectiveness, involving 165 people and constituting 84.6% of the total, indicates a lack of coordination, communication, or competency among subcontractors and labourers, leading to errors or delays. Poor quality of materials, affecting 125 individuals and 64.1% of the total, is a significant factor. Improper material storage is linked to 57 individuals and 29.2% of the total, while defective design is responsible for 34 people and 10.3% of the total. Poor workmanship is the highest in terms of the number of people affected, as it encompasses skill level, training, attention to detail, and adherence to quality standards. Addressing and improving workmanship should be a top priority to reduce defects and ensure a higher-quality outcome.

The findings that poor workmanship is the primary cause of construction defects, accounting for 94.4% of the total, are consistent with literature on the subject. According to

Neha & Shruti (2015), the failure of building structures is often due to workmanship negligence and the lack of effort put into quality control processes on construction sites. Poor workmanship typically arises when a contractor fails to follow industry quality standard practices, construction documents or installation instructions from the manufacturer. This can result in unfinished or defective work, which are signs of poor workmanship. Addressing and improving workmanship should be a top priority in the construction industry to reduce defects and ensure a higher-quality outcome.

An analysis of structural defects reveals that construction deficiencies accounted for the highest percentage of defects, with 178 people representing 91.3% of the total. Material deficiencies were reported by 79 people, accounting for 40.5%, while design deficiencies were identified by 108 people, representing 55.4%. A study on factors affecting defects occurrence in both structural design and construction stages of residential buildings in the Gaza Strip found that ignoring soil investigation or poor soil investigation, poor or lack of engineering supervision, and poor workmanship were the most important factors in the design stage (Al-Manassra, 2018).

Plumbing defects are primarily caused by construction deficiencies, affecting 97 people (49.7%), material deficiencies (46.7%), and design deficiencies (12.3%). Poor workmanship during installation, inadequate inspection and supervision, and insufficient training contribute to subpar installations. Construction deficiencies highlight the need for improved practices, quality control measures, and training programs to minimise defects. Plumbing defects can be caused by a wide variety of factors, including product defects and installation defects (Jaworski, 2020). Poor workmanship during installation, inadequate inspection and supervision, and insufficient training can also contribute to subpar installations.

Material deficiencies account for 66.2% of electrical defects, affecting 129 individuals. This is due to inadequate construction materials, poor material selection, and insufficient quality control measures during manufacturing or installation processes. Construction deficiencies affect 57 people (29.2%), while design deficiencies impact 10 people (5.1%). Proper material selection, quality control, and adherence to industry standards are crucial to minimise electrical defects. These findings support the notion that proper material selection, quality control, and adherence to industry standards are crucial in minimising electrical defects (Yacob, Ali, & Au-Yong, 2019). Meanwhile, construction and design deficiencies play a role in causing electrical defects. The literature suggests that material deficiencies have a more significant impact.

The analysis shows that construction deficiencies account for 61.5% of total defects, while material deficiencies account for 75.4%. Design deficiencies account for 25.1%. Material deficiencies are the primary cause of finishing defects attributed to inadequate quality control, substandard specifications, and compatibility issues. The higher number of individuals reporting material deficiencies highlights their importance as the leading factor contributing to these issues. The literature review provides additional evidence that inadequate quality control, substandard specifications, and compatibility issues with materials can contribute to finishing defects (Plan Radar, 2023). Overall, the literature supports the findings that material deficiencies are a primary cause of finishing defects in construction projects.

Construction deficiencies are the primary cause of roofing defects, accounting for 84.1% of reported issues. These deficiencies can result from poor workmanship, lack of quality control measures, and low-quality materials. Material deficiencies account for 68.7%, while design deficiencies account for 30.8%. Focusing on proper construction practices, skilled labour, quality control, and building codes and standards is crucial to mitigate roofing defects effectively. A review of common roofing defects identified improper design, poor workmanship, inadequate flashings, and improper maintenance as common causes of roofing deterioration (Neenu, 2020).

The findings from the statistics provided indicate that defects in residential buildings have a significant impact on the reduction of comfort and quality of life for residents. This aligns with relevant literature that highlights the negative effects of defects on occupant well-being and comfort. According to a study evaluating defect risks in residential buildings, the presence of defects can lead to dissatisfaction and reduced comfort for residents (Lee, Lee, & Kim, 2018). Additionally, research on living conditions and self-rated health has shown that poor living conditions can have direct or indirect effects on physical and mental health (Gu & Ming, 2021). These findings support the notion that defects in residential buildings can have a detrimental impact on the comfort and quality of life of residents, as they directly affect their overall well-being and living conditions.

CONCLUSION

The study successfully identified the different types of defects that commonly affect residential buildings. It revealed that finishing defects had the highest mean occurrence, followed by plumbing, electrical, roofing, and structural defects. This information sheds light on the specific areas that require attention and improvement to enhance the overall quality of residential buildings in Selangor. By achieving these research objectives, the study has contributed to the existing knowledge of the types of defects occurring in residential buildings. The findings can serve as a foundation for future research and inform policy-makers, construction professionals, and other stakeholders about the areas that need improvement to ensure the safety, functionality, and satisfaction of residents in Selangor.

The study revealed several significant causes of defects in residential buildings, and these causes were identified through survey responses. Common causes included poor workmanship during construction, inadequate quality control measures, use of substandard materials, lack of regular maintenance, and design flaws. By pinpointing these causes, the study contributes to understanding the root issues leading to defects in residential buildings.

Furthermore, the study categorised the causes of defects according to specific areas such as structural, plumbing, electrical, finishing, and roofing. This categorisation allows for a focused analysis of the causes relevant to each area, enabling targeted interventions and preventive measures. For example, the study found that structural defects were often linked to inadequate structural design or improper construction techniques. Plumbing defects were frequently associated with substandard plumbing materials or incorrect installation practices. Electrical defects were often a result of faulty wiring or improper electrical installations. Finishing defects were commonly caused by poor workmanship or the use of low-quality finishing materials. Roofing defects were often a consequence of improper installation or insufficient maintenance.

The study revealed that building defects have a significant influence on residents' lives. Structural defects, for example, can pose safety risks and lead to concerns about the stability of the building. Plumbing defects were found to cause inconvenience, such as water leaks and drainage issues, affecting residents' daily routines and quality of life. Electrical defects were associated with potential hazards and disruptions in power supply, impacting residents' safety and access to basic amenities.

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EVALUATING OPTIMAL LOCATIONS FOR FLOOD EVACUATION CENTRES USING THE SWARA-MCDM APPROACH

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Abstract
Flooding in Malaysia is common, affecting millions of people and causing millions of dollars in damage. Therefore, Malaysia's flood risk management is crucial, as securing flood shelters and evacuation areas is essential due to the high number of victims and evacuees. This study aimed to identify optimal locations for proposed evacuation centres in Terengganu, employing Geographical Information System (GIS) tools and the Step-Wise Weight Assessment Ratio Analysis (SWARA) Multi-Criteria Decision-Making (MCDM) approach. The research objectives were grounded in establishing criteria for flood evacuation centres, derived from an extensive review of relevant literature and background research. The weights for each parameter were calculated using the SWARA method approach utilising expert-completed questionnaires. Five (5) criteria were considered, including slope, population, location, accessibility, and land use in the study area. The criteria were then weighted according to importance, and those weighted criteria were combined to produce a suitability map. The study found that slope emerges as the most crucial factor in selecting an evacuation centre, carrying a weight of 0.236. The proposed method provides decision-makers with a framework to identify appropriate sites for establishing new evacuation centres away from flood-prone areas with suitable slope ranges, with careful consideration of potential environmental impacts. This study also underscores the critical role of the GIS-based SWARA technique in site selection, highlighting its robust and efficient approach to decision-making. The application of the study not only supports effective evacuation centre placement but contributes to broader sustainable development goals across different geographical contexts.

Keywords: *Flood Evacuation Centre; GIS-SWARA-MCDM; Site Suitability; Sustainable Development*

INTRODUCTION

The Department of Irrigation and Drainage (DID) in Malaysia 2023 defines floods as the inundation of land not typically submerged by water, and it includes overflowing rivers, lakes, or drainage systems due to factors like storms, ice melt, tides, or obstructions (DID, 2023; Khairilmizal et al., 2016; Task Committee on Flood Safety Policies and Practices, 2014). Flooding is a pressing social concern impacting urban areas globally, disrupting essential services, damaging infrastructure and affecting communities residing near water bodies. Not only that, but flooding causes expected consequences encompassing damage to homes and businesses, health issues from contaminated water, mental health problems like PTSD, and even fatalities (Ahmed et al., 2018; Ahmed et al., 2019). According to Ahmed et al. (2017) and Wardah et al. (2022), climate change, land-use alterations, and rapid urbanisation in flood-prone areas are projected to exacerbate these extreme events' risk and frequency.

Globally, floods are the most common cause of fatalities from natural disasters. Droughts have historically been the second most common cause of natural catastrophe mortality globally, after floods, according to Our World in Data (Our World in Data, n.d). During one-in-100-year floods, 1.81 billion people, or 23% of the world's population, are directly exposed to inundation depths of more than 0.15 m, which would significantly endanger lives, particularly those of vulnerable demographic groups. China, with 395 million, and India, with 390 million, account for more than one-third of worldwide exposure, and together, they comprise the majority of the affected population (1.24 billion) in South and East Asia (Rentschler et al., 2022).

Ranking as Malaysia's most frequent natural disaster, floods have impacted over two million people nationwide since 2015 (Muzamil et al., 2022). Floods are one example of a natural disaster that can affect people, animals, plants, buildings, and even infrastructure. They annually affect 4.9 million people and cause millions of dollars' worth of damage in Malaysia (Mohit et al., 2013). Twenty-nine thousand seven hundred twenty square kilometres, or 9% of the country's land area, are at risk of flooding (Department of Drainage and Irrigation, 2013). During the monsoon season, flooding affects the country's regions, including the north, central, east, and south. From December 2021 to January 2022, Malaysia experienced some of the worst flooding the country has ever experienced. Over 125,000 people were evacuated from their homes, and about 50 individuals lost their lives. Because of the higher numbers of flood victims and evacuees in Malaysia, securing flood shelters or areas to be evacuated around the nation is one of the most crucial duties of Malaysia's flood risk management.

Managing floods is difficult and complex, particularly in nations that frequently experience flooding. It is a worldwide issue that calls for cautious preparation, wise use of resources, and good public relations. However, more than providing an evacuation area alone is required; there are other crucial aspects to consider, such as the suitability of the evacuation area. Previous research has shown how important it is to improve disaster readiness by identifying and setting aside sufficient space for emergency shelters before disasters. Choosing a proper flood evacuation location is essential in planning evacuation areas since potential shelters may be dangerous and cause more damage than expected. For instance, a survey of shelters in Southern Florida revealed that 48% of those already established and 57% of candidates were situated in physically inappropriate areas (Chen et al., 2018).

The step-wise weight assessment ratio analysis (SWARA) method and the geographical information system (GIS) were combined to choose potential sites for a flood evacuation area to address the issue of an evacuation area. The SWARA method provides notable benefits by quantifying differences in the importance of criteria and incorporating the views of the experts (Deshiri et al., 2023). The first objective of this study is to identify suitable criteria based on past studies. Site suitability analysis helps identify suitable sites that match specific criteria or limitations to solve problems in decision-making. Through creating a matrix of pairwise comparisons, SWARA was utilised in this study to assess the consistency of weighting for the chosen criteria, with GIS playing a vital role in the suitability analysis (Ronald, 2011). Then, all the suitable evacuation areas that match the criteria will be turned into maps to produce a better understanding for the readers. In Malaysia, several studies have also demonstrated the capabilities of the GIS-MCDM approach to analyse and manage the flood issue appropriately, such as finding alternative routes (Abdul Rasam et al., 2023), flood risk

map development (Mohd Rasu et al., 2023) and 3D GIS mapping and geovisualisation (Sha'aban and monsoon catchment analysis (Adnan et al., 2014).

LITERATURE REVIEW

Flood in Terengganu, Malaysia

Terengganu endures significant rainfall during the North East monsoon, which spans from October to March each year, resulting in severe flooding across the state. The districts within the state suffer from these floods due to intense monsoon rainfall and physical factors, such as low elevation and proximity to the sea. In early 2022, all eight districts in Terengganu were affected by flooding, displacing 16,183 people from 4,223 families who sought refuge in 81 relief centres across the state (Bernama, 2022). An astronomical tide, combined with over six hours of heavy rainfall, led to rapidly rising floodwaters encroaching on previously unaffected areas. Consequently, ten roads in five districts were completely submerged, with water depths ranging from 0.3 to 2.0 meters (IFRC, 2022).

Earlier in 2022, Hulu Terengganu experienced its most devastating flood, impacting communities that had never faced such an event. According to Terengganu Police Chief Deputy Commissioner, water levels reached the roofs of residents' homes for the first time, creating an extremely critical situation. Some temporary evacuation centres (PPS) were also flooded, such as (Kg Lubuk Periuk and Kg Bukit Gemuruh), forcing residents to flee to higher ground (Bernama, 2022). The Terengganu Fire and Rescue Department (JBPM) reported that several of their staff lost communication while rushing to the disaster scene. Authorities had to use aircraft to survey the region before initiating boat rescue operations.

Optimal Location Criteria for Evacuation Centre

This study considers parameters such as slope percentage, land use cover, accessibility, shelter location, and population to develop a comprehensive flood evacuation plan. Slope plays a pivotal role in flood risk assessment. The slope was categorised into sub-criteria: low, normal, high, and very high. Land use cover is another essential factor, as are built-up areas, bare land, water bodies, forests, and vegetation. This classification helps understand the area's susceptibility to flooding and plan appropriate mitigation measures. The selection of shelter locations ensures they are in safe areas during evacuations.

Accessibility to evacuation facilities is constrained by cost and is essential for efficiently guiding evacuees to safety. It is also crucial for response teams to access evacuees' homes and shelters during evacuations. Therefore, site selection must consider the distance and visibility of roads to facilitate community evacuation. Evacuation areas close to residences or main roads are easier to access, with the accessibility constraint for shelters being less than one kilometre (Lee et al., 2021).

The social aspect is equally significant when determining the criteria for establishing new evacuation areas, as it is closely linked to human life. Research on project prioritisation and strategic planning for flood mitigation considers social parameters that impact flood incidents, population safety, healthcare, social and civil protection facilities, and facilities for protecting

against natural disasters. Thus, it is vital to understand how many people can be accommodated in the evacuation area during a disaster (Aidinidou et al., 2023).

Geospatial Technology for Disaster Management

Apart from floods and artificial disasters, Malaysia is located in a geologically stable zone, making it largely "disaster-free." The country is also in a climatologically stable area, positioned too far south to be affected by significant typhoon routes. However, it occasionally experiences the tail-ends of tropical storms (Chan, 2015). Most natural disasters in Malaysia are triggered by heavy rains, leading to floods and landslides. Geospatial technology is crucial in combating these disasters. Integrating GIS with remote sensing and photogrammetry technologies allows for the efficient application of this technology throughout all phases of the disaster management cycle.

The disaster management cycle is categorised into five phases: prevention, mitigation, preparedness, response, and recovery. Remotely sensed data and GIS applications are valuable at each stage, providing decision-makers with reliable data (Joyce et al., 2009). GIS helps identify potential hazards, such as flood zones, during the planning phase. In the mitigation phase, actions are taken to prevent or reduce disaster risks. GIS supports emergency management by offering critical data for preparedness, addressing "what if?" scenarios, like home vulnerability to floods. GIS and remote sensing (RS) help assess its severity during a disaster, guiding recovery operations. This data identifies critical areas needing immediate repair to restore normalcy.

Optimal location or site suitability analysis is performed in GIS to identify the ideal location or site for something. Thus, choosing a proper flood evacuation site is integral to shelter planning since potential shelter areas may be dangerous and cause more damage than expected. Testing numerous alternatives based on multiple factors is essential when making spatial decisions. Based on research from previous studies, a few factors have been used to develop the site suitability analysis conducted by DID and PLAN Malaysia. The SWARA-MCDM technique is a unique problem-solving approach designed for the practical deployment of specialised decision support systems and alternative conflict resolution in virtual settings, enabling more careful decision-making analytic methodologies (Keršuliene et al., 2010).

METHODOLOGY

Proper methodology planning is crucial to achieving good results and completing all objectives for the study. The workflow methodology used to carry out this study, including the preliminary study, data collection, data processing, and analysis, is represented in Figure 1 below.

Study Area

The selected area of study is Hulu Terengganu, Terengganu, Malaysia (Figure 2), which is listed as having a high risk of flooding under the National Physical Plan 3 (NPP3) (Plan Malaysia, 2016). Hulu Terengganu, a district in Terengganu, Malaysia, is renowned for its vibrant natural landscapes and intricate river systems. Geographically positioned at 5.0730°

N latitude and 103.0089° E longitude, the district is home to Kuala Berang, its administrative centre, which is situated approximately 40 kilometres (25 miles) from the state capital, Kuala Terengganu. Notable landmarks include the Terengganu Inscription Stone, a significant historical artefact, and Tasik Kenyir, known as Kenyir Lake, a popular destination for its stunning scenery and recreational opportunities.

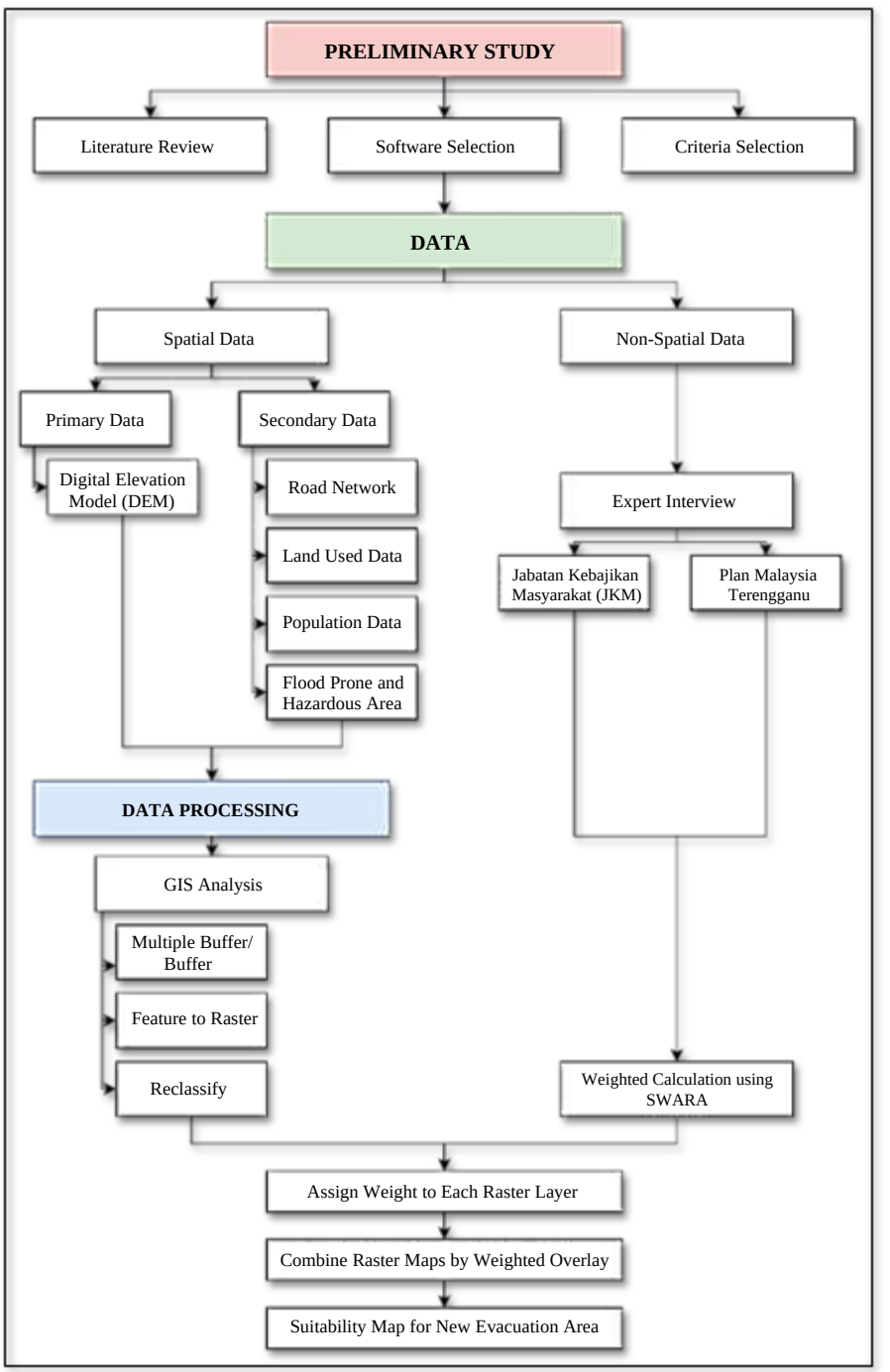
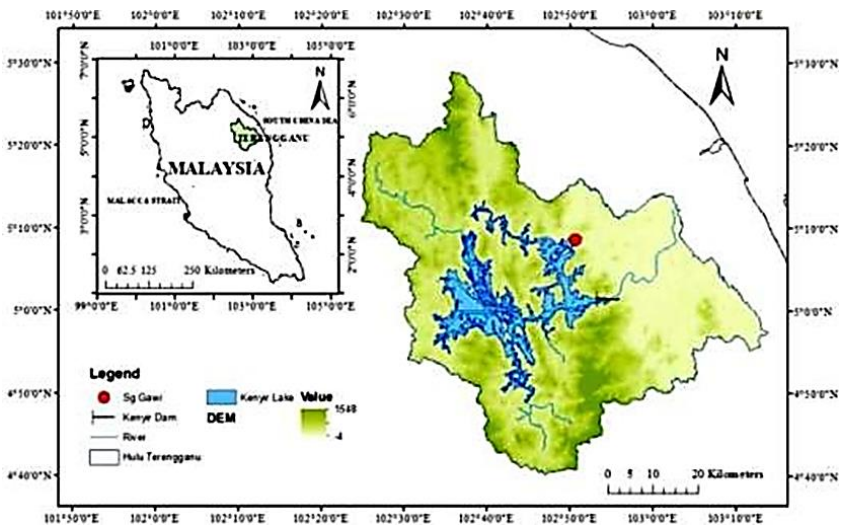


Figure 1. General Methodology Flowchart

A study of flood disaster management is comprehensive because it considers regional and local contexts concerning the rivers and the drainage system. The region has a tropical rainforest climate, with significant annual rainfall contributing to its lush greenery and diverse ecosystem. This area is prone to seasonal flooding, particularly during the monsoon season, which brings heavy rains and can lead to extensive waterlogging and river overflow. The district's topography and climatic conditions make it a critical area for studying flood impacts and implementing adequate disaster management strategies.



Source: (Che Wan Zainal et al., 2023)

Figure 2. Study Area of Hulu Terengganu

Criteria Selection

Choosing a new evacuation centre site in Hulu Terengganu involves ensuring evacuees' safety, accessibility, and welfare, maintaining environmental sustainability, and protecting local ecosystems while securing community support and adhering to safety and construction standards. Table 1 below presents the data required for this study, which includes five criteria for selecting a new evacuation centre location based on a review of previous research conducted by DID, PGN, and PLAN Malaysia.

Table 1. Data Collection

Data	Source(s)
Land Used	PLAN Malaysia Terengganu
Population Density	World Pop Mapping
Flood Prone Area	Department of Irrigation and Drainage (DID)
Hazardous Facilities	National Geospatial Centre (PGN)
Digital Elevation Model (DEM)	Earth Data Website
Road Access	National Geospatial Centre (PGN)
Interview	Welfare Department Hulu Terengganu and PLAN Malaysia Terengganu

The slope extraction procedure utilises DEM data collected from the ASTER database and employs ArcGIS software to analyse elevation values and generate a slope map for the study area. The contour data is analysed for each elevation value to create the slope map, which is crucial for understanding the terrain and identifying suitable locations for evacuation

centres. To determine road access in Hulu Terengganu, data from the National Geospatial Centre (PGN) is collected and processed to assess traffic patterns, the shortest paths, and accessibility to potential evacuation centres. This information ensures evacuees and response teams can reach the centres quickly and efficiently during a flood disaster.

Land use data retrieved from the Department of PLAN Malaysia Terengganu is categorised into different classes: built-up areas, vegetation, water bodies, forests, and bare land. The resulting land use map aids in identifying various land use types in the research region and assists in finding new areas for evacuation centres that are far from hazardous facilities or dumpsites, thereby avoiding discomfort for the evacuees. Interviews with the Welfare Department and the Department of Irrigation and Drainage (DID) Hulu Terengganu provide data on the worst flood levels and population distribution, which are crucial for disaster mitigation and prevention. Accurate spatial distribution data based on population is essential, as it helps determine how well the evacuation areas would serve flood victims. This examination aims to identify new evacuation sites that can be effectively used in emergencies, ensuring the safety and well-being of the affected population.

Data Preparation

According to Zhou et al. (2018), a spatial analysis tool known as buffering is essential for addressing proximity issues in GIS. The primary objective of buffering is to create buffer zones where areas are delineated at specific distances from a boundary and to evaluate the impact and service ranges of the surrounding region. This study employs a buffering tool to establish buffer zones around flood-prone areas and hazardous facilities, adhering to criteria that stipulate a buffer zone of approximately 1 km to ensure the safety of evacuees and the response team. The methodology involves mapping each hazardous area as a polygon.

The multiple-ring buffer technique is utilised in site suitability analysis to assess a site's suitability based on its proximity to various features or criteria. In road analysis, this technique evaluates a site's connectivity and accessibility to road networks by creating buffers at three distances: 1 km, 2 km, and 3 km. This ensures that roads are quickly accessible to evacuees and response teams.

Geospatial data from geodatabases, such as points, lines, and polygons, are then transformed into raster datasets. A composite raster layer is produced by merging multiple criteria and attributes, indicating the suitability index of locations based on weighted factors. This analysis converts land use, road networks, and flood-prone and hazardous sites to a raster format. The resultant map layers display attribute values for each pixel, providing a precise suitability index across the study area.

SWARA Method

Geographical Information Systems (GIS) are critical in incorporating geographical considerations into location selection processes, enhancing their effectiveness (Abdullahi et al., 2014). GIS works synergistically with Multi-Criteria Decision Making (MCDM) techniques as a robust decision support system, bolstering spatial analysis capabilities by integrating diverse data sources (Abdullahi et al., 2014; Joerin et al., 2001). Despite being introduced earlier than the Worst Method (BWM), the Step-wise Weight Assessment Ratio

Analysis (SWARA) method has received comparatively less attention in research concerning site suitability and its combination with GIS. Recent studies from Dehshiri et al. (2023) and Karakus (2023) have explored the application of SWARA in various fields alongside GIS, including in site suitability analyses of the evacuation centre. Notably, SWARA can effectively replace other MCDM methods, such as the Analytic Hierarchy Process (AHP) (Aidinidou et al., 2023) and the Analytic Network Process (ANP) (Dehshiri et al., 2023).

SWARA offers distinct advantages by quantitatively assessing the importance of different criteria and incorporating the perspectives of the decision-making panel (Hashemkhani et al., 2018; Thakkar et al., 2021). A significant benefit of SWARA is its reduced required pairwise comparisons to AHP, ANP, and BWM. This feature becomes particularly advantageous as the number of criteria increases, facilitating decision-makers in managing complex evaluations more efficiently. Consequently, this reduction enhances the accuracy and reliability of the results and improves the ease of implementation, making SWARA a compelling choice for comprehensive spatial analysis (Dehshiri et al., 2023; Karakus, 2023).

The SWARA method is a multi-criteria decision-making approach that can be used to assess site appropriateness and identify new evacuation zones. The primary characteristic of this strategy is its capacity to prioritise and incorporate expert opinions on the importance of criteria in the weighting process. One of the benefits of this strategy is that it allows specialists to coordinate their viewpoints. SWARA's primary capacity is to estimate the importance ratio of decision-making criteria in weighting based on expert opinions (Keršuliene et al., 2010). The SWARA method's mathematical equation provides a methodical approach to decision-making, guaranteeing that all factors are adequately addressed and weighted. In this procedure, the experts assess the importance of the decision-making criteria based on their opinions, and the criteria weights are calculated as follows.

Step 1: Define the problem and establish the criteria

- The initial step involves clearly defining the problem and determining the criteria for evaluating the alternatives. These criteria should be well-specified and relevant to the problem.

Step 2: Construct a decision matrix

- Develop a decision matrix with the alternatives listed in the rows and the criteria in the columns. Based on the criteria, assign scores to each alternative.
  $kj=1+sj,\ j\neq 1$

Step 3: Normalise the decision matrix

- Normalise the decision matrix by dividing each score in a column by the total sum of all scores in that column. This process ensures that all criteria are equally weighted.
  $qj=qj-1kj,\ j\neq 1$

Step 4: Calculate the relative weights of the practical criteria

- Assign weights to each criterion according to their relative significance.

The SWARA method provides a systematic and thorough approach applicable to decision-making. Moreover, the method frequently incorporates expert input, enabling individuals with specialised knowledge to contribute their insights. This collaborative aspect

ensures that diverse perspectives enrich the evaluation process, resulting in more resilient and well-founded decisions. This objective approach is a valuable tool for navigating the complexities of real-world decision-making. Consequently, deploying the SWARA method facilitates the identification of the most suitable location for the evacuation centre, ensuring safety, accessibility, and resilience in the face of potential emergencies, thereby contributing to the overall well-being and preparedness of the Hulu Terengganu community.

RESULT AND DISCUSSION

Weightage Value and Classification Map of Criteria for the Evacuation Area

The utilisation of SWARA in this investigation has yielded valuable insights into the relative significance of various criteria in evaluating the appropriateness of a new evacuation centre. The findings reveal that slope emerges as the most crucial factor in selecting an evacuation centre, carrying a weight of 0.236 (refer to Table 2). This discovery aligns with prior research emphasising the pivotal role of slope in determining suitable areas for evacuation centres (Mabahwi et al., 2021). Furthermore, the second and third most influential criteria identified in this study are the shelter's location and accessibility, with respective weights of 0.227 and 0.209. The shelter's location is essential due to the availability of safe evacuation routes and proximity to emergency services such as hospitals, fire stations, and police stations for immediate assistance and security. Regarding the primary criteria for shelter location, it is crucial to avoid constructing new evacuation areas in flood-prone zones, followed by areas housing hazardous facilities, as these locations pose risks.

Table 2. Weightage Value Ranking for Main and Sub-Criteria

Main Criteria	Criteria Weight	Sub-Criteria	Sub-Criteria Weight	Rank by Criteria
Slope	0.236	Less	0.252	4
		Normal	0.315	5
		High	0.224	2
		Highest	0.209	1
Land Used	0.167	Vegetation	0.215	4
		Bareland	0.260	5
		Forest	0.172	Restricted
		Built-Up	0.188	3
		Water Body	0.165	Restricted
Accessibility	0.209	<1km	0.391	5
		1km – 2km	0.319	4
		>2km	0.290	2
Location of Shelter	0.227	Away from Hazardous	0.465	Restricted
		Away from Flood Prone	0.535	Restricted
Population Density	0.150	Very High Population	0.265	5
		High Population	0.213	4
		Moderate Population	0.185	3
		Low Population	0.171	2
		Very Low Population	0.165	1

Additionally, easy accessibility is vital for swift access, particularly for vulnerable groups like the elderly, disabled, or families with young children. This reduces evacuation delays and

congestion, especially during critical times. Meanwhile, land use and population density rank fourth and fifth, respectively, with weights of 0.167 and 0.150. The land use criterion significantly influences land suitability for evacuation, as different land uses entail distinct requirements and preferences. The classification maps depicted in Figure 3 visually illustrate the various criteria and their spatial distribution in the study area and Table 2. These maps serve as invaluable aids for decision-makers and stakeholders, facilitating the identification of optimal evacuation centre establishment locations and formulating strategies for sustainable expansion.

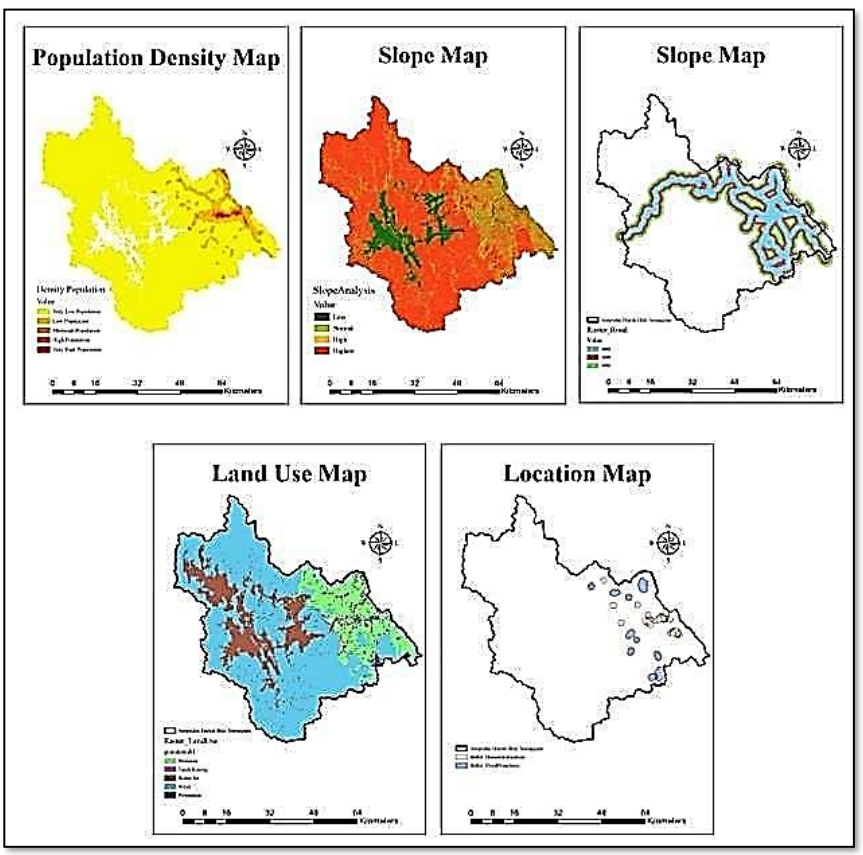


Figure 3. Classification Map of Criteria for the Evacuation Area

The Site Suitability Map of The New Evacuation Area

The area according to the criteria classification framework and coverage percentage of the suitability were summarised in Table 3. Unsuitable is shown by the red colour in the map, Figure 4. It comprises a vast area from the Hulu-Terengganu boundary, with 85.55% of the study area. This is mainly seen in the West and Central regions, with considerable forest and water body area. As half of Hulu Terengganu's land use is designated as forest reserve and water body area, these areas were classified as restricted. Industries were classified as restricted, as were flood shelters, which should not be built near industrial areas. Also, non-existing infrastructure, such as being far from roads and having a lower population, maybe a significant component because unsuitable regions are more common than others.

Less suitable lands for the new evacuation area comprise 0.15% of the study area. This area has a lower population density than the East region's centre. This area, in general, is quite far from the road as it takes a 3km buffer, and hence, it could be difficult for the emergency team and evacuees to reach the centre quickly. Finally, the slope factor can also be why this area is less suitable because it has a high slope range of 7% and above. Locating the evacuation area there is not suitable as it might be risky for other natural disasters, such as landslides, and it is hard for elderly and disabled people to get there. The moderately suitable areas, marked in yellow, constitute 2.22% of Hulu Terengganu's East region. This classification is primarily due to built-up areas, vegetation, and bare land, with distances from the nearest roads ranging from 1km to 2km, ensuring accessibility for response teams and evacuees to reach the centre efficiently. These areas also serve as buffer zones, maintaining adequate separation between flood-prone zones and hazardous facilities to prevent contamination or runoff of harmful substances. The gentle slopes ranging from 2% to 3% and 3% to 5% also significantly optimise the centre's resilience against large-scale flooding events.

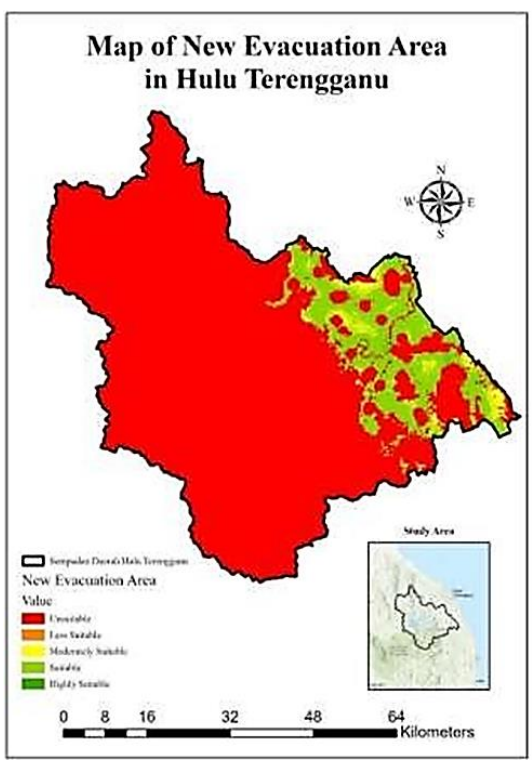


Figure 4. Site Suitability Map of The New Evacuation Area in Hulu Terengganu

Table 3. Summary of Area and Percentage of The Suitability Classes

Suitability Classes	Area (ha)	Percent (%)
Unsuitable	331,155.352	85.55
Less Suitable	582.944	0.15
Moderate Suitable	8,605.592	2.22
Suitable	46,455.704	12.00
Highly Suitable	321.410	0.08
Total	387,121.002	100

The most suitable land for the new evacuation area comprises 12.00% of the study area. Conversely, the area classified as highly suitable covers a smaller proportion than other categories (0.08%). This classification mainly includes bare land offering ample space for constructing the centre, unrestricted by zoning constraints. Additionally, slopes ranging from 3% to 5% are favourable for establishing an evacuation area due to their accessibility, reduced flood risk, and lower susceptibility to landslides. Proximity to road access within 1km is also crucial, facilitating quick evacuation and efficient supply distribution. Furthermore, locations distant from flood-prone buffer zones and hazardous facilities are deemed highly suitable, prioritising safety and logistical considerations in the planning of the evacuation area.

The application of GIS-based SWARA to select a new evacuation centre for flood disasters represents a significant advancement in disaster management. This approach utilises a multicriteria decision-making method, aiding decision-makers in choosing the optimal location for an evacuation centre based on various criteria. GIS is a robust spatial data analysis tool, enabling the integration of multiple criteria into the decision-making process. Meanwhile, SWARA assists in identifying the most suitable option by evaluating a set of criteria. This approach for evacuation centre selection addresses the critical need for effective disaster response planning. Choosing an appropriate site can mitigate the negative impacts of flooding on the environment and surrounding communities' health.

However, this method's success hinges on the accuracy and completeness of the data used in the analysis, emphasising the need for up-to-date, relevant, and reliable data. Additionally, involving all stakeholders, including the local community, in the decision-making process is crucial. Expert opinions can provide valuable insights into the proposed evacuation centre's potential social and environmental impacts. In conclusion, using GIS-based SWARA to select an evacuation centre is a valuable tool that ensures disaster management is conducted in an environmentally and socially responsible manner.

CONCLUSION

The study explored the application of GIS-based SWARA for selecting a new evacuation centre for flood disasters. This method utilises a multicriteria decision-making approach that integrates diverse criteria to assist decision-makers in identifying the optimal location for an evacuation centre. Choosing an appropriate site for an evacuation centre involves considering a range of environmental, socio-economic, and regulatory factors. GIS-based MCDM techniques, such as SWARA, have proven effective in this process by facilitating the selection of suitable locations. Implementing GIS-based SWARA for evacuation centre selection ensures that disaster response is conducted in an environmentally and socially responsible manner. It is critical to ensure the accuracy and trustworthiness of the data utilised in the analysis and include all stakeholders in the decision-making process. This strategy helps decision-makers to make educated and responsible decisions that benefit the environment, local communities, and society. One notable advantage of this strategy was the ability to combine quantitative and qualitative criteria.

Furthermore, after the evaluation, it was determined that the study region was classified into five categories: inappropriate, less suitable, moderately suitable, suitable, and very suitable. The final map acquired from this study can be used in the decision-making process to create new evacuation areas inside the study area, as it provides insight into determining

the best shelter locations. This supports an environmentally sustainable strategy, primarily based on its surrounding habitat. Future studies could combine real-time data, climate change effects, community input, and cost considerations when using Advanced 3D GIS-based SWARA MCDM to choose the best locations for evacuation centres.

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PSYCHOLOGICAL IMPACT FACTORS OF OPEN SPACES ON URBAN DWELLERS IN THE FEDERAL TERRITORY OF KUALA LUMPUR

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Abstract
Mental health issues have many causes; in many cases, this includes the changing and unpredictable elements of open spaces. Therefore, this study addresses alternative approaches to determine the psychological causes among urban dwellers exposed to Coronavirus Disease in 2019 (COVID-19). The objectives are to examine the magnitude of psychological causes (depression, anxiety, and stress) and the associated factors of open spaces among urban populations who have been exposed to COVID-19. The research employs a quantitative method as the main method. In addition to the secondary data collection, the Urban Mental Health Questionnaires (UMHQ-DASS21) questionnaire survey is utilized. Stratified random sampling for a total of 241 samples was performed in PPR Pantai Ria, Lembah Pantai, Federal Territory of Kuala Lumpur. The areas are selected due to their classification as COVID-19 red zone areas during the Movement Control Order. The findings reveal that most of the respondents demonstrate the symptomatology of depression, anxiety, and stress based on the perception of open spaces. Meanwhile, the correlation analysis demonstrates a high correlation between the respondents' psychological aspects and open spaces. The result of this research can benefit the Ministry of Health, Ministry of Housing and Local Government, and urban planning decision-makers to establish a new policy or improve the existing policies and guidelines that can mitigate the impacts of the complex dynamics of infectious diseases post-COVID-19.

Keywords: *Urban planning; open space; psychology; impact; Covid-19*

INTRODUCTION

Fear and anxiety about the Coronavirus Disease in 2019 (COVID-19) have forced millions of people to physically isolate, which further indicates a varying mental health impact amid the many global health, economic and societal disruptions (Raja, 2020). The COVID-19 outbreaks demonstrate how the supportive role of the built environment (such as land use planning) for mental health is essential to be translated into effective policy and practice (Pennix et al., 2022). As such, recent research has shifted to examining the immediate and long-term urban physical environmental determinants of mental health, particularly in response to the risk of infectious diseases such as the COVID-19 pandemic (Penbrooke, 2020). Helbich's (2018) phrased, "the environmental context affects people's mental health," informs the idea that the environment can also present devastating consequences for people's mental well-being. In fact, the COVID-19 pandemic has spotlighted how the urban physical environment, particularly open space, is affecting mental health. Similarly, a study by Yao et al. (2022) asserted that greenery areas mitigated mental health issues that COVID-19 imposed in China.

Thus, echoing recent calls for interdisciplinary research, a holistic and collaborative action needs to be taken to deal with the growing mental health issues and ways in which one can work towards improved mental health in the context of a pandemic. If these issues are not addressed, it is almost inevitable that mental disorders will rise even greater, and it is even more critical now, considering the stress that COVID-19 has induced. This is particularly true in determining the magnitude of psychological causes (depression, anxiety, and stress) and the associated factors of open spaces among urban populations that have been exposed to COVID-19. Therefore, this interdisciplinary research involving urban planning and psychological discipline is critical, as the burden of mental disorders has grown worldwide. Accordingly, from this study, adaptation strategies and policymakers can make the right decisions and also minimize the impact of psychology on urban dwellers.

World Health Organization (WHO) (2020) declared the COVID-19 a global pandemic on 11 March 2020. This outbreak has further led to "another alarming issue: the long-term mental health impact the pandemic is going to leave on society" (Campanella, 2020). Thus, understanding this new 'pandemic' after COVID-19 is critical since all the consequences are reflected as anxiety, stress, and depression and are impacting people in different ways (Dai et al., 2020). Accordingly, new measures are introduced to prevent COVID-19 transmission, such as Movement Control Orders, lockdowns, quarantine, and social distancing, with many people working from home, thus limiting how people interact physically. According to Cao et al. (2020), "the epidemic has brought not only the risk of death from infection but also unbearable psychological pressure." At the same time, the "levels of loneliness, depression, harmful alcohol and drug use, and self-harm or suicidal behavior are also expected to rise" (WHO, 2020). In fact, social isolation is also a health determinant and occurs more frequently in cities than in rural areas (The Lancet Psychiatry, 2017). Consequently, the effects of the built environment on health can be direct, for example, by providing open spaces or indirectly by influencing behaviors that impact infectious disease transmission, such as COVID-19. Recently, numerous works of literature have highlighted the importance of investigating the effects of the pandemic and various public health measures on mental health (Clothworthy et al., 2020). Therefore, understanding how the urban physical environment influences mental health is central (Adli et al., 2017; Douglas et al., 2017; Sandel, 2020). This is attributable to the fact that "Psychology transforms our understandings of how the built environment impacts people and determines our behaviour, and we provide a new foundation for planning and architecture that will promote better design, health, and community welfare" (Hollander and Sussman, 2020, p.1).

According to WHO (2018), mental health is a state of well-being in which an individual realises their abilities, can cope with the normal stresses of life, can work productively, and can contribute to their community. As such, mental health is an individual's ability to think, interact with communities, and earn a living. Meanwhile, mental disorder refers to a wide range of mental health conditions where it affects an individual's mood, thinking, and behaviour (WHO, 2022). Examples of mental disorders include depression, anxiety, stress, and other trauma-related disorders. However, mental health becomes a mental illness when ongoing signs and symptoms cause constant stress and affect an individual's ability to function (Mayo, n.d.).

The increased number of people with mental health problems during the COVID-19 pandemic is worsening alongside the increasing number of suicide cases and suicidal attempts. According to Salleh (2018), "With the current prevalence of 29.2%, every three in ten adults aged 16 years and above will have some sort of mental health problem(s) in the course of their lives. This indicates that 4.2 million out of 14.4 million Malaysians aged 16 and above will suffer from a form of mental illness." The National Health and Morbidity Survey 2019 reported that the prevalence of depression is 2.4% of adults, which is more than 500,000 population in Malaysia. Moreover, Bernama (2019) stated, "Despite calls to focus on rising mental health issues in Malaysia, no further action seemed to be taken to deal with the growing mental health issues in the country."

Psychological causes are defined in this research as the mental disorder symptoms of stress, depression and anxiety, but not psychiatric conditions such as schizophrenia disorders and bipolar disorder (WHO, 2014). Notably, urban planning is one of the potential determinants of psychological causes (Sarkar & Webster, 2017). In fact, Helbich (2018) claimed that "It is increasingly recognized that mental disorders are affected by both personal characteristics and environmental exposures." This suggests that open space may have direct and indirect effects on mental health that may contribute to mental health well-being decline due to the COVID-19 crisis. Hence, it is plausible that these fields influence each other over time, and understanding this sequencing is vital for understanding their relationships (Krabbendam et al., 2020).

The impact of the environment on health has been widely assessed; however, little is known about the impact of open space on the mental health of urban populations (Krabbendam, 2020; Moustaid et al., 2020; Gruebner et al., 2017; Sarkar & Webster, 2017). Helbich's (2018) phrased, "The environmental context affects people's mental health," informs the idea that the environment can also present devastating consequences for people's mental well-being. Furthermore, Douglas et al. (2017) claimed that "Urban policy has failed to provide specific design guidance for health and well-being." According to Kwon (2016), "Addressing the link is increasingly urgent… [due] to the proportions of people living in cities will rise from 54% of the world's population in 2014 to 66% by 2050." Accordingly, the high concentration of people and activity has made the residents vulnerable to various stressors, such as natural and man-made disasters, including disease outbreaks. Reflecting on this, it is worth quoting Moustaid et al. (2020) at length:

> "The study of urban mental health is shifting from a view where mental health planning and strategy is one that is the responsibility of healthcare provision systems to a problem where different systems covering different domains intersect and interact. Consequently, achieving a city with an excellent mental health status is a wicked problem that needs the exploration of the city structures…[and] need a careful investigation to bring answers to today's challenges in mental health."

According to Gruebner et al. (2017), greater access to urban parks and natural settings for urban residents and better walkability to open areas are associated with less depression and increased physical activity that promotes health. Meanwhile, Giles-Corti et al. (2015) stated that access and high-quality public open spaces with various supportive infrastructure that meets the needs of multiple user groups are good for mental health. The recreational aspects of well-maintained urban open spaces, such as urban gathering spaces, are linked to mental

well-being and have restorative potential (Gruebner et al., 2017). In addition, McCay (2017) stated that activity is one of the most critical design opportunities for mental health since exercise is effective as an anti-depressant medication for mild and moderate depression and can reduce stress and anxiety. However, urban dwellers still struggle to incorporate exercise into their daily routines. Thus, open public spaces or green spaces have become crucial as they are spaces for physical and social activities. Moreover, the presence of more open water and forests is linked to a lower spread of COVID-19 and fewer deaths (Li & Managi, 2023). During the pandemic outbreak, Poortinga et al. (2021) reported that access to public and private green spaces found that public open spaces for households that do not have private green spaces are essential and result in better health and well-being.

METHOD

This study focused on the psychological impact of open spaces on urban dwellers. A set of Urban Mental Health Questionnaires (UMHQ-DASS21) survey was used for the study to help inform further intervention in relation to the open spaces (Marzukhi et al., 2020). The questionnaires combine the General Health Questionnaire (GHQ-12) and the Depression, Anxiety, and Stress Scale (DASS-21). This questionnaire survey form was adapted from shorter questions of DASS-21, which initially consisted of 21 questions. The modification and adaptation of DASS-21 were conducted to suit the survey with the characteristics and environment variables of the neighbourhood area, home, and green spaces. The questionnaire consists of two sections: the first is on the respondents' demographic profile, and the second consists of the DASS-21 questions. All questions are compulsory for the respondents to answer.

The psychological impact was measured based on the perception of the residents in the study areas, i.e., PPR Pantai Ria, Lembah Pantai, Federal Territory of Kuala Lumpur. Stratified random sampling for a total of 241 samples (i.e., general residents, which may include participants with or without psychotic symptoms) was carried out with 95% confidence intervals and 5% margin of error for the selected areas in the Federal Territory of Kuala Lumpur. Sampling was conducted in the selected areas based on their classification as COVID-19 red zone areas. It represented the main aspects of the urban profile, namely, the location of an open space area. The questionnaire survey is stratified to represent the total population based on gender, age, education level, and activity status (including recent life events). The data were analyzed using the SPSS software.

Study Area

The district of Lembah Pantai in the federal territory of Kuala Lumpur has been classified as a COVID-19 'red zone' with 628 cases in April 2020 (Bernama, 2020). PPR Pantai Ria is a low-cost flat located in Pantai Dalam. It was selected due to the minimal provision of facilities and the lack of open spaces. The area is within the administrative boundary of Kuala Lumpur City Hall (DBKL). Figure 1 displays the satellite image of the study area in Kuala Lumpur city. PPR Pantai Ria consisted of four buildings, namely, Block A, B, C, and D, with a total of 1,264 residential units.

Source: Google (2023)

Figure 1. Satellite Image of The Study Area in Kuala Lumpur City

The total sample size is 257; however, the collected data is 241 samples, which is 94% of the data collected from the study areas. The 241 samples excluded non-response and incomplete questionnaire answers that could not be used for data analysis. Of the 241 respondents, 111 are male (46.3%), and 130 are female (53.7%). The background of the respondents is summarised in Table 1.

Table 1. Background of Respondents

Variables		Gender		Total
		Male (%)	Female (%)	
Age	15 – 24 years old	3.9	3.9	7.8
	25 – 34 years old	9.4	12.5	21.9
	35 – 44 years old	11.4	13.0	24.4
	45 – 54 years old	9.2	14.4	23.6
	55 – 64 years old	6.6	6.9	13.5
	Above 65 years old	5.8	3.0	8.8
Employment Status	Employed	34.6	15.2	49.9
	Student	2.2	2.2	4.4
	Housewife	-	31.3	31.3
	Unemployed	9.4	5.0	14.4
Household Income	Below RM 1,000	17.2	21.6	38.8
	RM 1,001 – RM 3,000	28.0	30.7	58.7
	RM 3,001 – RM 6,000	1.1	1.4	2.5

Method of Analysis

The data were analysed using the Frequency, Cross-tabulation, and Correlation tests as provided in the Statistical Package for Social Science (SPSS) software. The purpose of the analysis is to determine the magnitude of psychological causes (depression, anxiety, and stress) and the associated factors of open spaces among an urban population who has been exposed to COVID-19.

RESULTS AND DISCUSSION

The questionnaire was mainly used to assess the respondent's depression, anxiety, and stress level results. The results of UMHQ-DASS21 are self-reporting reports of the respondents for depression, anxiety, and stress (Fang et al., 2023). Based on the UMHQ-DASS21 scales questionnaire, one's mental health condition can be analysed based on the symptoms. The overall results of the UMHQ-DASS21 scores for the study areas were discussed in general in this section.

Respondent's Perception of Open Spaces

A home or neighbourhood acts as a shelter or place to release fatigue and stress. However, when people cannot rest or experience a positive feeling in their home or living area, they will seek an alternative to release stress and fatigue. The most common places are open spaces. Nevertheless, common problems for people with mental health problems, especially anxiety, will avoid crowded places due to their disorders. However, this focused on the person with the disorders and on those without disorders who may have poor mental health due to a lack of places and spaces that are suitable for them to release stress and fatigue.

Most respondents agreed that open spaces could help them to wind down easily for a good part of their time, which is 48.8%. A total of 33.9% of the respondents have also reported that they usually wind down easily in open spaces. Only 6.6% did not agree that open spaces can help them wind down when they have stress or fatigue.

Table 2. Respondents Find It Easy to Wind Down in Open Spaces

Scales	Nos	Percentage
Did not apply to me at all	16	6.6
Applied to me some of the time	26	10.7
Applied to me a good part of the time	118	48.8
Applied to me most of the time	82	33.9
Total	241	100.0

The respondents also questioned whether they tend to overreact to a situation in open spaces since they are typically crowded. Based on the survey, 32.2% of the respondents stated that they tend not to overreact to a situation in open spaces some of the time. Meanwhile, respondents who demonstrate a high percentage of not overreacting to a situation in open spaces is 56.2%.

Table 3. Respondents Tend to Overreact to A Situation in Open Spaces

Scales	Nos	Percentage
Did not apply to me at all	136	56.2
Applied to me some of the time	78	32.2
Applied to me a good part of the time	17	7.4
Applied to me most of the time	10	4.1
Total	241	100.0

This tendency is related to the respondents feeling worried about situations that make them panic and fool themselves in public spaces. This behaviour is one of the anxiety symptoms that causes anxiety attacks when facing an unpredictable situation. They are

worried about the situation and try to avoid going to open spaces. Based on the survey, only 4.1% of the total respondents are worried that they might panic and make a fool of themselves when there is a situation in open spaces.

Table 4. Respondents Worried About Being Panicked About a Situation in Open Spaces

Scales	Nos	Percentage
Did not apply to me at all	90	37.2
Applied to me some of the time	86	35.5
Applied to me a good part of the time	61	25.6
Applied to me most of the time	4	1.7
Total	241	100.0

Based on Table 4, 37.2% of the respondents are worried that they might panic and make a fool of themselves in open spaces if a situation occurs at some point in time. The highest percentage of respondents who panicked and made a fool of themselves in a situation in open spaces for a good part of the time is 25.6%. However, only 1.7% of the respondents worried that they might panic and make a fool of themselves during a situation in open spaces most of the time. People with anxiety will always worry over something that has not yet happened and overthink it. Moreover, people with anxiety will mostly avoid open spaces, especially crowded spaces, since these spaces trigger negative feelings, and they worry about possible situations.

Table 5 provides the percentage of respondents in each area who feel scared in public spaces without good reason. In addition to feeling worried about panicking and making a fool of themselves in open spaces, 11.6% of the respondents also felt scared without any good reason when they were in open spaces. Meanwhile, 67.9% of respondents did not feel scared without a good reason when they were in open spaces. This behaviour is a symptom that indicates that the respondents might experience anxiety disorders.

Table 5. Respondent's Feeling Scared Without Any Good Reason in Open Spaces

Scales	Nos	Percentage
Did not apply to me at all	152	67.9
Applied to me some of the time	62	25.6
Applied to me a good part of the time	27	11.6
Applied to me most of the time	-	-
Total	241	100.0

Psychology Impact Factors and The Correlation Analysis

Table 6. Respondents Worried About The Situation and Might Panic When in Open Spaces With A Psychological Impact (Depression, Anxiety, Stress)

Variables	Spearman's Correlation		
	Depression	Anxiety	Stress
Coefficient (r)	0.356**	0.521**	0.412**

The correlation analysis for depression establishes a relationship between being worried about the situation and panic when in public spaces and depression. Thus, the null hypothesis (H0) has no relationship between worry about the situation and panic in public spaces and depression. The results reject the null hypothesis.

Hence, the alternative hypothesis (H1) worried about the situation and panic in public spaces are related to depression in PPR Pantai Ria. Respondents who are worried about the situation and might panic when they are in public spaces and who are depressed are statistically significant at 0.01 level.

As for the correlation analysis, finding the possible relationship between anxiety and the respondents' worries about the situation might cause panic when in open spaces. The null hypothesis (H0) is that there is no relationship between anxiety and the respondents who are worried about the situation and who might panic in open spaces. According to Table 6, the null hypothesis is rejected for the study area. The respondents who were worried about the situation and might panic in open spaces presented a significant value of 0.01. The study area has a strong two-way correlation.

The correlation analysis for stress reports that respondents are worried about the situation and might panic when in public spaces and stress. Thus, the null hypothesis (H0) suggests no relationship between worrying about the situation and panicking in open spaces and stress. The results reject the null hypothesis for the study area. Hence, the alternative hypothesis (H1) worried about the situation and panicking in open spaces related to stress. The feelings of worry about the situation, panic in open spaces, and stress in PPR Pantai Ria are significant at 0.01. The study area indicates a two-way medium correlation. However, no evidence in the sample suggests a relationship between stress and the respondent's worries about the situation and panic in open spaces. As such, the respondents being worried about a situation and panicking when in open spaces can be associated with depression, anxiety, and stress.

Table 7. Worrying About A Situation and Panic in Open Spaces Relationship With A Psychological Impact (Depression, Anxiety, Stress)

Variables	Spearman's Correlation		
	Depression	**Anxiety**	**Stress**
Coefficient (r)	0.273**	0.441**	0.241**

The correlation analysis for depression discovers a weak relationship between worrying about a situation and panicking in open spaces and depression. Thus, the null hypothesis (H0) indicates no relationship between worrying about a situation and panic in open spaces and depression in PPR Pantai Ria. Based on the results, the null hypothesis is rejected. Hence, there is an association between worrying about a situation and panicking in open spaces and depression in the study area. The results demonstrate a significant level of 0.01 with a two-tailed correlation between worrying about a situation and panicking in open spaces. This result reveals that worrying about a situation and panic in open spaces are associated with depression in two ways.

The correlation analysis of anxiety and worrying about a situation and panic in open spaces is conducted to search for any possibility in the relationship. The null hypothesis (H0) suggests no relationship between anxiety and worrying about a situation that might cause panic in open spaces. According to Table 7, the null hypothesis is rejected. The correlation reveals a significant 0.01 value with a medium two-tailed correlation in the sample, indicating the relationship between worrying about a situation and panicking in open spaces and anxiety. This result indicates that worrying about a situation and panic in open spaces affect anxiety.

The correlation analysis for stress finds the relationship between worrying about a situation and panic in open spaces and stress. Thus, the null hypothesis (H0) is that there is no relationship between worrying about a situation and panicking in open spaces and stress. Based on the results, the null hypothesis is rejected. Hence, there is an association between worrying about a situation and panicking in open spaces and stress in PPR Pantai Ria. The correlation presents a significant level at 0.01 with a two-tailed small correlation. This result reveals that worrying about a situation and panicking in open spaces affect stress in a two-way relationship.

One of the anxiety symptoms is overthinking. A person who has anxiety always worries about a situation that has yet to occur and worries that they might panic when a situation happens. Based on the worry about a situation and panicking in open spaces, depression, anxiety, and stress significantly correlated at the 0.01 level and in two ways. The findings suggest that anxiety has a medium correlation; meanwhile, depression and stress have a small correlation value. From the findings, a person who feels worried about a situation and might panic in open spaces in the study area has a medium correlation and is not the main factor for anxiety.

Table 8. Feeling Scared Without Good Reason in Open Spaces Relationship with A Psychological Impact (Depression, Anxiety, Stress)

Variables	Spearman's Correlation		
	Depression	Anxiety	Stress
Coefficient (r)	0.341**	0.586**	0.586**

The correlation analysis for depression indicates a relationship between feeling scared without a good reason in open spaces and depression. Thus, the null hypothesis (H0) is that there is no relationship between feeling scared without a good reason in open spaces and depression in PPR Pantai Ria. Based on the results, the null hypothesis was rejected. Hence, there is an association between feeling scared without a good reason in open spaces and depression in Kuala Lumpur. The results present a significant level of 0.01 with a medium two-tailed correlation between feeling scared without any good reason in open spaces and depression. The result reveals that feeling scared without any good reason in open spaces affects depression.

As for the correlation analysis of feeling scared without any good reason in open spaces, it is conducted to examine a possible relationship with anxiety. The null hypothesis (H0) is that there is no relationship between anxiety and feeling scared without any good reason in open spaces. According to Table 8, the null hypothesis is rejected. The correlation presents a significant 0.01 value with a strong two-tailed correlation in the sample, suggesting the relationship between feeling scared without good reason in open spaces and anxiety. This result suggests that feeling scared without a good reason in open spaces affects anxiety.

The correlation analysis for stress finds a relationship between feeling scared without any good reason in open spaces and stress. Thus, the null hypothesis (H0) is that there is no relationship between feeling scared without a good reason in open spaces and stress in PPR Pantai Ria. Based on the results, the null hypothesis is rejected. Hence, there is an association between feeling scared without a good reason in open spaces and stress in the study area. The correlation exhibits a significant level at 0.01 with a two-tailed medium correlation. This

suggests that feeling scared without a good reason in open spaces affects stress in a two-way relationship.

This analysis is very similar to the previous one, except that the setting has changed. A person with anxiety would usually have problems socialising or being in crowded places or public spaces. The result suggests that depression, anxiety, and stress have a very significant value of 0.01. However, anxiety also demonstrates a strong correlation with this action. The results also reveal a medium correlation between depression and stress. The results are almost similar to the previous analysis, although the correlation of depression is slightly lower than in the previous analysis. This result also has the probability of a person feeling scared without a good reason when they are in open spaces, which is a sign of anxiety and could cause depression and stress.

CONCLUSION

Psychological well-being is crucial as it affects a person's everyday life routine. Mental health problems are non-communicable diseases and cannot be observed, albeit being diagnosed with them (Huppert, 2009; Stein et al., 2019). Notably, many factors can contribute to mental health problems and cause them to worsen in a person. The finding of the respondent survey reveals that most respondents demonstrate the symptomatology of depression, anxiety, and stress based on the perception of open spaces. Meanwhile, the correlation analysis demonstrates a high correlation between the respondents' psychological aspects and open spaces. Moreover, it is reported that unsafe neighbourhood area creates insecurities in the residents and create a negative feeling toward their living environment, which can be associated with depression symptoms. However, high-density housing, especially public housing in the urban area, could not be avoided due to land and construction costs. Thus, the provision of open spaces, green spaces, and facilities should focus on the residents' usage, and the location should be safe and within a walkable distance.

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CLAY SOIL IMPROVEMENT USING COCONUT COIR FIBRE AS A REINFORCEMENT

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Abstract
In Malaysia, geotechnical failures are among the biggest issues with design and building operations. This is due to the strength and bearing capacity of typical soil that might be highly loose and weak. One way of improving the soil strength is by using the Reinforced Soil Technique. Studies into preserving and improving the quality of this sort of soil are required in achieving a more effective and cost-efficient solution. Past studies found that clay soil can be strengthened by adding tiny amounts of coconut coir fibre which then has improved many engineering qualities of the soil and generated a better construction material. This study describes the performance of coconut coir fibre combined with clay soil. The clay soil was reinforced with coconut coir fibre with the following percentages: 0.25%, 0.50%, 0.75%, 1%, and 1.25%. The effect of the coconut coir fibre as a reinforcing material prepared at Optimal Moisture Content was (OMC = 15.49%) and Maximum Dry Density was (MDD = 1.86/cm^3) at various fibre percentages. The findings reveal that increasing the coconut coir fibre content increases the soil's maximum dry density and decreases the optimal water content. And optimum moisture content is best achieved with 1.00% of coconut coir fibre added to the 7-day clay soil curing testing as compared to the non-curing testing of the Standard Proctor Test. According to the results of the Unconfined Compression Test (UCT) for soil samples, the unconfined compressive strength has increased at best with 1.00% of coconut coir fibre added to clay soil. Overall, employing coconut coir fibre to reinforce clay soil is a smart ground improvement approach that can help to create a more sustainable environment for the geotechnical world.

Keywords: *Weak soil; Coconut coir fibre; Clay soil reinforcement; Sustainable environment; Ground improvement technique*

INTRODUCTION

Sustainability in soil has been crucial for maintaining the environment and ecosystems for centuries. Current soil stabilization methods have improved with the addition of ash and lime mixtures, but a standardized indicator of soil health has yet to be established. Das et al. (2016) found that using coconut coir fibre as a reinforcement method can effectively strengthen soil. The coconut coir fibre industry utilizes the fibrous husk of coconut fruit, which contains lignin – a hard natural fibre that enhances soil stability, strengthens it, and reduces erosion. These fibres are hygroscopic, retaining 10% to 12% of their weight in water at 65% relative humidity and 22% to 55% at 95% relative humidity. According to Cornu et al. (2020), soils play critical roles in major ecosystem services. This has prompted the present study, to investigate the use of coconut coir fibre as a reinforcement material for soil improvement in a tropical country like Malaysia.

This study emphasizes the importance of understanding and enhancing subsurface properties in limestone formations, particularly in the Batu Caves region. This area is characterized by complex geological features, including fractures, cavities, and variations in

material composition. A major challenge lies in accurately interpreting and validating geophysical data, such as seismic wave refraction results. The inherent variability of limestone complicates subsurface mapping and reduces the effectiveness of traditional methods. To address these challenges, integrating laboratory analyses of limestone samples with geophysical data is essential for improving subsurface characterization, especially in engineering and construction projects.

This aligns with broader challenges in geotechnical engineering highlighted by Kumar et al. (2022) and Veershetty et al. (2022), the importance of validating soil stabilization techniques with field and laboratory results to address complex ground condition. Sujata et al. (2017) noted the need for accurate evaluation methods to enhance the understanding of soil behaviour in compressible environments. These past studies emphasized the need to integrate diverse data sources to enhance the interpretation and application of subsurface engineering solutions.

Hence, the objectives of the research are to determine the properties of soil samples tested, to determine the effects of coconut coir fibres on soil strength behaviour using Standard Proctor Test and Unconfined Compressive Test (UCT), and to determine the optimum percentage of coconut coir fibre for soil strength behaviour. This research was conducted by preparing samples, administering various tests, and collecting data in Universiti Teknologi MARA Shah Alam.

METHODOLOGY

The study aims to evaluate the effectiveness of coconut coir fibre as a soil adjustment for improving clay soil quality. It involves collecting soil samples from Kampung Bukit Kapar, 42200 Kapar, Selangor, and procuring coconut coir fibre from Glorious Nursery, Subang Jaya. A total of six samples were tested according to sample preparation and specified laboratory testing as indicated in Table 1 to find the index values of soil and the strength testing.

Table 1. Summary Sample Preparation of Clay Soil with Coconut Coir Fibre

Batch	Clay Soil Sample with Fibre (%)	Testing
1	No fibre	• Moisture Conte • Particle Size Distribution Test • Specific Gravity • Liquid Limit Test • Plastic Limit Test • Standard ProctorCompaction Test • Unconfined Compressive Strength Test
2	0.25% Coconut Coir	• Standard Proctor Compaction Test • Unconfined Compressive Strength Test
3	0.50% Coconut Coir	
4	0.75% Coconut Coir	
5	1.00% Coconut Coir	
6	1.25% Coconut Coir	

Materials

This research gathered a sample of clay soil from a construction site in Kapar, Selangor. In this study, coconut coir fibres were added to clay soil at various percentages ranging from

0 to 1.25 percent (%). This investigation focussed on two primary materials, which were clay soil and coconut coir fibre. Clay soil is a natural substance composed of fine-grained clay minerals that exhibits adhesive properties when exposed to water in which the particle size, shape, and moisture content influence its elasticity. Clay particles that are smaller than 0.002mm in diameter are classified as clay. Due to their sensitivity to moisture fluctuations, soils with a high silt content can be challenging to stabilize.

Data Collection

To investigate the impact of coconut coir fibre-reinforced soil, a series of thorough experiments were conducted as part of the data collection methodology. The Specific Gravity Test was conducted with a pycnometer to determine the specific gravity (Gs) of the soil at 20°C. Following BS 1377: Part 2: 1990 guidelines, the Atterberg limit test determined the liquid limit (LL) and plastic limit (PL) of the clay soil. The PL test consisted of compacting soil particles to a diameter of 3 mm and measuring the moisture content upon disintegrating. Standard Proctor compaction experiments determined the maximum dry density (MDD) and optimal moisture content (OMC) of the soil. Compaction moulds were then constructed, and soil samples with varying moisture contents were compacted to achieve the desired compaction energy. According to BS1377: Part 7:1990, the unconfined compressive strength test evaluated the soil's strength properties under undrained conditions. The unconfined compressive strength (qu) was determined by plotting stress-to-axial strain relationships and dividing the maximal axial load (P) by the cross-sectional area (A) of the soil sample. By utilising computerised devices for the automated testing, the study had generated accurate and reliable data. These tests provided valuable insights into the behaviour of coconut coir-reinforced clay soil.

Data Analysis

The research employed tabulation techniques, such as tables and graphs, to systematically organize numerical data and support statistical analysis. This approach ensures effective data interpretation and validation of the findings. Graphical representations, in particular, facilitate visual comparisons, especially between reinforced and unreinforced soil.

RESULTS

Soil Index Testing

Three tests are required to determine the Soil Index for clay soil, which are the Sieve Analysis Test, the Specific Gravity Test, and the Atterberg Limit Test (including the Liquid Limit Test and the Plastic Limit Test).

Table 2 confirms that the soil type is clay with high plasticity. The Sieve Analysis Test showed the particle size distribution, revealing 60% clay particles, 2% sand particles (0.06 to 2 mm), 38% silt particles, and no gravel particles. It was found that, fine-grained clay contributed to the high plasticity of the soil. Meanwhile the Specific Gravity Test assessed the ratio of soil particle weight to water volume and provided insights into soil density and permeability. Then the Atterberg Limit Test that includes both the Liquid Limit and Plastic Limit evaluations. At 78% moisture, the soil changed from plastic to liquid, and from

malleable to solid at 23% moisture. The difference between the Liquid Limit and Plastic Limit, known as the Plasticity Index (PI), was at 23%, indicating the soil's adaptability to varying levels of moisture. The soil sample had a moisture content of 28.24%, which reflected its water content relative to its dried weight. This soil was identified as Clay Soil due to its high clay content and adaptability. The result presented in Table 2 is useful in deciding the engineering properties and suitability of clay soil for various geotechnical and construction projects. Thus, understanding soil behaviour is essential for effective and sustainable construction practices.

Table 2. Soil Index Properties

Description	Soil Index Values
Particle Size Distribution Gravel (>2 mm) Sand (0.06 – 2mm) Silt (<0.06 mm) Clay	0 % 2 % 38 % 60 %
Specific gravity	2.6
Liquid Limit LL (%)	97 %
Plastic Limit PL (%)	44 %
Plasticity Index PI (%)	53 %
Moisture Content	78 %
Soil Classification	Clay Soil with High Plasticity

Standard Proctor Test

A soil sample was air- dried, and varying amounts of water were added to attain various moisture contents by using the Part 4:1990 of BS 1377 test. In a mould, these samples were then compacted using a specific energy. After compaction, the desiccated density of each specimen was determined. The test results for two soil samples; one without additives and one with coconut coir, revealed values for optimum moisture content (OMC), maximum dry density (MDD), and corresponding water and fibre content.

Table 3. Standard Proctor Test Values for Optimum Moisture Content

No. Sample	Water Content (%)	OMC (%)	MDD (%)
1	7	6.60	1.62
2	10	8.60	1.69
3	13	10.78	1.86
4	16	13.60	1.85
5	19	15.49	1.86
6	22	17.98	1.80

The above Table 3 illustrates a good correlation between the water content and the optimum moisture content (OMC) of the samples. There was an increase in water content from sample 1 to sample 6 that resulted in a gradual increase in the OMC and indicated the optimum moisture content for the clay soil. The results indicated that the soil's compaction

and attainment of optimal density were enhanced as the moisture content rose to a specific threshold. However, it was also found that, once the water content reached to a certain level, the optimum moisture content (OMC) remained stable, suggesting that additional moisture may not substantially enhance compaction.

Table 4. Standard Proctor Test Values for Soil Added with Coconut Coir

No. Sample	Fibre Content (%)	OMC (%)	MDD (%)
1	0.00	16.16	1.98
2	0.25	17.49	1.87
3	0.50	18.49	1.85
4	0.75	19.35	1.92
5	1.00	20.26	2.02
6	1.25	19.81	2.00

Table 4 presents the results of the Standard Proctor Test on soil samples with varying coconut coir fibre amounts (0.0% to 1.25%). The data revealed a direct correlation between coconut coir fibre content and optimum moisture content (OMC) and maximum dry density (MDD). Samples with higher coir content showed increased OMC and MDD values. Notably, sample 5 with 1.00% coir had the highest OMC (20.26%) and MDD values (2.02%). These findings highlight how coconut coir fibre influenced soil properties, with optimal percentages leading to enhanced soil behaviour and density.

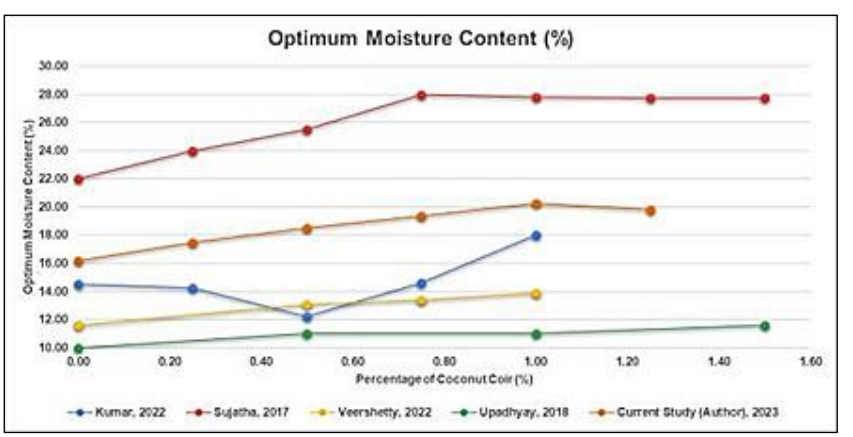

Figure 1. Graph of Optimum Moisture Content values (%) for Clay Soil Reinforced with Coconut Coir Fibre Between Current Study and Previous Research

Figure 1 provides a detailed analysis of the percentage of coconut coir fibre incorporated into clay soil and the optimal moisture content corresponding to that percentage in comparison of past and current studies. Kumar et al. (2022) found that optimal moisture content fluctuated as coconut coir fibre content increased in which the optimal moisture content was 14.53% when at 0% coconut coir fibre. With an increased fibre content of 0.50%, however, there was a noticeable reduction to 12.25%. Surprisingly, the optimal moisture content increased to 18.00% at 1.00% coconut coir fibre content. On the other hand, Sujata et al. (2017) suggested that an exhaustive investigation found a positive correlation between fibre content and optimal moisture content. The optimal moisture content rose from 22.00% at 0.00% coconut coir fibre to 278.00% at 1.00% coconut coir fibre. Veershetty et al. (2022) also discovered a positive correlation, with optimal moisture content ranging between 11.60% and 13.90% as the

coconut coir fibre content varied from 0.00% to 1.00%. Upadhyay and Singh (2017) in contrast, reported consistent optimal moisture content values ranging from 10.00% to 11.60% across all coconut coir fibre content levels. Notably, the presence of 1.25% coconut coir fibre resulted in a moisture content of 19.81%, signifying a threshold above which the moisture content stabilises.

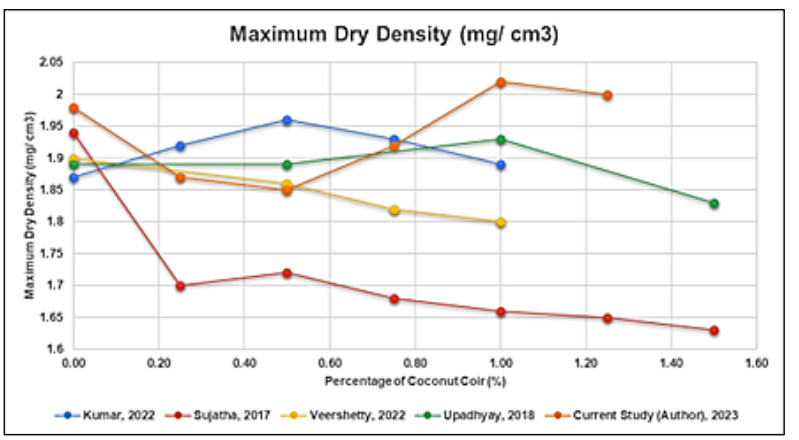

Figure 2. Graph of Maximum Dry Density Values (%) for Clay Soil Reinforced with Coconut Coir Fibre Between Current Study and Previous Research

Figure 2 demonstrates a wide range of maximum dry density values and fibre content levels across the investigations in comparison of past and current studies. The maximum dry density increased from 1.87 mg/cm^3 at 0% coconut coir fibre content to 1.96 mg/cm^3 at 0.50% coconut coir fibre content, followed by a modest decrease to 1.93 mg/cm^3 at 0.75% coconut coir fibre content and 1.89 mg/cm^3 at 1.00% coconut coir fibre content. In contrast, Sujata et al. (2017) found a negative correlation between the proportion of coconut coir fibre and the maximal dry density, indicating a decreasing trend. For an example, the maximal dry density decreased from 1.94 mg/cm^3 at 0% coconut coir fibre content to 1.66 mg/cm^3 at 1.00% coconut coir fibre content and then to 1.63 mg/cm^3 at 1.50% coconut coir fibre content. Similarly, Veershetty et al. (2022) discovered a similar finding to Sujata's. In contrast, Upadhyay and Singh (2017) observed relatively consistent maximum dry density values spanning from 1.89 mg/cm^3 to 1.93 mg/cm^3 for various fibre content levels.

Ultimately, among the results from the Standard Proctor Test, sample 5 in Table 4 showed the most significant and optimum value. With the coconut coir fibre content of 1.00%, the optimum moisture content (OMC) was 20.26% and its maximum dry density (MDD) was 2.02%. The increased OMC suggested that the incorporation of 1.00% coconut coir fibre into the soil increased its water retention capacity. In addition, the improved MDD value indicates that the presence of coconut coir fibre positively impacts the soil's compaction behaviour, leading to a denser and more stable soil structure.

Unconfined Compressive Test

The Unconfined Compression Test involved the measurement of strain, stress, and compressive strength for each sample. Table 5 presents the results of the Unconfined Compression Test conducted on samples with varying ratios of coconut coir fibre, subjected to different curing periods.

Table 5. Unconfined Compression Test Values

Curing Period	Percentage of Coconut Coir Fibre Added (%)	Strain (%)	Stress (kPa)	Compressive Strength (kPa)
0 days (Instant Testing)	0.00	7.97	126	63
	0.25	7.97	160	80
	0.50	9.95	194.1	106
	0.75	10.85	259	130
	1.00	11.94	334	167
	1.25	15.02	150	75
7 days	0.00	8.5	90	72
	0.25	9.38	97	49
	0.50	10.51	217	108
	0.75	11.53	380	190
	1.00	17.03	411	205
	1.25	18	444	222

The data presented in Figure 3 and Figure 4 present shear strength values of investigations conducted by different curing days and the latter on the findings of various researchers. Shear strength measurements were conducted on specimens containing varying proportions of an undisclosed substance.

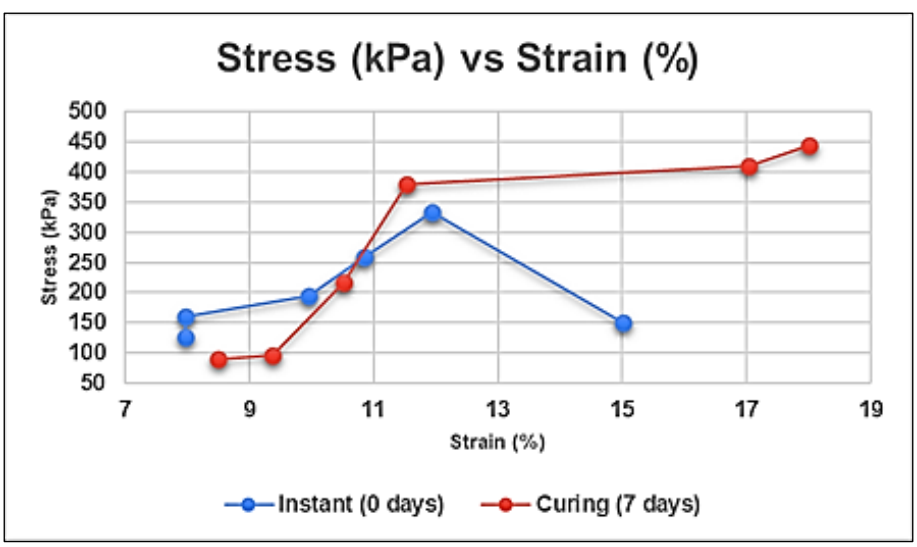

Figure 3. Graph of Stress Vs Strain Values for Instant and 7 Days Curing of UCT Test

The information presented in both Figures 3 and 4, depict shear strength values derived from a variety of investigations conducted on various curing days and the findings from multiple researchers. Kumar et al. (2022) indicated that increasing the percentage of the substance from 0% to 0.75 % caused an initial increase in shear strength from 20.59 kPa to 37.27 kPa, followed by a reduction to 33.34 kPa at 0.75 % coconut coir fibre content. Singh and Mittal (2014) demonstrated a discernible upward trend in the shear strength values when the substance was added. In particular, Widianti et al. (2021) examined the substance and discovered comparable patterns where the shear strength consistently increased from 269.68 kPa to 620.76 kPa as the percentage of the substance increased from 0.00% to 1.00%. Similarly, Lakshmi et al. (2018), demonstrated a similar pattern of the results indicating that

there was a positive correlation between substance concentration and shear strength. As the substance content increased from 0.00% to 1.00%, the shear strength steadily increased from 41.7 kPa to 86.1 kPa. An increase in substance content from 0% to 1.50 % was associated with a progressive increase in shear strength from 89.94 kPa to 132.59 kPa, except for a small decrease at 1.50 %. As a result, it was evident that the shear strength values increased generally after the curing period. This suggests that the material could potentially exhibit enhanced adhesive or densification properties as time passes.

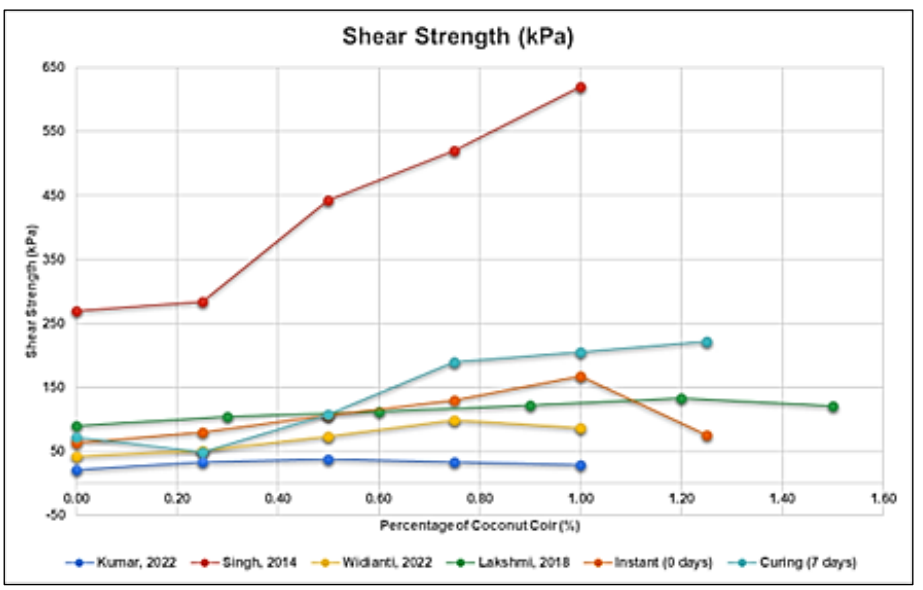

Figure 4. Graph of Shear Strength Values of UCT Test Between Current Study and Previous Research

CONCLUSION

Laboratory experiments revealed that incorporating coconut coir fibres significantly altered clay soil's engineering properties, making it suitable for various geotechnical applications. In conclusion, this study concluded all objectives with the following findings:

1. With various properties testing the first objective indicated that the soil sample was clay soil with high plasticity.
2. The study explored the impact of adding coconut coir fibre (0.25% to 1.25%) to clay soil in which it increased the maximum dry density but reduced the ideal water level. The best moisture content was achieved with 1% coconut coir fibre after 7 days curing. This reinforcement improved the clay soil's strength, making geotechnical systems more sustainable within a specific percentage limit.
3. The study found that adding 1% coconut coir fibre to clay soil improved its strength and structure which further strengthened the ground and promoted sustainability in geotechnical systems. Using 1% coconut coir fibre in clay soil for 7 days also enhanced soil strength and aggregation while reducing compaction. Incorporating coconut coir fibre into samples can enhance mechanical properties, resulting in stronger and more stable engineering and construction materials.

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EVALUATION PHYSICAL, CHEMICAL AND MECHANICAL PROPERTIES OF GIGANTOCHLOA SCORTECHINII FOR COMPOSITE MATERIALS

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Abstract
The growing demand for environmentally friendly products is driven by concerns about global climate change and sustainable development. In this context, natural fibres and culm from bamboo plants are gaining attention as substitutes for synthetic fibres in composite material production. Bamboo, with its rapid growth and abundance in Malaysia's tropical rainforests, shows significant promise. However, the commercialization of bamboo in Malaysia is limited by insufficient information on its properties, genetics, and resources. Accurately characterizing bamboo's properties, focusing on culm and species, is crucial for assessing fibre quality and determining suitability for specific products. This research aims to determine the physical, chemical, and mechanical properties of various parts along the culm of Gigantochloa Scortechinii (Buluh Semantan) species, establishing criteria for composite materials. A sample of the G. Scortechinii species was found in Royal Belum State Park for this research. Experiments on bamboo fibre and culm were conducted based on ISO 22157 and TAPPI standards. The results showed that bamboo fibre from the top of the culm exhibited superior mechanical strength, lower moisture content, and higher density compared to the middle and basal portions due to higher lignin content. These findings provide valuable information for assessing the potential of G. Scortechinii as a composite material in the construction sector.

Keywords: *Natural fibre; Bamboo; Composite materials; Gigantochloa Scortechinii; Material properties*

INTRODUCTION

Bamboos have gained attention in recent years because of the fabrication of sustainable bamboo fibre-reinforced composite materials. Aside from having outstanding material qualities, bamboos are a fast growing, inexpensive and readily available natural resource in most developing countries. Bamboos, or *Bambusa bambos*, have 7–10 subfamilies (Suhaily, Khalil, Nadirah, & Jawaid, 2013). More than 1000 different species ranging from wood type to herbs can be found in Asia and South Africa. Each species of bamboos has different properties and qualities. In Malaysia, at least 70 bamboo species belonging to 10 genera are found (S. A. H. Roslan, Rasid, & Hassan, 2018). Among the species, only 13 bamboo species can be used commercially (Abdullah Siam, Uyup, Husain, Mohmod, & Awalludin, 2019).

Bamboos are a hierarchical cellular material that has good mechanical properties (e.g. tensile and flexural strengths) along their fibre direction (Yap, Ming, King, & Israr, 2017). The interfaces between bamboos' different ingredients, including fibres, parenchyma cells and lignin matrix, have significant impact on their mechanical properties (Abdullah Siam et al., 2019). The hierarchical microstructure of bamboos arises from the vascular bundles in the parenchyma matrix that are surrounded by supporting cellulose fibres. These fibres provide the main mechanical properties of bamboos (Abdullah Siam et al., 2019; Li & Shen, 2011). Furthermore, cellulose fibres act as reinforcement to strengthen the lignin matrix, which is

similar to fibre-reinforced polymer matrix composites. Bamboos have higher mechanical properties along its fibre direction than across them (Li & Shen, 2011). The unique microstructural properties of bamboos make them a suitable renewable material for composites in high-performance applications. The density of bamboos in the outer surface is usually high and decreases towards the inner layers of the wall's cross section (Anokye, Bakar, Ratnansingam, & Awang, 2016). However, no comprehensive and systematic studies on the properties of bamboos in terms of density and culm geometry (e.g. wall thickness, culm diameter and culm height) have been established. The identification of sections with high fibre densities, which may signify superior quality in terms of physical and mechanical properties, can greatly impact the performance of fabricated composite materials (Javadian, Smith, Saeidi, & Hebel, 2019). Moreover, moisture content is an important property of raw bamboos, especially in building and construction applications and composite fabrication (Anokye et al., 2016; Zou, Wu, & Zhang, 2019). Moisture content may adversely affect the bonding strength of bamboo fibre in composite products (Zou et al., 2019). Research on the mechanical properties of hierarchical structures of raw bamboos can lead to better fabrication control and higher quality of novel bamboo-based composites. The mechanical properties along the bamboos' culm lengths may vary substantially because bamboos reach a height of 20–30 m within a few months (Javadian et al., 2019).

Malaysia's tropical rainforest areas host an abundant array of bamboo varieties, which can also be cultivated on plantations. Despite the prevalence of bamboo in forests, there is a notable dearth of exploitation and research data concerning the anatomy, as well as the physical, chemical, and mechanical properties of various bamboo varieties and age groups found in the wild, such as those in Royal Belum State Park. Understanding these bamboo properties is crucial as fibre formation differs among culms, ages, and species (Kaur, Pant, & Kaushik, 2019). Selecting the appropriate age and species of bamboo is vital as it impacts manufacturing processes, treatment techniques, and the ultimate product's use and durability (Anokye et al., 2016). The lack of comprehensive data on specific bamboo species hampers regional assessments of their properties, qualities, and distribution patterns in natural forests. This information gap makes it challenging for investors and consumers to discern the potential and derived products from a particular bamboo species. Consequently, it hinders the maximization of local bamboo resources' benefits and value for industrial applications, ultimately affecting competitiveness in the global market.

Understanding the properties of commercially valuable bamboo varieties is pivotal for reproductive biology, genetic engineering identification, and increasing bamboo yield productivity for commercial cultivation. Despite Malaysia's potential to flourish in the bamboo market, statistical data indicates that the country's bamboo industry's yield production lags significantly behind that of other nations like China, Indonesia, and Vietnam (Khalil et al., 2012; S.A.H. Roslan et al., 2015). Adequate bamboo specification data can play a vital role in identifying suitable varieties for the bamboo sector's future development. This initiative will stimulate the creation of high-yield bamboo varieties, the conservation of existing genetic materials, and encourage the responsible cultivation of bamboo on a large scale to ensure a continuous supply of bamboo in the market.

Therefore, this study aims to understand the properties of fibre-producing species of bamboo culms in the Royal Belum State Park. Specifically, the objectives of the study are to investigate the physical properties of bamboo culms, including density, moisture content, and

dimensional stability, and to assess the chemical properties such as cellulose, hemicellulose, and lignin content across different culm sections (basal, middle, and top). Additionally, the study evaluates the mechanical properties of bamboo fibres, focusing on tensile strength, elasticity, and other mechanical characteristics. By establishing the relationship between the physical and chemical properties of bamboo culms and the mechanical properties of the extracted fibres, the study seeks to better understand the hierarchical structure of bamboo culm geometries. This understanding is crucial for the synthesis of novel bamboo fibre-reinforced composite materials. Furthermore, the study highlights the specific properties of bamboo that are suitable for use in reinforced composite materials, providing insights that can guide the development of sustainable, high-performance applications in the bamboo industry.

EXPERIMENTAL PROGRAM

Sample Preparation of Bamboo

For this investigation, the bamboo species *Gigantochloa scortechinii* sourced from Royal Belum State Park in Perak was chosen. A specific bamboo culm sample was selected from a 3-year-old mature plant, and a particular length was taken. This selected sample was then divided equally into three distinct portions: basal (B), middle (M), and top (T). A total of 3 culms were used, resulting in 9 portions (3 for each section). Using a handsaw, each bamboo culm was accurately cut according to the internode lengths. Each internode was cut 20 mm upwards and 20 mm downwards from the neighboring nodes to ensure separation. Additionally, the internodes of the bamboo culms were further divided into strips using a cast iron bamboo splitter.

Fibre Preparation from Bamboo

The bamboo strips, segregated into the three designated portions, underwent an alkali treatment using a 2.5% Sodium Hydroxide (NaOH) solution for 24 hours, following established research (Jin, Zhang, & Yao, 2018). Subsequently, the fibre was manually extracted (see Figure 1). The extracted fibre was air-dried after the extraction process. Measurements of the fibre's length, diameter, and thickness were conducted using a caliper and an optical microscope. The average diameter of 20 fibres and the length of the extracted fibre, relative to the internode length, were measured and recorded in line with the methodology outlined by Abd. Latif et al. (1993).

Figure1. Extraction of Bamboo Fibre from The Bamboo Strip

Physical Testing

The physical dimensions of the bamboo culms, encompassing length, diameter, girth, and the count of internodes, were meticulously measured and documented. The method employed for fibre extraction from bamboo was adapted from a procedure proposed in prior research (Zakikhani, Zahari, Haji Hameed Sultan, & Majid, 2017). For moisture content and density determination, bamboo samples were prepared in alignment with ISO 22157 Part 1. The moisture content was assessed using specimens of approximately 25 mm x 25 mm, weighed, and subsequently oven-dried at 103 ± 2 °C for 24 hours. The moisture content was then calculated based on the mass after oven drying. For density testing, following ISO standards, specimens were prepared and weighed to 0.001g, and the volume was measured to 10 mm^3 for density calculation.

Mechanical Testing

This study encompassed three primary tests: compressive, tensile, and bending, all adhering to ISO 22157 Part 1. Testing was bifurcated and focused on both bamboo fibre and bamboo culm. For bamboo fibre, samples were extracted from the basal, middle, and top sections of the bamboo culm for tensile testing. Tensile testing for bamboo fibre was conducted using the Instron 3365 Machine at a constant rate of 5 mm/min. Figure 2 illustrates the tension test configuration, conducted in parallel to the grain of the bamboo fibre, to assess its tensile strength.

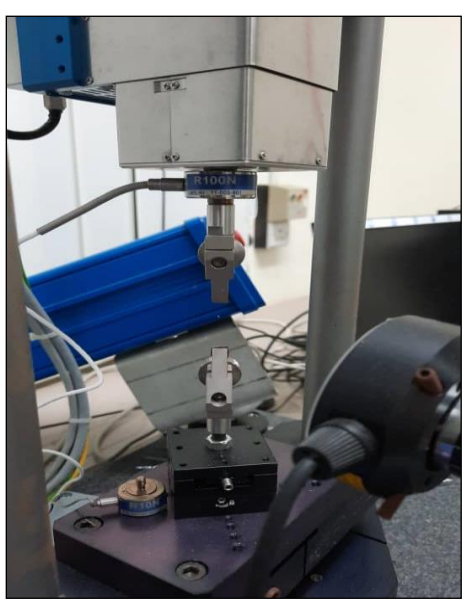

Figure 2. Instron Machine for Fibre Tensile Test

All bamboo culm specimens were categorized into basal, middle, and top sections, labelled as B, M, and T, respectively. Specimens with free nodes were chosen for compressive and tensile tests. The outer diameter and wall thickness of the bamboo specimens were measured. Subsequently, compressive tests were performed on bamboo specimens utilizing a Universal Testing Machine at a constant rate of 0.01 mm/s, as depicted in Figure 3.

Figure3. Illustrates The Setup for Conducting The Compressive Strength Test

In compliance with the ISO 22157 Part 2 standard for tensile strength testing, specimens were shaped into a 'dogbone' shape. For this investigation, the specimens were radially cut from the culm wall to form the 'dogbone' shape, with all specimens cut and processed parallel to the bamboo fibre. A 0.01 mm/s load was gradually applied to the specimens to measure their tensile strength. Figure 4 presents the tension test configuration, conducted parallel to the grain of the bamboo that was sliced into a 'dogbone' shape, and was tested for tensile strength.

Figure 4. Illustrates The Setup for Conducting The Tensile Strength Test

The bending test adhered to the procedure outlined in ISO 22157 Part 2, where the outer diameter and wall thickness were measured. The culm was positioned under the bending machine, and a load was applied at the midpoint of the upper surface of the bamboo culm, as demonstrated in Figure 5. Loading of the culm was carried out at a consistently uniform speed.

Figure 5. Illustrates The Setup For Conducting The Bending Test

Chemical Testing

Additionally, major chemical constituents of the fibre were analysed selectively from the bamboo culm with the highest mechanical properties to comprehend their characteristics. Chemical properties of the bamboo culm, including holocellulose and lignin alpha-cellulose, were determined. These chemical properties were assessed using the standard guidelines in the TAPPI test method T257. Chipped samples were dried in a 50 °C oven for 3 days. The dry material was ground into powder using a Willey mill to pass through a BS 40-mesh (425 m) filter and retained on a BS 60-mesh (250 m) sieve. In this method, the material was prepared, and holocellulose, lignin content, and alpha-cellulose were determined based on prior research (Wahab et al., 2013).

RESULTS AND DISCUSSIONS

Physical Properties

The physical properties of bamboo culm were involved in recording the dimension such as outer diameter, girth, length, number of nodes and internodes. The samples were divided into the following three 3 portions: Basal (B), Middle (M) and Top (T). The morphological characteristic of bamboo culm samples included in this study was the culm length, culm diameter, nodes and internodes in Tables 1 and 2. It is observed that the diameter of samples decreased from the bottom to the top because of a drop in wall thickness.

Table 1. Properties of Bamboo Stem

Average Length	10287 mm
Average Node	28
Average Internode	28

Table 2. Diameter and Wall Thickness of Bamboo Culm

Bamboo Section	Outer diameter	Wall thickness
Top (T)	155 mm	5.30mm
Middle (M)	230 mm	6.00mm
Basal (B)	230 mm	7.40mm

Moisture content is a pivotal factor impacting the mechanical properties of bamboo. Table 3 presents the moisture content results, classified into three sections: top, middle, and bottom parts. The findings indicated that the top portion exhibited the lowest reading at 8.55%, followed by an increase to 11.36% for the middle portion, and the bottom portion recorded a moisture content of 10.92%. Conventionally, green bamboo retains a moisture content ranging from 60% to 75%, influenced by variables such as age, season, geographical location, species, and watering practices (Wakchaure & Kute, 2012). The moisture content of a bamboo species significantly affects its applicability in material selection. Due to its internal structure, plant fibres, including bamboo, can retain water molecules (Väisänen, Das, & Tomppo, 2017). Notably, bamboo can effectively retain water, a characteristic correlated with the abundance of parenchyma cells, varying across different species (Kenneth & Uzodimma, 2021).

Table 3. Moisture Content of Bamboo Culm

Part	Moisture content (%)
Top (T)	8.55
Middle (M)	11.36
Basal (B)	10.92

Table 4 displays the density findings for the bamboo culm. The results indicate that the highest density was observed in the top section at 875 kg/m³, followed by the middle section at 820 kg/m³, and a decrease in density for the bottom section at 725 kg/m³. The elevated density in the top portion of the bamboo culm may be attributed to a notable concentration of sclerenchyma fibres (Abdullah Siam et al., 2019). The density of fibres in a bamboo shell's cross-section exhibits variations in relation to thickness and height. Across all bamboo heights, the outer layers exhibit higher specific gravity compared to the inner layers (Zakikhani et al., 2017). In bamboo, approximately 60%–70% of its weight is attributed to fibres, with the remaining comprising parenchyma, vessels, and capillaries (Nayak & Mishra, 2016). The specific gravity of bamboo typically ranges from 0.4 to 0.8, contingent upon anatomical structure and species (Wakchaure & Kute, 2012).

Table 4. Density of Bamboo Culm

Part	Density (kg/m^3)
Top (T)	875
Middle (M)	820
Basal (B)	725

Mechanical Strength Properties of Fibre

Table 5 recorded the readings tensile strength of a single *G. Scortechinii* fibre. The results show that the top part is higher than the middle part with readings of 43.83 MPa and 39.06 MPa, respectively, whereas the reading of the bottom part is reduced to 25.26 MPa. This result shows the identical pattern of reading in which the value for the bottom part of tensile strength increases towards the height of the culm. It is observed the MOE of fibre also demonstrated a similar pattern revealed increasing in reading for the top section, 1397.70 MPa then slightly decreased to 1041.40 MPa in the middle and continue to reduce to 263.30 MPa for the bottom section.

Table 5. Mechanical Strength Properties of Fibre

Part	Outer Diameter (mm)	Modulus of Elasticity (MPa)	Max. Force (N)	Tensile Strength (MPa)	Total Elongation (%)
Top (T)	0.734	1397.70	21.056	43.83	1.211
Middle (M)	0.540	1041.40	10.573	39.06	1.247
Basal (B)	0.868	263.30	14.948	25.26	3.446

The tensile strength of *G. Scortechinii* fibre was notably higher in the top part compared to the middle and bottom parts, as evident in the results. This heightened tensile strength at the top part is likely attributed to the varying chemical composition of bamboo species along the length of a bamboo culm. Lower tensile strength values are associated with lower amounts of holocellulose and lignin (Abdullah Siam et al., 2019). A previous study (Wang, Zhan, Ding, Wang, & Lin, 2016) affirmed that the superior tensile strength, MOE (Modulus of Elasticity), and MOR (Modulus of Rupture) are linked to the mean percentage of a vascular bundle observed in the top portion of the bamboo culm, followed by the middle portion, with the lowest observed in the bottom portion. All species studies made by Abdullah Siam et al., (2019), indicated that an increase in MOR and MOE was concurrent with a rise in the amount of vascular bundles along the culm's height. Furthermore, this increase in MOR and MOE was influenced by the growing density towards the top section.

Relationship of The Physical Properties of Culm with The Mechanical Properties of Gigantochloa Scortechinii Fibre

A correlation is made between the mechanical and physical properties of bamboo fibre and bamboo culm, respectively. Table 6 shows the correlation between the tensile strength of *G. Scortechinii* fibre and the physical properties of the bamboo culm. Specifically, tensile strength exhibits a negative and significant correlation with moisture content, reflected by 'r' values of -0.52 and -0.65 for tensile strength and MOE, respectively. This signifies that lower moisture content is associated with higher tensile strength, highlighting the influence of moisture on the mechanical properties of the bamboo fiber. Conversely, density displays a positive correlation with tensile strength, as evidenced by 'r' values of 0.83 and 0.98 for tensile strength and MOE, respectively. This indicates that an increase in density corresponds to an increase in tensile strength. The negative correlation of moisture content but a positive correlation of density underscores the influence of density on the strength of bamboo, with higher parenchyma cell content in the inner zone contributing to greater water-holding capacity and influencing shrinkage (Anokye et al., 2016). Additionally, culm thickness and culm diameter display a negative and significant correlation with the tensile strength of bamboo fiber, with an 'r' value of -0.68. The consistent decreasing pattern from the bottom to the top portion observed in both samples is attributed to the varying density of bamboo culms, increasing from the bottom to the top portion, as supported by Zakikhani et al. (2017).

Table 6. Correlation Coefficient of Physical Properties with Tensile Strength and MOE of *Gigantochloa Scortechinii* Fibre

Properties	Bamboo Fibre	
	Tensile Strength	MOE
Moisture content	-0.52	-0.65
Density	0.83	0.98
Culm thickness	-0.68	-0.41
Culm diameter	-0.68	-0.70

Mechanical Strength Properties of Culm

Table 7 shows the tensile strength of b. The result demonstrates that the top part recorded a reading of 131.39 N/mm^2 while for bottom part recorded a reading increased to 129.54 N/mm^2. However, the reading for the middle part is reduced to 110.16 N/mm^2. This similar pattern of tensile strength was also recorded by previous studies (Zakikhani et al., 2017).

Table 7. Tensile Strength of Bamboo Culm

Part	Tensile Stress (N/mm^2)	Modulus of Elasticity (N/mm^2)
Top (T)	131.39	32663.81
Middle (M)	110.16	16174.83
Bottom (B)	129.54	15317.25

Figure 6 revealed the failure of tensile test specimens. Most of the specimens failed similarly because of the combination of tension and shear parallel to the grain. This type of failure differs from timber, which includes rays and knots that allow it to withstand less force down the length of the stalk.

Figure 6. Mode of Failure Tensile Specimen

It's noteworthy that the tensile strength of bamboo varies based on its location along the culm. The results of this experiment demonstrate a linear increase in tensile strength with culm height. While both samples didn't exhibit a consistent rise in tensile strength, the findings are considered valid since the value at the top surpasses that of the bottom part of the *G. Scortechinii* culm. This suggests that, on the whole, the tensile strength tends to increase as we move from the bottom to the top of the culm. The consistent composition or increase in fibre composition with culm height contributes to this phenomenon. Meanwhile, the diameter and culm thickness decrease with height, thus limiting the area over which the stress is determined (Zhan et al., 2021). The observed increase in apparent tensile strength of bamboo is attributed to the fact that tensile strength is predominantly conveyed through the fibres. Consequently, the volume percentage of fibres increases as the culm grows taller (Krause, de Andrade Silva, Ghavami, Gomes, & Filho, 2016).

Results for the compressive strength of the *G. Scortechinii* culm are shown in Table 8. The top section indicated the highest compressive strength of approximately 44.41 N/mm^2 as compared to the middle and bottom sections which are 35.18 N/mm^2 and 33.74 N/mm^2, respectively.

Table 8. Compressive Strength of Bamboo Culm

Part	Wall Thickness (mm)	Cross-Sectional Area (mm^2)	Density (kg/m^3)	Compressive Strength (N/mm^2)
Top (T)	5.30	1350.70	764	44.41
Middle (M)	6.00	984.04	756	35.18
Bottom (B)	7.40	452.39	740	33.74

As shown in Table 8, the compressive strength was high at the top part as compared to the bottom part. This is attributed to the bamboo wall's thicker thickness and larger cross-sectional area at the top part when compared to the middle and bottom sections (Awalluddin et al., 2017). Moreover, the specimen's wall thickness is smaller at the middle and top, thereby resulting in a more compact distribution of fibres and an improvement in compressive strength (Jusoh, Ahmad, & Azmi, 2013). The bamboo's anatomical structure, which is composed of dense fibre, has strengthened its elasticity. Jusoh et al, (2013) also stated that bamboo is composed of parenchyma and sclerenchyma cells connected by vascular bundles. Furthermore, bamboo's mechanical qualities are determined by the orientation and density of vascular bundles.

Table 9 illustrates the MOR and MOE of the bamboo culm. In general, the samples show the trend for MOR and MOE from the bottom to the highest reading and slightly reduced from the middle to the top section. As shown in the table, the bottom part has the greatest result with 89.13 N/mm^2 and lowered in the middle part with 43.23 N/mm^2 and persistently declined to 41.37 N/mm^2 in the top part.

Table 9. Bending Result for Bamboo Culm

Part	Modulus of Rupture (N/mm^2)	Modulus of Elasticity (N/mm^2)
Top (T)	41.37	6700.8
Middle (M)	43.23	8127.62
Bottom (B)	89.13	13835.73

The findings presented in Table 9 emphasize that culm dimensions, specifically culm diameter and culm wall thickness, significantly influence the ultimate load. As anticipated, the bottom section of the bamboo culm, characterized by a larger culm diameter and a thicker culm wall, exhibited a higher capacity to withstand bending load compared to the middle and top sections, which had smaller culm diameters and thinner culm walls. This aligns with previous research findings (Chaowana, Wisadsatorn, & Chaowana, 2021). The variation in culm sizes is linked to the distribution density of vascular bundles within the bamboo culm. The outer layers of bamboo possess a higher density of vascular bundles, while the inner layers have a lower density. Consequently, the volume of vascular bundles and the quantity of parenchyma cells increase from the outer to the inner layers. This structural variation contributes to the bottom part exhibiting higher ultimate load readings compared to the middle and top parts (Osman et al., 2022).

Chemical Properties

Chemical characteristics are one of the fundamental qualities that might influence the material properties and processing of woody materials. The chemical components of *G. Scortechinii* as shown in Table 10. In this study, holocellulose content were found higher in culm samples, which is 70.4%, follow by lignin content with 50.6% and alpha-cellulose

content with 41.3%. However, it has been discovered that the chemical composition varies according on species, growing state, age, and culm portion (Nayak & Mishra, 2016).

Table 10. Chemical Properties of Bamboo Culm

Content	Mean (%)	Std Deviation
Lignin	50.6	0.63
Holocellulose	70.7	2.06
Alpha-Cellulose	41.3	1.81

Moisture content and density play significant roles in influencing the chemical composition of bamboo. As highlighted by Wahab, et al., (2013), a low content of holocellulose and alpha-cellulose tends to result in higher moisture content. Moreover, these chemical components have a direct impact on the density of bamboo; higher levels of lignin, holocellulose, and alpha-cellulose contribute to increased density. The composition of the cell wall, particularly cellulose and lignin, significantly affects the yield, efficiency, and characteristics of products obtained through pulping and nanofiber extraction processes (Seo et al., 2019). Holocellulose constitutes the complete polysaccharide fraction, encompassing alpha-cellulose and hemicellulose. Bamboo with a higher lignin concentration can serve as a valuable raw material for bioenergy production (Maulana et al., 2020). Additionally, lignin plays a crucial role in reinforcing cell-to-cell connections, enhancing cell wall strength, and providing protection against infections during subsequent growth (Vanholme, De Meester, Ralph, & Boerjan, 2019). In summary, bamboo with lower lignin content is better suited for papermaking and bioenergy applications, while bamboo with higher lignin content finds optimal use in the construction and furniture sectors (Zhu et al., 2020).

Relationship of The Physical Properties of Culm As Well As The Mechanical Properties of Fibre with The Mechanical Properties of Culm

Based on the statistical analysis presented in Table 11, it is evident that there exists a significant correlation between the tensile strength of *G. Scortechinii* culm and moisture content. The negative 'r' value of -0.66 indicates that lower moisture content is associated with higher tensile strength. Similarly, density exhibits a positive correlation with the tensile strength of *G. Scortechinii* culm, as reflected by an 'r' value of 0.33, suggesting that an increase in density corresponds to an increase in tensile strength. However, the correlation between the tensile strength of *G. Scortechinii* culm and fibre diameter is weak and insignificant, indicated by the 'r' value of -0.21. On the other hand, a positive correlation is observed between the tensile strength of *G. Scortechinii* culm and fibre tensile strength, with an 'r' value of 0.27. Furthermore, culm thickness and culm diameter display a negative correlation with tensile strength, denoted by 'r' values of -0.25 and -0.51, respectively. These findings align with the results of tensile strength presented in Table 7, which indicate a linear increase in tensile strength with culm height. As previously highlighted by Zhan et al., (2021), the fibre content within the culm remains essentially constant or increases throughout the culm's height, while the culm's diameter and thickness decrease with height. This structural arrangement reduces the area over which stress is determined. Given that fibres play a crucial role in transferring tensile strength, the apparent tensile strength of bamboo increases. Consequently, the volume percentage of fibres increases throughout the culm's height.

Table 11. Correlation Coefficient of Physical Properties of Culm and Properties of Fibre with Strength of *Gigantochloa Scortechinii* Culm

Properties	Bamboo Culm		
	Tensile Strength	Compressive Strength	Bending
Moisture content	-0.66	-0.81	-0.88
Density	0.33	0.76	-0.60
Fibre tensile	0.27	0.74	0.79
Culm thickness	-0.25	-0.86	0.45
Culm diameter	-0.51	-0.88	0.46

Table 11 exhibits the relationship between compressive strength and various factors. There is a significant negative correlation between compressive strength and moisture content, denoted by an 'r' value of -0.81, indicating that lower moisture content is linked to higher compressive strength. Additionally, density displays a notable and positive correlation with compressive strength, as evidenced by an 'r' value of 0.76, suggesting that higher density corresponds to increased compressive strength. On the other hand, there exists a negative and statistically insignificant correlation between fibre diameter and compressive strength, with an 'r' value of -0.29. Conversely, fibre tensile strength exhibits a significant and positive correlation with compressive strength, with an 'r' value of 0.74. Furthermore, culm thickness and culm diameter demonstrate a noteworthy negative correlation with compressive strength, reflected by 'r' values of -0.86 and -0.88, respectively.

In the context of bending strength, Table 11 showcases its correlation with moisture content. A significant negative correlation is observed, with an 'r' value of -0.88, implying that lower moisture content is associated with higher bending strength. Conversely, density exhibits a significant and negative correlation with bending strength, with an 'r' value of -0.60. However, the correlation between fibre diameter and bending strength is weak and negative, indicated by an 'r' value of -0.14. Moreover, fibre tensile strength demonstrates a notable negative correlation with bending strength, with an 'r' value of -0.79. In contrast, culm thickness and culm diameter exhibit a positive correlation with bending strength, reflected by 'r' values of 0.45 and 0.46, respectively. These findings are in line with observations from Table 9, reinforcing the understanding that larger and thicker culm walls contribute to higher bending strength due to the distribution of vascular bundles' density within the bamboo culm (Osman et al., 2022).

Furthermore, these findings affirm the significance of moisture content and density as pivotal factors influencing the mechanical properties of bamboo. This affirmation is consistent with earlier research positing that bamboo's strength is contingent on various factors such as species, moisture content, density, age, and culm height (Kamruzzaman, Saha, Bose, & Islam, 2008). Bamboo's strength augments with age due to the solidification of the culm walls. As bamboo matures, culm wall thickness increases, resulting in maximal strength (Anokye et al., 2016). The mechanical characteristics of most bamboo varieties are closely tied to their specific gravity and density, with specific gravity leading to heightened strength and rigidity (Anokye et al., 2016; Ming, Jye, & Ahmad, 2017). Considering the mechanical attributes of *G. Scortechinii*, it stands as a suitable material for commercial applications such as furniture, parquet, and structures (Siam, Uyup, Husain, Mohmod, & Awalludin, 2019).

CONCLUSION

The following conclusions can be drawn based on the physical, chemical and mechanical properties in various parts along the culm of species *G. Scortechinii:*

Based on the investigation, there is a pattern in moisture content where the basal and intermediate bamboo parts maintained more moisture than the top section. The samples showed a similar trend, with the top and centre having more density than the bottom. The results demonstrate that bamboo samples with low moisture content had a higher density.

The tensile strength of bamboo fibre results in the top and middle parts being stronger than the bottom section. A similar tendency was seen for compressive strength, which shows that the top and middle sections have more compressive strength than the bottom section. On the contrary, for bending strength, it was demonstrated that the bottom component is stronger than the middle and top parts.

In addition, the bottom part of the samples was tested for chemical properties including lignin, holocellulose and alpha-cellulose. It is found that the percentage of holocellulose is highest as compared to lignin and alpha-cellulose. Thus, this outcome may lead to low density and higher moisture content for the basal section of bamboo.

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THE STANDARDIZE MAINTENANCE CHARGES BUDGETING FOR STRATA DEVELOPMENT IN KLANG VALLEY

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Abstract
Maintenance fees are essential for managing any property, especially strata buildings. A significant challenge in strata developments is prioritising maintenance expenses, which directly impact overall charges. Proper budgeting practices are crucial for maintaining and sustaining these shared spaces. This research aims to develop standardized maintenance charges for budgeting purposes in strata developments. This study was conducted in the Klang Valley, covering various strata developments, including low-cost, medium-cost, and high-cost residential buildings. Data were collected through semi-structured interviews and focus group discussions for comprehensive insights into current practices and challenges. The findings reveal that budgeting practices largely depend on historical expenditures, which may not accurately reflect future maintenance needs. Key factors influencing maintenance charges include the building's age, available facilities, and other variables such as occupancy rates and maintenance frequency. The insights were validated through an iterative process involving expert interviews and focus groups to ensure data accuracy. Based on expert feedback, the proposed standardized rate was refined to better reflect actual maintenance costs. This research lays the groundwork for a standardized maintenance charge rate that enhances budgeting accuracy, financial planning, and sustainability in strata developments. Nevertheless, by adopting this approach, property owners and management committees can ensure more equitable and effective maintenance charge allocations, resulting in better-maintained living environments and increased resident satisfaction.

Keywords: *Budgeting; Maintenance Charges; Strata Development; High-Rise Residential*

INTRODUCTION

Strata development refers to properties that consist of multiple individual units sharing common property and facilities, such as condominiums, apartment complexes, and gated communities. The management and maintenance of these developments are regulated by the Strata Management Act 2013 (Act 757) in Malaysia (Tan et al., 2019) and similar legislation in other jurisdictions. The Management Corporation, an operation organisation, is responsible for overseeing the management of the housing scheme once it has been occupied, making this form of dwelling distinct from others. The Management Corporation plays a crucial role in administering the management of their own multi-storey housing scheme and is responsible for managing and maintaining the joint facilities available in the scheme (Teo, 1993; Jamila, 1994; Mani, 2006; Tiun, 2006). One significant issue in determining maintenance charges for strata development is the lack of standard guidelines or a structured framework for developing budgets. This absence often leads to challenges such as overbudgeting or underbudgeting for maintenance activities (Firouz and Ghadimi, 2015). In addition, the absence of guidelines can

result in a lack of clarity and consistency in the determination of maintenance charges, causing frustration and disputes among strata owners and tenants (Ali et al., 2010). However, managing the maintenance budgets for strata developments involves various challenges. These challenges include the lack of implementation and adherence to maintenance policies, procedures, and strategies (Hashim et al., 2019). In some cases, maintenance works are conducted without clear scopes of work, leading to contradictions and inefficiencies (Hashim et al., 2019). This lack of order and organization can hinder proper budgeting and fund allocation for maintenance activities. The allocation of funds to essential facilities services versus value-added facilities services can greatly impact cost performance and budgeting efficiency (Au-Yong et al., 2019). Careful consideration of the maintenance needs and priorities is essential to optimize the maintenance charges while ensuring the necessary upkeep of the property. In addition, inadequate awareness and understanding of the significance of maintenance among strata owners and management bodies can also pose challenges. Furthermore, lack of preventive maintenance and delayed response to maintenance issues can result in higher costs and more significant problems in the long run (Zolkafli et al., 2019). Therefore, it is crucial to establish a standard maintenance guideline and provide education and support to strata owners to promote a culture of regular maintenance and responsible budgeting. Moreover, the absence of standardised maintenance management systems and frameworks in developing countries further compounds the challenges in budgeting and managing maintenance charges. Most developing countries, including Malaysia, lack established maintenance standards and practices adopted from developed countries (Ogunbayo et al., 2022). This absence impacts the consistency and effectiveness of maintenance budgeting and can result in inefficient resource allocation.

RESEARCH METHODOLOGY

This research employs a qualitative methodology through expert interviews and focus group discussions. The research process involved three stages. In the first stage, semi-structured interviews were conducted with building managers and building executives from three different housing schemes. These expert interviews aimed to gather in-depth insights into the challenges and elements of service charges in high-rise residential buildings. In the second stage, the data collected from the expert interviews were validated through separate focus group discussions consisting of 20 respondents from each type of housing scheme. These discussions provided a platform for further exploration and validation of the initial findings. Table 1 provides the respondents involved in focus group discussions for the low-, medium-, and high-cost housing schemes.

In the final stage, the information gathered was consolidated and further validated by an experienced industry panel. This panel consisted of professionals involved in preparing maintenance budgets for strata developments, ensuring that the findings were robust and applicable in real-world scenarios. Table 2 summarizes the expert interview for data validation.

Through all these stages, the study aimed to comprehensively address the research questions and provide a detailed understanding of the service charge elements in high-rise residential buildings.

Table 1. Respondents for Focus Group Discussion

No	Respondents	Position	Work Experience (Years)
Low-Cost Housing Scheme			
1	R1	JMB Committee Member	20
2	R2	JMB Committee Member	7
3	R3	JMB Committee Chair	10
4	R4	Admin Staff	7
5	R5	JMB Committee Member	9
6	R6	JMB Committee Member	10
7	R7	JMB Committee Member	10
8	R8	Building Executives	5
9	R9	Building Executives	3
Medium Cost Housing Scheme			
10	R1	Property Manager	20
11	R2	Building Executives	7
12	R3	Building Manager	10
13	R4	Building Manager	15
14	R5	Building Manager	9
High-Cost Housing Scheme			
15	R1	Property Manager	20
16	R2	Property Manager	7
17	R3	Property Manager	10
18	R4	Property Manager	15
19	R5	Property Manager	9
20	R6	Property Manager	20

Table 2. Respondents for Expert Interviews Data Validation

No	Respondents	Position	Work Experience (Years)
1	R1	Director	15
2	R2	Building Manager	7
3	R3	Building Manager	10
4	R4	Account Manager	8
5	R5	Account Manager	6
6	R6	Building Manager	5
7	R7	Building Manager	7
8	R8	Building Manager	6
9	R9	Building Engineer	3
10	R10	Building Engineer	3
11	R11	Property Manager	9
12	R12	Building Manager	15

RESEARCH RESULTS

Development of Standard Rate of Maintenance Chargers Budgeting for Strata Development

The development and adherence to comprehensive guidelines for maintenance budgeting are essential for ensuring effective financial planning, resource allocation, and decision-making in maintenance operations. It is emphasized that a maintenance budget is an essential element of maintenance management, dealing with financial planning for maintenance

operations and execution within a maintenance organization. However, preparing maintenance budgets is crucial for ensuring that budget estimations are systematic, considering essential factors such as capital expenditure, aligning with financial constraints, and enabling effective tracking of maintenance spending within the overall operating budget. Below are the proposed guidelines as below:

a. Introduction to Guidelines for Maintenance Charges Rate

The following Guidelines for Maintenance Charges Rate for Strata Development are designed to offer direction to facilities management teams and stakeholders involved in the development of procedures and recording of transactions related to maintenance services and products within a facility. The underlying principle of these Guidelines is to ensure that budget allocation methods do not lead to the subsidization of facilities' non-maintenance services or products unless explicitly authorized by the relevant regulatory authorities. It is important to note that these Guidelines do not serve as rigid rules or regulations dictating how maintenance budgeting and cost allocations should be conducted. Instead, they are intended to provide a flexible framework for facilities and regulatory authorities to develop their own policies and procedures in managing maintenance budgets and related transactions. The diverse regulatory environments may warrant variations in cost allocation methods that are different from those outlined in these Guidelines.

b. Maintenance Charges for Strata Building

The following information regarding maintenance charges is provided for general guidance purposes only. It is essential to note that actual charges may vary based on several factors, including but not limited to the building's age, location, specific services, and amenities provided. The maintenance charges detailed herein are approximations (median price range) and intended for informational purposes only. These charges are indicative and reflect the estimated costs for the upkeep and management of the strata building and are subject to change due to various influencing factors such as major repairs, improvements, and changes in service contracts. These estimates can fluctuate based on annual budgets, special levies, government regulations, revisions of government subsidies, and necessary improvements or repairs. Table 3 provides the criteria of the sample buildings scheme used in this study to determine the standard rate of maintenance charges budgeting for strata development. These charges are only applied to high-rise residential building schemes with the following characteristics.

Table 3. Features of The Stratum High-Rise Residential Building that are Utilised to Calculate Maintenance Costs

Criteria	Low Cost Residential	Medium Cost Residential	High Cost Residential
Building Age	Below 20 years	Below 10 years	
Development Area	min. 2.67 acre max. 11.56 acre	min. 5.72 acre max. 18.75 acre	min. 1.05 acre max. 12.50 acre
No of Block per Development	min. 1 block max. 6 blocks	min. 2 blocks max. 12 blocks	min. 1 block max. 3 blocks
No of Storey per Block	min. 4 storeys max 12 storeys	min. 5 storeys max. 19 storeys	min. 27 storeys max. 50 storeys
No of Unit per Storey	min. 10 units max. 26 units	min. 10 units max. 24 units	min. 8 units max. 18 units
Landscape Area	10% open space from the total development area, with the assumption that the open spaces are complete with landscaping, including planting and ornamental features.		
Basic Services and Facilities	Basic Services based on audited documents: • Cleaning Services • Pest Control • Fire Protection • Genset • Water Pump & Tank • Waste Disposal • Plumbing and Sanitary	Basic Services based on audited documents: • Security Services • Cleaning Services • Pest Control • Landscape • Fire Protection • Genset • Spiral Waste • Water Pump & Tank • Waste Disposal • Plumbing and Sanitary	
	Facilities based on audited documents: • Lift • Office Equipment • Office Air Conditioning • Hardware & Tools • Office Computer	Facilities based on audited documents: • CCTV • Gym Equipment • Lift • Swimming Pool • Barrier Gate • Office Equipment Maintenance • Air Conditioning • Hardware & Tools • SMATV • Computer & Software	Facilities based on audited documents: • CCTV • Gym Equipment • Lift • Swimming Pool / Jacuzzi /Landing Pool • Barrier Gate • Office Equipment Maintenance • Air Conditioning Maintenance • Hardware & Tools • SMATV • Computer & Software Maintenance
Minimum Salary for Staff Cost	The minimum salary is based on the national minimum salary law. However, the median cost shown varies depending on other factors such as experience, skills, allowance, etc.		

c. Important Notice on Maintenance Charges Rate

This document outlines the estimated maintenance charges for the strata building. The maintenance charges are calculated to ensure the smooth functioning and upkeep of common areas, facilities, and essential services such as security, landscaping, and cleaning. These charges were determined based on the median price range from the selected buildings according to the categories shown in the previous table. Stakeholders are advised to regularly check for updates, communicate with the strata management, or refer to the official documentation for the most current information. Regular meetings and updates from the strata committee will provide insights into any significant changes or upcoming maintenance projects. Furthermore, stakeholders are encouraged to participate in annual general meetings to stay informed about the financial health and maintenance plans of the strata building. These maintenance budgets are subject to periodic review and adjustment, with a recommended

review frequency of every 12 months or earlier if triggered by significant changes such as operational requirements, inflation, government regulations (e.g., subsidy revisions), or unforeseen maintenance needs. The review dates should be clearly outlined in the maintenance budget to ensure timely updates and compliance.

d. Compliance Cost Requirements

The standard rate of maintenance charges for strata development shall be read together with the service standard for each item (refer to Table 5) to ensure transparency and clarity in the allocation of charges based on the quality and extent of services provided to residents. The compliance costs for residential high-rise buildings can vary widely depending on the building's age, size, and location, as well as the specific requirements of local authorities. These costs may include the following:

i. Building and Structural Compliance

- Building Code Adherence: Compliance with Malaysia's Uniform Building By-Laws (UBBL), which outlines the standards for the design, construction, and maintenance of buildings.
- Structural Integrity Inspections: Regular inspections to ensure the building's structural soundness, including checks for any potential hazards or required repairs. Mandatory periodic inspection every ten years as required by Section 85A of Act 133 (Periodic Inspection pursuant to Section 85A, Street, Drainage and Building Act 1974).

ii. Fire Safety Compliance

- Fire Safety Systems: Installation and maintenance of fire detection and suppression systems, such as sprinklers, alarms, and extinguishers, according to the Fire Services Act 1988.
- Fire Drills and Safety Training: Regularly scheduled fire drills and training sessions for residents and staff.
- Fire Certificates: Obtaining and renewing fire safety certificates yearly, which may involve inspections and updates to safety equipment or procedures.

iii. Environmental and Energy Compliance

- Energy Efficiency Standards: Compliance with energy efficiency regulations, which may require energy audits and the implementation of energy-saving measures. Energy reports need to be submitted every six months.
- Environmental Impact Assessments (EIA): Necessary for certain projects, ensuring that the building's impact on the environment is minimized and meets regulatory requirements.

iv. Health and Safety Compliance

- Water Quality Testing: Regular testing of water systems to ensure compliance with health standards (minimum every two years – including water tank cleaning).
- Lift and Escalator Safety: Regular inspections and maintenance of lifts and escalators, including obtaining safety certifications. It includes load tests at least every two years and yearly inspections for renewal certificates.
- Waste Management Compliance: Ensuring proper waste disposal and recycling practices are in place and in line with local regulations.

v. Legal and Regulatory Compliance

- Strata Management Act Compliance: Adhering to the Strata Management Act 2013, which governs the management and maintenance of stratified properties.
- Licenses and Permits: Obtaining necessary licenses and permits for various building operations, including electrical installations, air conditioning systems, and other mechanical systems. Yearly licenses for JKKP, Fire Certification, and Fire Extinguisher. A minimum of every two years is required for calibration (Suruhanjaya Tenaga).

vi. Periodic Building Inspections

- Building Inspections: A mandatory inspection is required at least every ten years to assess the overall safety and compliance of the building based on the provision Street, Drainage and Building Act 1974 (Act 133).
- Audit Reports: Prepare detailed audit reports to ensure all compliance measures are met.

vii. Insurance Compliance

- Building Insurance: Ensuring the building is insured against risks such as fire, natural disasters, and other liabilities as required by law.

e. Maintenance Charges Rate

The standard rate of maintenance charges for strata development shall be read together with the service standard for each item and above preambles to ensure transparency and clarity in the allocation of charges based on the quality and extent of services provided to residents. Table 4 provides the median cost of each item, which determines the standard rate of maintenance charges.

Table 4. Maintenance Charges Rate for Strata Development

Item		Frequency	Unit	Standard Cost per Unit (RM)		
				Low-Cost	Medium-Cost	High-Cost
Utilities, Quit Rent, Assessment, Insurance						
1	Electricity	Monthly	L/S	10,000	18,000	40,000
2	Water	Monthly	L/S	600	2,150	3,500
3	Sewerage - IWK	Monthly	L/S	-	94	120
4	Quit Rent* *If strata title is issued, the owner needs to pay "cukai petak" to the Land Office	-	L/S	1,500	6,000	75,000
5	Assessment *Owner paid directly to Local Authority) – 2 times per year	Yearly	-	-	-	-
6	Fire Insurance	Monthly	L/S	20,000	38,000	70,000
Services Provider/Outsourcing						
1	Security Services (current rate min RM 9.50)	Man/Month	No of guards	1-2 persons	4-8 persons	10-15 persons
			Rate for supervisor	2,000	3,000	3,500
			Rate for general worker	1,750	2,250	3,000
2	Cleaning Services	Man/Month	No of cleaners	1-2 persons	5 – 7 persons	10-12 persons
			Rate for supervisor	2,000	2,500	3,000
			Rate for general worker	1,500	2,250	2,500
3	CCTV Maintenance services/ repair	Quarterly	Per visit	-	800	1,500
4	Pest Control	Monthly/Twice Monthly	Per visit	500	387.50	780
5	Landscape Maintenance	Monthly	No. of landscaper	-	1-2 persons	3-4 persons
			Rate of landscaper	-	2,800	3,500

Table 4. Maintenance Charges Rate for Strata Development (continuation)

Item		Frequency		Unit	Standard Cost per Unit (RM)		
					Low-Cost	Medium-Cost	High-Cost
Services Provider/Outsourcing							
6	Lift - Maintenance/Repair	Monthly contract		General services/lift	300	500	850
				Comprehensive services/lift	480	750	1,570
7	Electrical Inspection & Supervision	Monthly		Per visit	600	550	1,250
8	Fire Protection Services	Quarterly		Per visit	850	800	1,500
9	Swimming Pool Maintenance / Jacuzzi /Landing Pool	Monthly contract/ Non – comprehensive		Per unit	-	2,800	3,800
10	Water Tank Maintenance / Repair	Quarterly		Per visit	-	650	1,750
11	Waste Disposal (Bulk Waste)	Monthly (services collection + rental of roro bin)		Per trip	(direct to local authority)-KDEB		
				Per roro	340	340	430
12	Property Management Fee/ Management Agent	Monthly		Per Company	2000	8,750	13,500
Building Maintenance (Upkeep)							
1	General Expenses Maintenance & Repair	Ad – Hoc		Monthly	5,000	4,500	6,000
2	Security Equipment Maintenance (Barrier Gate)	Ad – Hoc		Monthly	-	4,000	5,800
3	License Renewal	Yearly	JKKP (Lifts)	Per lift	390	390	483.00
				L/S	2,200	2,890	3,935.00
			Fire Extinguisher	Per unit	35	35	35
			ST	L/S (kW)	2,600	3,000	3,000
			Calibration LV System	Every 2 years	-	3,500	5,200
			ISCADA	Yearly	-	2,798.40	2,798.40
4	Signage Expenses	Ad – Hoc		Monthly	Under General Expenses Maintenance & Repair		
5	Office Equipment Maintenance	Ad – Hoc		Monthly	Under General Expenses Maintenance & Repair		

Table 4. Maintenance Charges Rate for Strata Development (continuation)

Item		Frequency	Unit	Standard Cost per Unit (RM)		
				Low-Cost	Medium-Cost	High-Cost
Building Maintenance (Upkeep)						
6	Air Conditioning Maintenance	Twice a year	Monthly	Under General Expenses Maintenance & Repair		
7	Common Area Maintenance	Ad – Hoc	Monthly	Under General Expenses Maintenance & Repair		
8	Hardware & Tools Maintenance	Ad – Hoc	Monthly	Under General Expenses Maintenance & Repair		
9	Computer & Software Maintenance -update antivirus -renewal Microsoft	Ad – Hoc	Monthly	250	450	320
10	Gym Equipment Maintenance	Ad – Hoc	Monthly	-	Under General Expenses Maintenance & Repair	
11	Lift parts and repair Maintenance	Ad – Hoc	Monthly	Under General Expenses Maintenance & Repair		
12	SMATV and CCTV Maintenance	Ad – Hoc	Monthly	-	200	280
13	Swimming Pool Parts Maintenance	Ad – Hoc	Monthly	-	Under General Expenses Maintenance & Repair	
14	Water Tank Maintenance	Ad – Hoc	Monthly	Under General Expenses Maintenance & Repair		
15	Plumbing and Sanitary Maintenance	Ad – Hoc	Monthly	Under General Expenses Maintenance & Repair		
Administrative Expenses						
1	Audit Fee	Yearly	L/S	2,800	3,300	4,500
2	Accounting Software Fee	Monthly	-	-	300	420
3	Bank Charges	Monthly	L/S	-	30	53
4	Depreciation of Fixed Assets	Yearly	Per month	312.50	500	730
5	Meeting Expenses (AGM/EGM)	Yearly	L/S	3,000	7,000	8,800
6	Event Decoration Expenses	Yearly	L/S	-	1,200	3,000
7	Postage, Courier & Stamping Fee * Less defaulter and inter-floor leakage/less issue	Monthly	L/S	1,000	542.50	364.00

Table 4. Maintenance Charges Rate for Strata Development (continuation)

Item		Frequency		Unit	Standard Cost per Unit (RM)		
					Low-Cost	Low-Cost	Low-Cost
Administrative Expenses							
8	Rental – Copier *Mostly refer to brand	Monthly		Per unit	220	250	280
9	Rental - Water Dispenser	Monthly		Per unit	-	120	150
10	Stationery & Printing	Monthly		L/S	375	225	200
11	Sundry Expenses			-	-	-	-
12	Telephone / Internet & Fax	Monthly		L/S	225	290	450
13	Travelling & Petrol Expenses	Yearly		L/S	2,000	2,500	3,000
14	Committee Allowances *Applicable upon approval during AGM	Monthly		Per meeting	-	-	-
15	Cloud-based apps (VMS + Accounting system)	Monthly		L/S	-	700	
Staff Cost							
1	Staff Cost (Salary, EPF, SOSCO, Bonus, Staff Insurance, Staff Medical, OT, Uniform)	Monthly	Building Manager	No. of staff required	-	1	1
				Rate per staff	-	5,450	6,500
			Building Executive	No. of staff required	1	1	1
				Rate per staff	2,600	3,450	3,800
			Administrative Staff	No. of staff required	1	2	1
				Rate per staff	2,000	2,850	2,900
			Account Executive	No. of staff required	-	1	2
				Rate per staff	-	3,400	3,200
			Technician	No. of staff required	2	2	2
				Rate per staff	2,000	2,600	2,800
			Chargeman (outsourcing)	No. of staff required	-	1	1
				Rate per staff	-	2,775	4,500
2	Staff Appreciation	Yearly 70% - 1 month salary from staff cost		L/S	-	-	-
3	Staff Refreshments	Monthly		L/S	200	90	200

Table 5. Standard of Services (*Based on Service Level Agreement (SLA))

Item		Frequency/Unit	Standard
Utilities, Quit Rent, Assessment, Insurance			
1	Electricity	Monthly	- Landlord and tenant meter
2	Water	Monthly	- Bulk meter and hydrant
3	Sewerage - IWK	Monthly	- Refer to the excess water usage
4	Quit Rent	-	- If strata title is issued, the owner needs to pay "cukai petak" to the Land Office
5	Assessment	Yearly	- Owner paid directly to Local Authority – 2 times per year
6	Fire Insurance	Yearly	- Fire - Public Liability - Burglary - Fidelity Guarantee - Machinery - All Risks - Plate Glass - Error & Omission - Money in Transit
Services Provider/Outsourcing			
1	Security Services	Monthly	Security location as required by the management, for example: Main Entrance - To station a minimum of two personnel at the main entrance at all times - To register all visitors and contractors to the building and ensure passes are duly issued - To attend any enquiry and complaint pertaining to security matters and/or any other matter, inform management for immediate action - To accept, act upon, or convey messages, whenever necessary, from tenants or the authorities. - To check on items and parcels carried into the building whenever necessary, especially by suspicious characters and/or unauthorised person - To ensure no unauthorized person is allowed into the building after operation hours - To ensure the contractor provides a work permit - To ensure all the practices conducted by the security shall follow the standard procedures, rules, and regulations by the Malaysian government and Local Authorities from time to time. - To ensure the contractor pass is always displayed, monitor the movement of the contractor and ensure the contractor does not damage the lift

Table 5. Standard of Services (*Based on Service Level Agreement (SLA)) (continuation)

Item		Frequency/Unit	Standard
Services Provider/Outsourcing			
			Clocking and Patrolling - To carry out one (1) hourly clocking (or as varied by the client) and patrolling in the building. The patrolling frequency at certain areas may increase subject to the client's instruction - To place patrol baton at FCC after patrolling to be checked and verified by security supervisors on patrol clocking reports - To ensure that all the fire staircase doors are properly closed - To report to management any missing hose reels and nozzles noticed while patrolling - To ensure no wastage of electricity and water in the building - To enforce the no-smoking rule in the common area of the building - To ensure that all ongoing renovation works are approved by checking copies of work permits with contractors - To report any damaged, faulty, or vandalised equipment and facilities in the building - To ensure the safety of staff, residents, and authorised visitors - To act upon any occurrence of criminal activities, emergency situations, and intrusion in the vicinity of the building - To check on all work activities of contractors, permits, and passes during and after operation hours - To check and investigate any trigger of smoke detection and fire alarm in the building and report to the management for immediate action - To report immediately to management upon any emergency in the building during and after operation hour - To deter any unauthorised person and suspicious character from entering the building. Traffic Control - Prevent any visitors/occupants from indiscriminate parking - To ensure all vehicles are parked at designated areas/parking or clamping, enforcement should be taken immediately. Package inclusive: - Full set uniform with badge - Batons - Boots - Torchlight - Raincoat - Whistles - Report book and stationery

Table 5. Standard of Services (*Based on Service Level Agreement (SLA)) (continuation)

Item		Frequency/Unit	Standard
Services Provider/Outsourcing			
2	Cleaning Services	Monthly	- Daily cleaning of all designated areas, including management office, control room, common areas, clubhouse, restroom, refuse chamber, surau, parking areas - Trash & waste material collection on a daily basis - Mopping and scrubbing of floors - Window cleaning on a scheduled basis - Dusting and wiping furniture, fixtures, and surfaces - Ad hoc cleaning tasks as required
3	CCTV Maintenance/repair	Monthly	- Monthly service inspection - In-depth service inspection (once a year) - Configuration inspection - Storage inspection - Camera view and focus inspection
4	Pest Control	Monthly/Twice Monthly	- General pest control: Common ants, cockroaches, rats & subterranean termites inspection once a month - Fumigation: Mosquitoes (Water-based fogging & larvicide) twice per month
5	Landscape Maintenance	Monthly	- Mowing the grass and maintenance of landscaping, - Periodic fertilization, - Weeding and repairs, - Trimming of bushes, trees, hedges, and - Trimming the areas surrounding the trees and bushes.
6	Lift - Maintenance/Repair	Monthly contract	Comprehensive Service Monthly - Check the traction machine and traction motor for abnormal noise, temperature rise, and oil leakage - Check the control panel, governor, car top, car door, door sills and pit - Check the break action and justify if necessary - Check the movement of the car door switch and emergency stop switch - Check the indicator lamps and position indicator display - Enunciator lights and buzzer - Check the lift's running condition and riding comfort - Check the movement of hall and car calling buttons, switches, etc - Check the alarm bells and batteries - Check the car fan/blower. - Check the lift intercom system. - Check the car lighting. - Check the monitor lamp and supervisory panels. - Top up gearbox oil if necessary. - Top up rail lubrication oil if necessary.

Table 5. Standard of Services (*Based on Service Level Agreement (SLA)) (continuation)

Item		Frequency/Unit	Standard
Services Provider/Outsourcing			
			Quarterly - Test safety gear function. - Check the condition of safety gear. - Check the condition of the governor. - Test all landing door locking devices. - Check the condition of the ropes. - Check the condition of the controller. - Check the condition of the brakes. - Check the bearing and traction machine. - Check the condition of the gear oil. - Test terminal stopping devices. - Check the condition of terminal stopping devices. - Test final stopping devices. - Check the condition of the wiring. Half-yearly - Clean and check the traction machine. - Overhaul traction machine brake. - Service governor machine. - Service landing door hanger rails. - Check and adjust landing doors. - Check and tighten landing door ropes. - Check and tighten landing door shoes. - Lubricate bearing for landing door drive rollers. - Check and tighten landing door hanger rollers. - Check and service hoisting ropes and adjust rope tension. - Check and service governor ropes. - Adjust the car door chain and belt. - Check and lubricate where necessary for the car door operator. - Clean car door rail. - Check and tighten car door hanger rollers. - Check and tighten car door shoes. - Adjust safety door edge tension. - Adjust the safety door edge micro switch. - Overhaul the magnetic contactors inside the control panel.

Table 5. Standard of Services (*Based on Service Level Agreement (SLA)) (continuation)

Item		Frequency/Unit	Standard
Services Provider/Outsourcing			
			Annually - Check and adjust indicator plates. - Check and service car guide shoes. - Check and service counterweight guide shoes. - Check and service safety gear. - Check, adjust, and tighten the top slow-down switches. - Check and adjust all control voltages in the lift control panel. - Check and service the tacho sensor. - Clean the connection box of every floor and car top. - Tighten all screws and check the condition of cables at the conduit inlet and outlet at the junction box. - Clean the condition of the worm gear and thrust bearing of the gearbox. - Clean and tighten the screws of the control panel and auxiliary panel. - Test all safety devices. - Assist with the annual inspection for the renewal of the lift certificate with dosh *All inspections shall include second schedule inspection, aiding in JKKP audit inspection, smoothing over process for CF certificate acquisition, timely advice to the clients on lift status or recommended repairs
7	Electrical Inspection & Supervision (Visiting Engineer)	Monthly	- Checking overall electrical installation to comply with Suruhanjaya Tenaga Requirement and Electrical Act & Regulation 1994. - To prepare a report and submit it to the building owner (Borang I) - Perform a visual check and inspection on the electrical installation, i.e., HT switchgear (11KV/33KV), Transformers, MSB panels, and generator sets - Predictive and repair maintenance for high voltage powers in switch rooms and power generators, - Test run the generator on "Off Load."
8	Fire Protection Services	Quarterly	Non-Comprehensive Services - Check, test, and service alarm - Check, test, and service the Main Fire Alarm Panel, inclusive of all components therein (1 set), and rectify and replace defective components accordingly - Check, test, and refill the portable fire extinguisher at the power station and township, including acquiring BOMBA certification for the fire extinguisher.
9	Swimming Pool Maintenance	Monthly contract/ Non – comprehensive	- Basic cleaning and clearing of the pool surface of leaves/dead insects - Pool vacuuming - Checking and maintaining the treated water level and adding chemicals to balance water chemistry - Checking pumps, filters, piping - Recording chlorine results, checking water temperature, recording PH tests in logbooks, - Backwash the pool filter and rinse the sand filter

Table 5. Standard of Services (*Based on Service Level Agreement (SLA)) (continuation)

Item		Frequency/Unit	Standard
Services Provider/Outsourcing			
			- Checking water clarity, cleaning and scrubbing the side walls, bottom, and pool deck. - Checking out all pool equipment, electrical and mechanical, and informing clients of the working condition - To check water supply pipes (brass ball float valve) - To ensure all valves are in the right position before leaving - To keep all cleaning aids at the required place after vacuuming the pool
10	Water Pump & Tank Maintenance / Repair	Yearly	- Maintenance of water pumps and pimp filters every 6 months - Testing of water quality-yearly - Cleaning of tank-yearly - Cleansing of water filter, if any – In every 6-month time.
11	Waste Disposal	Monthly	- Roro bin provided. - Waste collection services and disposal at appropriate dumping sites approved by the government of Malaysia - Report of waste collection services and disposal activities
12	Property Management Fee	Monthly	- Building Operation and Maintenance Management - Preventive Building Maintenance Programme - Database Management - Contract Service Management - Financial Accounting and Administration - Performance and Audit Reporting Programme - Credit Control Policy and Procedure - Strata Title Consultancy
Building Maintenance (Upkeep)			
1	General Expenses Maintenance & Repair	Monthly	Practice: increase 5-10% from the last year expenses
2	Security Equipment Maintenance (Barrier Gate)	Monthly	
3	License Renewal – JKKP & ST & Gondola & Fire Extinguisher	Yearly	
4	Signage Expenses	Monthly	
5	Office Equipment Maintenance	Monthly	
6	Air Conditioning Maintenance	Monthly	

Table 5. Standard of Services (*Based on Service Level Agreement (SLA)) (continuation)

Item		Frequency/Unit	Standard
Building Maintenance (Upkeep)			
7	Common Area Maintenance	Monthly	
8	Hardware & Tools Maintenance	Monthly	
9	Computer & Software Maintenance	Monthly	
10	Gym Equipment Maintenance	Monthly	
11	Lift parts and repair Maintenance	Monthly	
12	SMATV Maintenance	Monthly	
13	Swimming Pool Parts Maintenance	Monthly	
14	Water Tank Maintenance	Monthly	
15	Plumbing and Sanitary Maintenance	Monthly	
Administrative Expenses			
1	Audit Fee	Yearly	Recommended audit fee: https://www.klmanagement.com.my/audit/recommended-audit-fee-in-malaysia/
2	Accounting Software Fee	Monthly	-
3	Bank Charges	Monthly	-
4	Depreciation of Fixed Assets	Yearly	10% increase every year
5	Meeting Expenses (AGM/EGM)	Yearly	
6	Event Decoration Expenses		
7	Postage, Courier & Stamping Fee	Monthly	
8	Rental - Copier	Monthly	The monthly Rental Charges shall include the following: - - Rental of the Photocopier machine. - Cost of all technical repairs and maintenance services on-site (excluding the cost of spare parts). - Cost of consumables such as rollers, toners & printer drum. - Cost of insurance of the Photocopier. - License fees to use the software and its new releases (if applicable).

Table 5. Standard of Services (*Based on Service Level Agreement (SLA)) (continuation)

Item		Frequency/Unit	Standard	
Administrative Expenses				
			- Additional printing/scanning software shall be installed at no additional cost (if applicable). - Cost of delivery (including transportation and installation); - Travel and other expenses that may be incurred by the prospective Supplier's employee, - Cost of relocation of the Photocopier (if necessary); and - Supply of 1,500 copies of A4 paper per machine per month.	
9	Rental - Water Filter	Monthly		
10	Stationery & Printing	Monthly	Petty cash	
11	Sundry Expenses		-	
12	Telephone / Internet & Fax	Monthly	Expenditure variable (cheque issuance)	
13	Travelling & Petrol Expenses	Monthly	Petty Cash	
14	Committee Allowances	Monthly	Upon approval during AGM	
15	Cloud based apps	Yearly	The yearly subscription excludes the initial cost, i.e., device cost, etc.	
Staff Cost				
1	Staff Cost (Salary, EPF, SOSCO, Bonus, Staff Insurance, Staff Medical, OT, Uniform)	Monthly	- Administering the terms of contracts and other agreements relating to the property. - To manage and monitor all aspects of the management and maintenance of the common area and facilities are carried out accordingly (if required) - Conduct JMB/MC AGM/EGM and JMC Meeting	1 Building Manager
			- Monitoring expenditures for the property and making payments out of the income from the property - Liaise with authority bodies, including to attend tribunal case - To attend residents' enquiries with regards to the property and liaise with Maintenance Staff or Security Personnel for the matters arising	1 Building Executive
			- Formulating budgets and upholding the fiscal accounts for the property - To attend residents' enquiries (phone calls, walk-in, and email enquiries or complaints) - Administrative management is responsible for overall general office administrative duties, including data entry, filing, reception duties, and information channel	1 Administrative Staff

Table 5. Standard of Services (*Based on Service Level Agreement (SLA)) (continuation)

Item		Frequency/Unit	Standard	
Staff Cost				
			- Credit control (billing and collection) - Ensure that the receivables are properly accounted for and documented. - Arrange annual auditing of accounting records and liaise with external auditors on all auditing issues. - Process payment details for expenses in accordance with approved procedures and agreed credit terms. - To prepare budget	2 Account Executive
			- Immediate/Minor Repair and Maintenance Works - Perform regular checks on the electrical switchboard and other services to ensure all of them are functioning in a proper manner. - Attend to emergency/urgent complaints when required and constantly monitor the current Workflow to ensure job effectiveness and efficiency in response time. Execute scheduled preventive maintenance work - Perform electrical troubleshooting and carry out electrical repair	2 Technician
			- To perform, lead, and supervise preventive and predictive maintenance, troubleshooting and corrective maintenance, work order scheduling, planning, system operation, and inspection, especially in the electrical section. - Liaise with utility providers such as TNB and government regulatory bodies on utility services and compliance issues.	1 Chargeman
2	Staff Appreciation	Yearly	Based on the approval of MC or AGM	
3	Staff Refreshments	Monthly	Petty cash	

CONCLUSION

The standardized rate for maintenance charges in strata development addresses critical needs for transparent and equitable financial planning in property management. By categorizing rates across three distinct housing schemes: low-cost, medium-cost, and high-cost, the study provides a tailored approach that reflects the unique requirements and financial realities of each category. Notably, the rates were derived from a thorough analysis of yearly audited accounts, ensuring a data-driven foundation. These rates are influenced by several key factors, including the standard level of services provided, the age of the buildings, and compliance with relevant laws and regulations. This multi-faceted approach ensures that the maintenance charges are both fair and reflective of the specific needs and conditions of each housing scheme. Benchmarking maintenance charges for strata development is a vital practice that involves comparing and evaluating the costs incurred by similar strata developments within a particular region or industry to develop an acceptable rate of maintenance charges. This process aids in establishing a baseline for maintenance charges, allowing strata communities to gauge the reasonableness and competitiveness of their own financial allocations. By examining benchmarks, strata developments can identify areas of potential cost efficiency, negotiate competitive service contracts, and ensure that their maintenance charges align with industry standards. Additionally, benchmarking fosters transparency within strata communities, enabling stakeholders to make informed decisions about their financial commitments. This ultimately contributes to the overall financial health and sustainability of the strata development in Malaysia.

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A FRAMEWORK TO ENHANCE THE ADOPTION OF BUILDING INFORMATION MODELLING IN THE CONSTRUCTION INDUSTRY OF PAKISTAN

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Abstract
The construction sector is getting increasingly complex as a result of the limited use of information technology application tools in emerging nations such as Pakistan. BIM provides numerous benefits to construction stakeholders, including cost savings, reduced rework time, and faster and earlier detection of clashes and faults. However, there are some hurdles to the adoption of BIM in Pakistan's building industry. This study attempts to create a framework for the implementation of BIM in Pakistan's construction industry. The challenges associated with BIM execution are identified to provide a framework. The secondary data consisted of a literature study, while a questionnaire survey collected the primary data. Unstructured interviews were also conducted before the completion of the questionnaire survey. A total of 150 questionnaire surveys were distributed, with 132 questionnaires received. The top five challenges to BIM deployment include lack of training and skills, lack of a BIM Manager, and gap in knowledge for project stakeholders, corrupt people are resistant to BIM because it provides transparency, while contractors and subcontractors need more understanding and experience. Following the identification of impediments to BIM adoption, a conceptual framework is developed based on interviews with associated subject specialists. The framework is separated into three categories: government, organization, and employee. There are specific procedures outlined that must be followed by these three categories. The study finds that the conceptual framework outlined above will improve the deployment of BIM in Pakistan's building industry.

Keywords: *Building Information Modelling; Barriers; Adoption; Framework; Construction Industry*

INTRODUCTION

The Construction Industry plays a vital role in any nation's socioeconomic development by greatly aiding in its GDP. The construction industry holds significant importance in Pakistan. The sector is the largest contributor to employment in the country and plays a crucial role in driving economic development (Ali et al., 2018a). However, the construction sector faces several problems because of its complex operations like; increased time, poor quality, rising costs, too much construction waste, communication hindrances, and poor coordination among the projects' stakeholders. Hence, building information modeling (BIM) can help enhance construction performance by correcting these problems. Building Information Modeling (BIM) is a cutting-edge technique and collection of tools that enable the use of paperless drafting of projects for construction (Azhar, 2011). Building information modeling is the software-driven procedural method required for the construction of the AEC industry (Aranda-Mena et al., 2009). Previously, construction industry project managers did not rely

much on IT, but now it is more frequently being used. CAD mainly refers to the Computer-Aided Designs that construction firms apply to design, modify, assess, and optimize construction plans. Building information modeling benefits include improvement in infrastructure planning and construction because of the use of 3D design information representation on a parametric CAD system. A database interrelating with BIM accommodates details about the building and its layouts (Gao, Doumbouya, and Guan, 2016). Some definitions of BIM are as follows: In the studies of Kasim et al. (2017) and Azhar & Brown (2009), BIM is stated as planning, designing, constructing, and operating a building in virtual modeling by using Building Information Modeling software. BIM is an enhanced version of CAD as mentioned by Yaakob et al. (2018) as it allows n-D modeling, virtual construction, virtual design, and project modeling through enhanced and integrated data. Based on the information retrieved about the research subject, building information modeling or BIM is an object enabling construction companies to collaborate through the generation, classification, and overview of data about a project's execution (Mohammad et al. 2018a). As stated by Kekana et al. (2015), "BIM is a technological tool which facilitates the development of a building within a virtual environment." BIM is a technique that involves the application of IT to building and construction projects with the aim of making a model of a building and the related data at every phase of the project, including maintenance. Some of the software that are use in designing and constructing buildings include; structural model, mechanical model, electrical and architectural model. The primary purpose of evolving Building Information Modeling was to process data exchange and enable relationships between these models. When initially designed, it was mainly employed for developing 3D models, structural analysis, cost and mechanical analysis also and now it is being utilized in energy modeling as well. Recent studies prove its effectiveness in energy optimization and modeling (Kamel and Memari 2019).

To enhance the aspect of building envelope, BIM also considers building shape and massing. This can also aid in effective approaches to building layouts. More efficient thermal and cooling control is possible with heat transfer evaluation and control. Essentially, energy modeling makes it possible for an individual to identify the total cost that is incurred on energy use of a structure before the construction process is completed. Thus, immense time can be saved by feeding the geometric models of the building into the BIM software's simulation engine (Abanda et al., 2018). Currently, when conducting research in building energy management, many researchers pay attention to Build Information Modelling (BIM). For example, concerning how changes in thermal and physical properties of building envelopes and habitation influence the Building energy consumption analysis, Lee & Ham (2016) used gbXML-based BIM for statistical and regression analysis. They found out that, in a warmer climate, population density had a significant and positive effect on the relative sensitivity of habitation fluctuations. Habibi (2021) used Building Performance Simulation (BPS) methodologies, namely BIM-based simulation analysis, to study zero-net energy homes (ZEHs). Depending on the selected options, it could provide information about how much energy buildings use. According to Somboonwit et al. (2017), the main benefit of using BIM for energy-based modeling, simulation, and information is that it makes data processing easier. This can lead to automated energy modeling, improved output demonstration, the ability to store and organize new building data, updated models, especially with real-time information, and the addition of new features to the current energy simulation by enhancing existing libraries. Moreover, the automated modeling process is a major advantage of using BIM for building energy simulation. This has the potential to reduce time and money while removing the possibility of human error compared to the traditional approach to energy modeling. The

latter involves creating a graphical model in a BEM tool using data related to geometry, material quality, equipment, and schedules. According to Tu & Vernatha (2016), BIM's second noteworthy contribution to energy modeling is BIM facilitates in the absence of a Graphical User Interface of computer tools and provides a good output display of energy management systems. In order to conduct a real-time energy simulation using eQuest through the installation of smart meters and sensors, Jen and Vernatha investigated the theoretical basis for a Building Information Modeling (BIM) Energy Management Support System (BIM-EMSS) (Tu and Vernatha, 2016). Building Information Models (BIMs) created in Revit are utilized by this device. The user can track the energy efficiency of individual areas in a building in real-time by viewing the results using the geometric data included in the BIM model. The organization and storage of building information with an emphasis on energy efficiency is another significant advantage of using BIM. Energy monitoring systems in real-time, for instance, generate data on the usage of energy at home, temperature, and occupancy, it must be controlled under acceptable thermal zones, equipment, and building components (Kamel and Memari, 2019). However, there are considerable limitations, such as the need for additional processes when updating models and the absence of real-time simulation and feedback (Abanda and Byers, 2016).

Various obstacles have hindered the potential spread of BIM implementation, despite its numerous advantages (Walasek and Barszcz, 2017). The effective adoption of BIM is impeded by a variety of hurdles, which leads to a number of issues that arise during the implementation of BIM in the construction industry. In other words, a number of different challenges together account for the delayed BIM adoption rather than a single problem. These problems must be fixed in order to successfully integrate BIM into the Construction Industry (Lindblad, 2013). Ironically, the implementation of BIM in developing countries like Pakistan is lagging, if compared with the developed nations (Ali et al., 2018). Developing nations such as Pakistan, Sri Lanka, and India are persistently worried about the implementation of BIM. In Pakistan, only 11% of related industries have implemented BIM and only generate 3D models which is a very limited part of BIM (Bhatti et al., 2018). Therefore, the research questions of this study are, What are the Potential Barriers to the adoption of Building Information Modelling in Construction Industry of Pakistan? How can the adoption of Building Information Modelling be Enhanced in the Construction industry of Pakistan? Thus the main aim of this study is to identify the challenges faced by the construction industry of Pakistan to adopt the BIM at its highest maturity level. Also, to motivate the construction practitioners by highlighting the BIM Benefits. Ultimately, the goal is to provide a conceptual framework for implementing Building Information Modeling (BIM) in the Construction Industry of Pakistan. Previous studies in the literature have examined the application and obstacles of adopting BIM in the construction industry. However, no framework has been designed to improve the adoption of BIM specifically in the construction industry of Pakistan.

BARRIERS TO THE ADOPTION OF BIM

Although Building Information Modelling has many advantages, many scholars have defined its hindrances and barriers to its adoption in the construction industry worldwide.

In Malaysia, (Yaakob et al., 2018b) conducted research to find out what was preventing the construction industry from using Building Information Modeling. The hurdles that have been discovered can be broadly classified into six categories: ownership disputes,

interoperability issues, inadequate training, high implementation costs, and lack of client demand. (Sardroud et al. 2018) carried out research to identify the barriers preventing the construction sector from implementing BIM. BIM is a relatively new method of working that presents both benefits and challenges to the AEC sector. After reviewing 100 articles, the researcher selected 47 that were relevant to the current study, which was focused on the difficulties associated with implementing BIM. Some examples of these challenges include the areas of security (6%), finances (17%), law (20%), culture (27%), and management (30%), with the latter two constituting the most serious. An examination of these research articles revealed that, while facing substantial and pervasive cultural obstacles, the United Kingdom is in the forefront of BIM adoption. After considering all of the points raised, the most important ones are related to security and contracts. These issues contributed to the perception that the construction industry was less innovative than others.

Kekana et al. (2015) sought to determine in his research how BIM is being used by the South African construction sector and the difficulties encountered. The absence of BIM standards is linked to a number of problems, including challenges in design and professional responsibilities, problems with data intellectual property, and a general lack of knowledge and experience. Chan (2014) examined the issues surrounding the utilization of BIM and how it influenced the Hong Kong building industry. The following are some problems that have been linked to BIM that have been observed; These include issues like the company's inability to hire enough skilled chefs, the requirement for education and training, the absence of industry standards in the cooking industry, and lack of client demand. Liu et al. (2015) highlighted fundamental problems that organizations experience while using Building Information Modeling (BIM). The shortage of qualified specialists, the high cost of applications, and the lack of national application rules were the most pressing issues. Hamada et al. (2016)identified the following difficulties in putting building information modeling into practice. Legal requirements, the high cost of BIM software and "human" resources, the availability of staff lacking in BIM knowledge and understanding, people's resistance to change, project owners' lack of interest, the low level of awareness of the benefits of BIM, other expertise gaps, well-organized workflow, and the lack of government support are some examples of these factors.

According to Al-Btoush & Haron (2017) One barrier to adopting building information modeling (BIM) is that organizations lack sufficient training in BIM usage. Because there is no financial basis for the expenditures associated with BIM operations, you may be unwilling to train new workers or educate current ones. The earnings from BIM are not high enough to warrant its continuous use. Furthermore, there is insufficient funding to buy the software and hardware needed to implement BIM. The need to adopt Building Information Modeling (BIM) is nonexistent for those who oppose societal progress. Matarneh & Hamed, 2017), defined several barriers that impede building information modeling (BIM) from becoming extensively used. In addition to resistance to change and exorbitant expenses, these include a lack of government incentives, regulations, education, and resources. The implementation of BIM has been hindered by Ghavamimoghaddam & Hemmati (2017) who listed unclear duties and responsibilities related to using numerical data in a model, unclear benefits of BIM in terms of performance improvement, and unclear support for the model. Poor comprehension of building information modeling (BIM) installation, Miscommunication and a lack of knowledge on building information modeling (BIM), Missing revenue from BIM tool-related software and hardware, There is no reliance on the model's consumption at various project stages by project stakeholders. There is a dearth of resources and a suitable legislative framework for

considering owners' opinions throughout the design and building processes. Among the many problems that Alhumayn et al. (2017) named as holding back BIM adoption are administrators' reluctance to embrace new practices, an absence of workable standards and guidelines, and indifference from government and regulatory agencies. Some of the major obstacles to building information modeling that Hatem et al. (2018) listed include a lack of strong government initiatives, a lack of understanding of the benefits of BIM, reluctance to change, a high cost of BIM software, and the expenses linked with its revisions. Not enough people with expertise in BIM (Building Information Modeling). Staff resistance, a variety of software and hardware options, a lack of data and knowledge about BIM, operational costs and benefits, a lack of client demands, and the absence of policy and standard creators are some of the challenges that Mohammad et al. (2018) listed as preventing the implementation of BIM.

METHODS

The research study's methodology, including its flowchart and several analytical methodologies, is detailed in this part. Below this, in Figure 1, is the research approach flow chart.

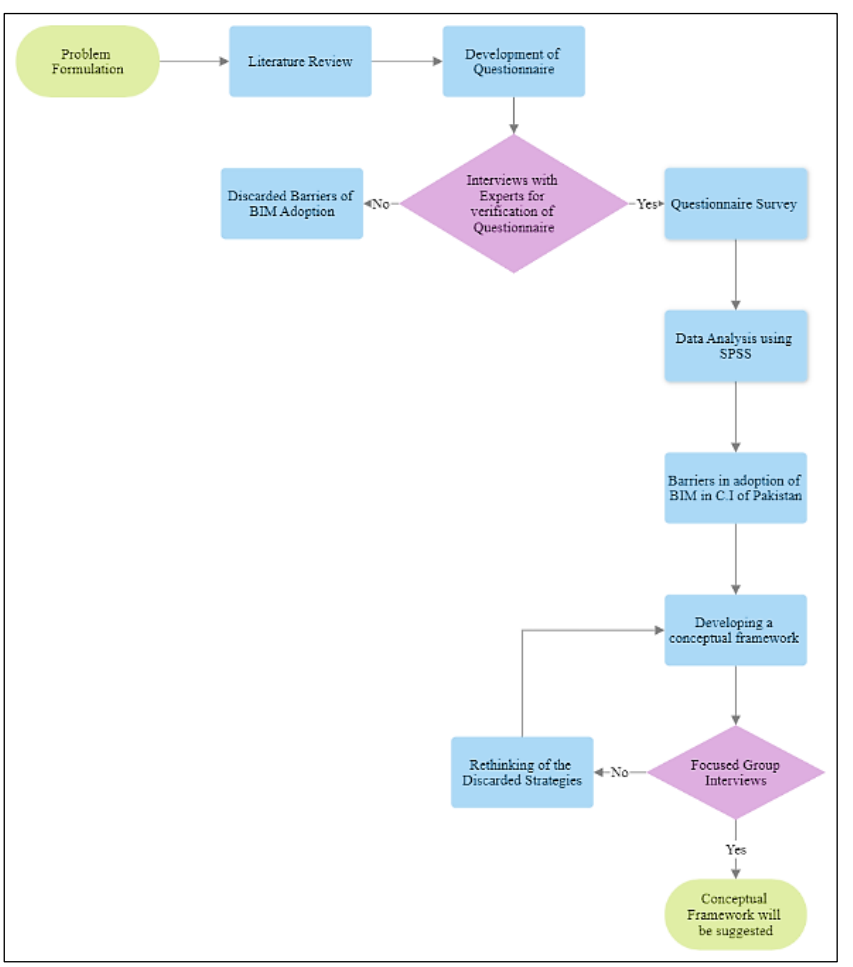

Figure 1. Flow Chart of Research Methodology

Data Collection Procedure

In order to determine what is preventing the construction industry in Pakistan from utilizing Building Information Modeling (BIM), this study conducts a Literature Review. The next step in determining and identifying these challenges was to conduct semi-structured interviews with relevant professionals. A questionnaire survey was used to collect the data in the end.

Based on the main obstacles to its adoption, a conceptual framework was provided to improve the deployment of building information modeling (BIM) in Pakistan's construction industry. The relevant specialists validated the provided framework in the end.

Questionnaire Survey and Sample Size

To collect the data, a questionnaire survey was utilized. The questionnaire went through two stages of development. The first stage involved gathering potential obstacles to BIM implementation through a literature review and using that information to create a questionnaire. The second step was to conduct unstructured interviews with relevant specialists to ensure the validity of the results. The survey is divided into two sections: The demographic questions in the first section of the survey ask about the respondent's job title, years of BIM experience, industry experience, etc., while the barriers to BIM adoption in the construction industry make up the second section. On a Likert scale from 1 to 5, we asked respondents to rate the difficulty they had in implementing building information modeling (BIM) in Pakistan's construction industry.

The prepared questionnaire was then introduced in the field for the view of the samples to be sought from. The questionnaire survey was done in the Public/Private sector of the Construction Industry. The approach used in the conduct of the survey was a random sample technique. This way, there is a probability of selection equal or likely to happen since each person in the population likely has the same chance of being involved as a response. Due to cost savings, faster response time, and improved data accuracy, this approach is recommended. Engineers, researchers and academics, architects, town planners, BIM technicians, contractors, and consultants were all given a total of 150 questionnaires. 132 questionnaires were returned out of 150 leads to 88%, which is fairly excellent according to the recommendations of (Dulaimi, Ling, and Bajracharya 2003). Out of one hundred and thirty-two construction professionals, seventy-six are engineers, eight are architects, eight are contractors, eleven are managers, one is owner, two are BIM technicians, two are town planners and twenty-four are from research or academics.

Data Analysis

The data was analysed using different methods. Different analysis techniques are applied in order to ensure a strong conclusion. The Statistical Package for Social Sciences (SPSS) Version 20 was used for the data analysis. Now, regarding the first part of the survey, data was depicted with the help of pie charts and bar graphs. This is because, through the help of the bar chart, it becomes easier to tell how frequent and in what measure each of the elements is likely to occur. A Reliability Test and Descriptive Statistics (mean and standard deviation) were used to analyse the questionnaire's second portion.

To arrange the factors in descending order based on the respondents' perceived significance level, we calculated their means and standard deviations. This method required calculating the mean and standard deviation of each variable and then ordering the variables from most to least significant based on these values.

Several categories' means from the survey questionnaire were quite close to one another. To rank the criteria and examine how they differed, we utilized the standard deviation (SD). To illustrate the dispersion or variance among data values, one statistical tool is the standard deviation (SD). A modest standard deviation indicates that most of the observations are clustered around the statistical mean or expected value. Data points are more evenly dispersed throughout a larger range of values when the standard deviation is large.

In order to determine if the recovered variables were homogeneous, we used Cronbach's alpha (α), a coefficient that assesses internal consistency, to evaluate the reliability of internal consistency. Each individual factor's average interaction between variables determines the value of Alpha (α). The average factor loading score for every group is represented by Cronbach's alpha. A higher alpha coefficient (α) indicates a more reliable factor or questionnaire, and it can vary from 0 to 1. Generally, a Cronbach Alpha value of 0.6-0.7 is considered acceptable (Ursachi, Horodnic, and Zait, 2015).

RESULTS AND DISCUSSIONS

Version 20 of the SPSS statistical package was used for the data analysis. There are two parts to the data. Respondents' names, addresses, dates of birth, places of employment, and whether they are public or private sector employees are all part of the personally identifiable information portion. In Section 2, we will examine the challenges that the Pakistani construction sector has encountered while trying to apply Building Information Modeling (BIM).

Working Position of Respondents

The received responses depicted the positions of the respondents within their various businesses, as illustrated in Figure 2. The participants that completed the survey consisted of 76 Engineers, 8 Architects, 8 Contractors, 11 Managers, 1 Owner, 2 BIM technicians, 2 Town planners, and 24 individuals from the Research/Academia field.

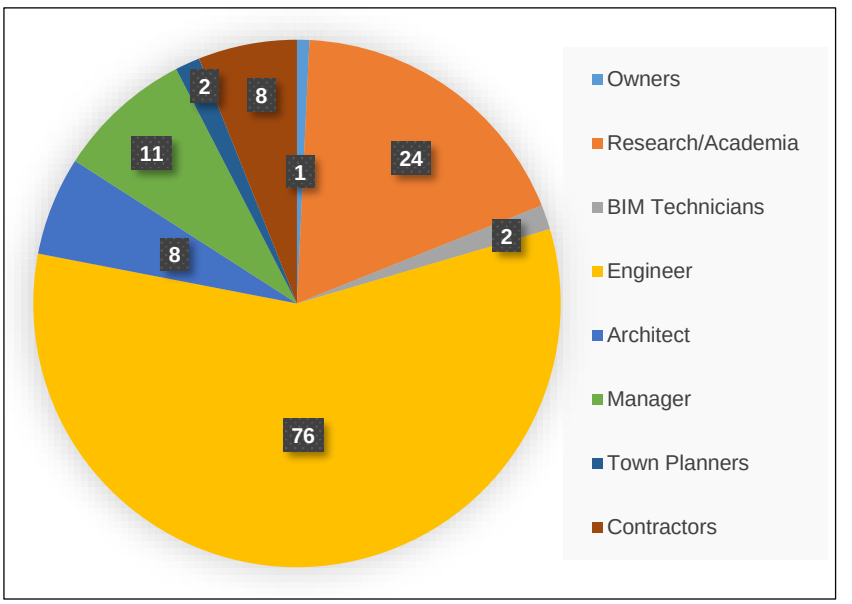

Figure 2. Working Position of Respondents

Working Experience of Respondents

According to Figure 3, 14 respondents have no experience, 74 respondents have 1-3 years of experience, 19 respondents have 4-6 years of experience, 13 respondents have 7-10 years of experience, and 12 respondents have 11 years or more of experience.

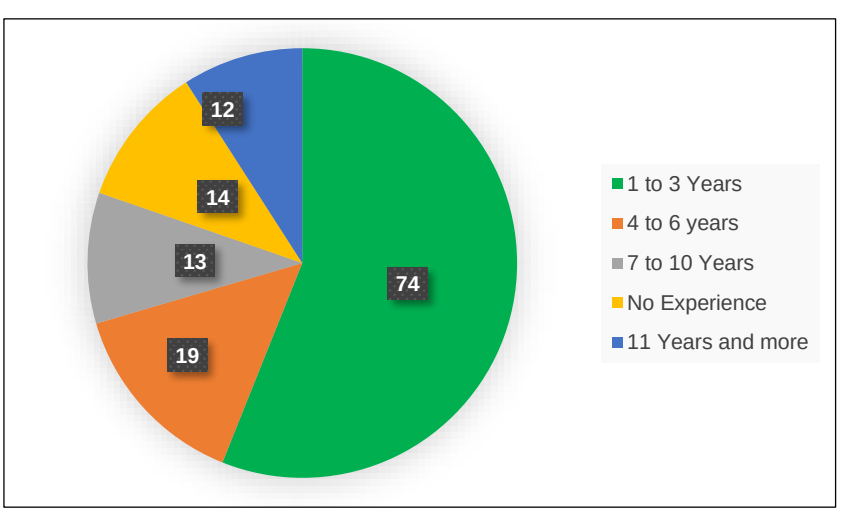

Figure 3. Working Experience of Respondents

Organization Sector of Respondents

The results of ownership inside the organization or organizational sector are shown in Figure 4. There are a total of 58 respondents working for government agencies, 73 for private companies, and 1 who did not specify which sector their employer falls under.

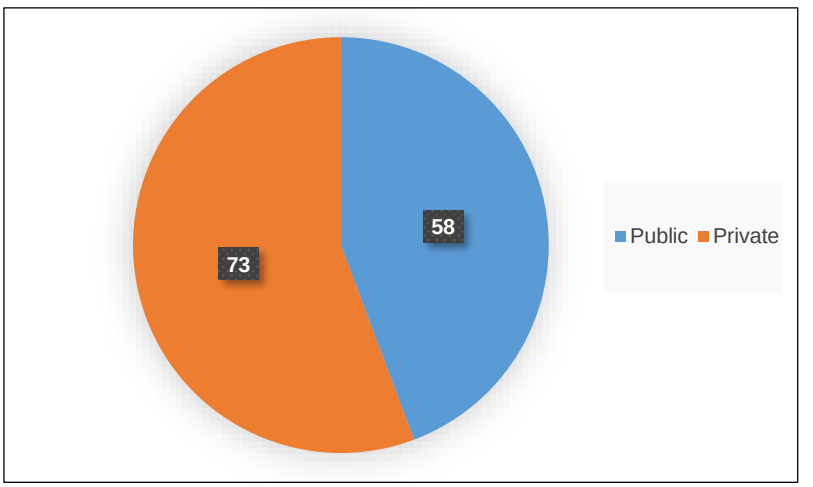

Figure 4. Organization Sector of Respondents

Barriers to The Adoption of BIM

In Section 2 of the survey, we ask about the problems that have prevented Pakistani construction companies from using Building Information Modeling (BIM). Several researchers provided explanations for the twenty obstacles found in the literature review in their investigations. We used the Likert scale to rank these obstacles, where 1 is "Strongly disagree" and 5 is "Strongly agree.". We calculated the Mean and Standard Deviation values from the data collected from these 132 participants. The next step was to sort the Barriers from highest to lowest by Mean value, with the highest Mean value barrier at the top. For each barrier to BIM implementation, Table 1 displays the average and variability of the scores.

Table 1. Barriers to the Adoption of BIM in The Construction Industry of Pakistan

Rank of Barrier	Name of The Barrier	Mean Value	Standard Deviation
1	Scarcity of training and skills	4.30	0.701
2	Lack of BIM Manager	4.29	0.766
3	Resistance of corrupt people as BIM provides Transparency	4.29	0.599
4	Shortage of knowledge to project stakeholders	4.24	0.680
5	Deficiency of knowledge and experience with contractors and sub-contractors	4.23	0.729
6	Resistance to the adoption of change	4.21	0.807
7	Lack of specified standards	4.19	0.781
8	Resistance to changes in employment patterns	4.17	0.808
9	Inappropriate government policies	4.15	0.731
10	Unclear BIM advantages regarding growing practices.	4.14	0.689
11	Collaboration issues at the Pre-construction stage	4.11	0.763
12	Data and intellectual property issues	4.11	0.675
13	Lack of demand for the use and acceptance of BIM	4.09	0.715
14	Interoperability issues at the construction stage	4.07	0.742
15	Reluctance of Clients/Contractors	4.05	0.745
16	Organizational Issues	4.04	0.665
17	High cost of implementation	4.04	0.737
18	High cost of BIM software	3.99	0.626
19	Cultural issues	3.93	0.991
20	Legal issues	3.69	0.773

Reliability Test

To determine how trustworthy the participant data is, the Cronbach's alpha coefficient is calculated. We calculate the overall alpha value for all the barriers to BIM implementation. With a Cronbach's alpha of 0.750, the survey results are reliable; the acceptable range is 0.6-0.7.

Framework for Enhancing the Adoption of BIM

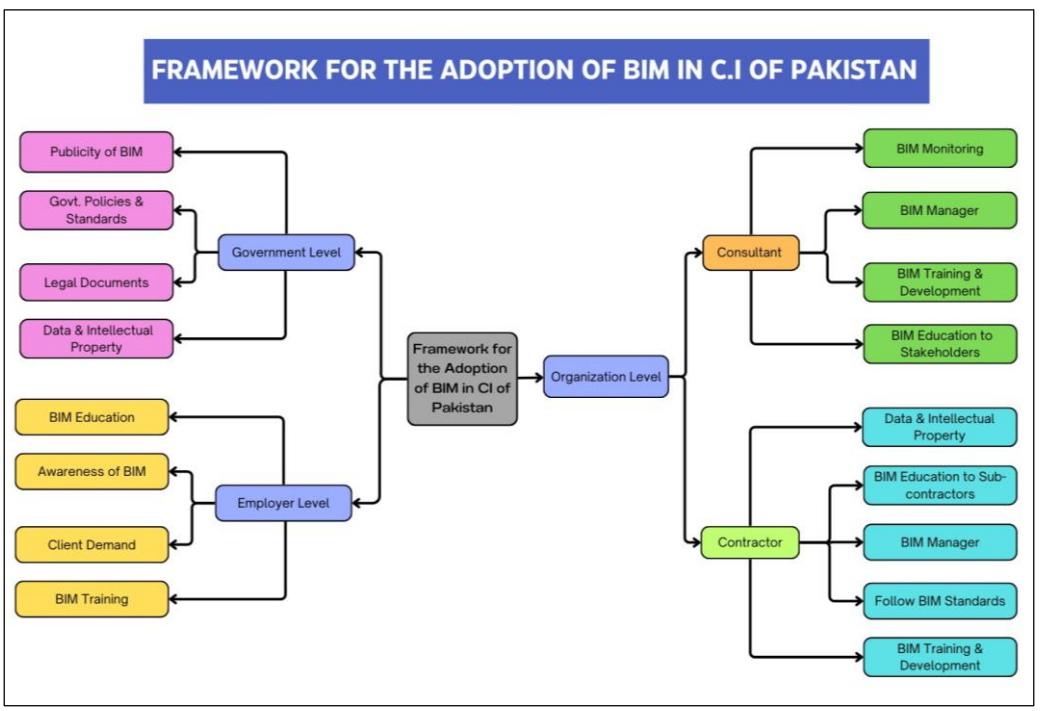

Figure 5. Framework for The Adoption of BIM in The Construction Industry of Pakistan

After identifying the barriers to building information modeling (BIM) implementation in Pakistan's construction industry, a theoretical framework was proposed. There are three separate parts to the suggested structure: the government, the organization, and the employee. Subsequently, the validity of this framework was established by the administration of unstructured interviews with field specialists with a minimum of 10 years of expertise. Twenty professionals in the field validated this theoretical framework. The unstructured interview comprised four components. The initial segment pertained to the respondent's personal information. The second segment pertained to the measures implemented by the Government. The final segment pertained to the measures implemented by the organization. The fourth and last section pertained to the actions carried out by the organization's employees.

Explanation of The Steps in The Framework for Improving The Adoption of BIM

The following sections elaborate on the conceptual framework's depiction of the actions that need to be taken to improve the adoption of BIM in Pakistan's construction sector.

Staff Training

Construction companies want to develop suitable training programs for their staff. Furthermore, the government must offer training programs to facilitate the adoption of BIM in the construction industry. Having BIM-trained people will strongly incentivize construction firms to use BIM.

BIM Manager

The senior management should decide whether or not to implement BIM in Pakistan. The effective application of construction technologies requires the commitment of all levels of the organization, with a particular emphasis on the involvement of senior-level management. Managers should be provided with an accurate assessment of the impact of the fluctuations, as well as the potential benefits, in order to allocate resources, train individuals, and minimize disruptions to regular business operations.

Education on Building Information Modeling (BIM)

The majority of the employed creators are highly proficient and experienced in the traditional 2D computer-aided design (CAD) setting. In order to expedite the adoption of BIM in design businesses, it is necessary to provide BIM training for professionals and aspiring designers. Experts in the field should collaborate with educational institutions to assess the curriculum for civil engineering and architectural education in order to incorporate Building Information Modeling (BIM) as the primary instructional platform.

The syllabus or course prospectus should aim to equip students with both recruiting abilities and cooperating skills in the BIM environment in an unbiased manner. Nevertheless, the primary aspect of the administration should not be overlooked. These BIM courses could vary greatly in quality since the government has not supported any clear BIM initiatives.

Promotion and Familiarity with BIM

It is necessary to increase awareness about BIM among construction organizations in order to support the deployment of BIM. In this case, it is possible to conduct seminars and workshops for employing personnel of construction companies. To motivate the BIM usage, awareness has to be created among the Stakeholders, contractors, sub-contractors, and consultants. This can be done by providing assistance, handouts, and samples. An analysis of such cases will help to strengthen the understanding and interpretation of BIM as useful for various clients.

Government Policies

Financial support from the government is usually vital in the process of BIM integration and deployment. There are professional bodies that the government needs to encourage the use of building information modeling (BIM) in their projects. It is imperative for this study that construction projects which are under the government to incorporate the use of Building Information Modeling (BIM). Being aware of the importance of BIM, the government should promote its adoption in the projects of private companies. Another key development for

organizations in Pakistan's private sector is also involved in creating strategies of BIM in prescriptive guidelines through working groups meeting for government-led building information modeling. Our goal is to address the reluctance to embrace BIM and make sure that noncompliance is dealt with appropriately.

Specified Standards

Standards for building information modeling (BIM) in the construction industry must be established by experts from both the public and private sectors working together with the government. The implementation of these criteria should be strict to the extent that supervision should be conducted by the senior executives of the building organization.

BIM Software, Data, and Intellectual Property

Construction organizations should purchase BIM software and get approval from specific licensing authorities like Autodesk for issues concerning information and property. This will establish the fact that the software will be under the direct control of a certain company utilizing the software Administrator's account.

Customer Demand

The deployment and operation of BIM within an organization are significantly influenced by the demand from clients. BIM can be indispensable for clients when they recognize the advantages and benefits of BIM. Given that the Government of Pakistan is the primary customer in the construction industry, it is imperative for the government to take the initiative in promoting the adoption of Building Information Modeling (BIM) in projects. This requirement will compel the service providers to prepare themselves for the adoption of BIM in their companies.

Legal Documents

To ensure their approval for any organizational, cultural, and legal concerns, the government's legal representative (the Government Advocate) should be involved in the creation of the legal paperwork related to BIM adoption in the construction sector. Pakistani constitutional legislation must be followed by these documents.

To improve the adoption of BIM in the construction industry of Pakistan, the following steps might be taken in different categories. Building participants will be able to mimic a wide range of drawing kinds thanks to this, including structural, mechanical, plumbing, and electrical blueprints.

CONCLUSION

The analysis revealed that the implementation of BIM in the construction industry of Pakistan is hindered by several barriers, with the primary obstacles being a deficiency in training and skills, as well as a lack of a dedicated BIM Manager. Inadequate understanding among project stakeholders, Insufficient knowledge and expertise of contractors and sub-

contractors, and factors hindering the acceptance of change include resistance, absence of defined standards, and inappropriate government policies.

Finally, a framework is proposed as a means of improving BIM usage in Pakistan's construction industry. Separate sections of the framework are devoted to the three main types of organizations: government, organizations, and employees because they all have to be in harmony as they work hand in hand to deliver their mandates. As highlighted in the research, each stakeholder in the construction industry of Pakistan, inclusive of the government, organizations, and personnel is expected to enhance the use of BIM. In other words, there are several things that the government must do to get optimal results from BIM such as BIM awareness and push, BIM standard and specification, BIM legal document drafting, BIM policy formulation data, intellectual property management, and BIM utilization. The contractors should implement several protocols including appointing a BIM Manager, increasing subcontractors' BIM awareness, safeguarding data and IP, creating and delivering the BIM training sessions, and collaborating with government entities and BIM oversight bodies to establish standard BIM. Among the consultants' proposals, the first one is the key performance which is the appointment of a BIM Manager. Other steps include developing and training stakeholders, working with the government to establish BIM standards, and finally, implementing BIM monitoring. In the end, it's up to the company's employees to prioritize BIM training, reacting to clients' increasing demand, raising awareness about BIM, and enhancing their knowledge and abilities in the field. The following actions, organized into several groups, can be done to increase the use of building information modeling in Pakistan's construction sector.

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LEVERAGING ARTIFICIAL INTELLIGENCE IN THE CONSTRUCTION INDUSTRY: APPLICATION AREAS AND FUTURE OPPORTUNITIES

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Abstract
Overly manual operation and heavy reliance on labourers have led to low productivity in construction. The construction sector is therefore widely recognized as one of the most under-digitized industries. At the forefront of digitalization, Artificial intelligence (AI) would be the game changer to drive magnificent improvement to the performance of the construction industry. Past efforts have been made to put AI into a sharper focus and extend the application scope in construction. However, there are still a lot of grey areas in the AI applications and future opportunities of adopting AI in construction are under explored. This paper therefore examines the application areas of AI in the construction industry and identifies the future opportunities of AI adoption in construction. A questionnaire survey was employed to collect views from a wide construction community to investigate the application areas and future opportunities of leveraging AI in construction. The results show that construction stakeholders generally perceived AI to impact construction jobs positively. The study also identified various application areas to leverage AI in construction. Progress monitoring and scheduling are among the popular application areas for deploying state-of-the-art AI solutions in the construction industry. By investigating state-of-the-art AI and future opportunities in construction, the study offers empirical results to support the development of AI in construction. The paper also gives insights into understanding the stakeholder perceptions towards AI adoption. AI plays a role in revolutionizing the construction industry, leading to more productive, automated, and reliable workflows in construction.

Keywords: *Artificial intelligence; Construction industry; Applications; State of the art; Future Opportunities*

INTRODUCTION

The construction sector is one of the most under-digitized industries globally and its sluggish adoption of new technologies (Sivalingam, 2020; Abioye et al., 2021). Productivity and the total economic output per worker in construction have remained constant over the past decades while the productivity in retail, manufacturing, and agriculture industries has grown 1500% since 1945 (Sivalingam, 2020; Bughin et al., 2017). The construction sector is estimated to be worth more than $10 trillion per year, approximately 13% GDP of a nation (Blanco et al., 2018). This was echoed by Fateh et al. (2024) highlighted that the construction industry in Malaysia is one of the most productive sectors of the country's economy. It has also been emphasized that involvement in the construction sector plays a role in optimising people's living conditions. However, around a $1.6 trillion productivity gap within the construction industry is anticipated, arising from a loss in a lack of digitalization (Blanco et al., 2018). Overly manual operation and heavy reliance on labour have led to low productivity in construction, attributing to existing challenges from a shrinking workforce, cultural

barriers, low profit margins and low investments in innovations. Artificial intelligence (AI) at the forefront of digitalisation would be the game changer to drive magnificent improvement to the performance of the construction industry by tackling the technological and social challenges the industry faces.

As described by Abioye et al. (2021), the adoption of AI helps to improve business operations, service processes and automation. AI transforms massive data into useful knowledge for optimized performance when tackling complex problems and supporting decision-making. However, the construction industry has been slow in embracing digital technologies to move from an analogue state to a digitalization. The industry struggles to reap significant benefits from AI (Abioye et al., 2021) and people attribute this to limited applications of AI in the construction industry. Past efforts have been made to put AI into a sharper focus and extend the application scope in construction but there are still a lot of grey areas in the AI applications and future opportunities to adopt AI in construction (Abioye et al., 2021; Pan & Zhang, 2021). It is paramount to examine the application areas of AI in the construction industry and their future opportunities.

AI AND ITS CAPABILITY AND FUNCTIONS

The research of AI has been carried out for decades. Alan Turing, a British mathematician, coined the question "Can Machine Think?" in one of his papers known as “Computing Machinery and Intelligence” in 1950 (Naveen, 2020). Newell and Simon designed the first AI program in 1955. However, the word ‘Artificial Intelligence’ was introduced by John McCarthy, the father of AI during the Dartmouth Conference in 1956 (Marr, 2018; Naveen, 2020). AI was used to represent "thinking machines" due to its neutrality characteristic, beating other terms such as complex information processing and cybernetics that were being pursued for "thinking machines" at that time (Marr, 2018).

Artificial Intelligence (AI) is "*the theory and development of computer systems that can perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between language*s"(Marr, 2018). In like fashion, Merriam-Webster defines AI as a branch of computer science dealing with the simulation of intelligent behaviours in computers and the ability to imitate intelligent human behaviours by a machine. AI can be a digital computer or computer-controlled robot to work on tasks that are usually associated with intelligent beings with the ability to adapt to constantly changing situations (Copeland, 2020). In the past few years, there has a rapid growth in deploying AI technologies, with significant improvements achieved in the storage capacity, cloud capacity, robotics, and machine learning (Marr, 2018). The advent of Industry 4.0 gearing towards data-driven technologies has offered more competitive advantages to the development of AI. Increased availability of sensing technologies that are offered at an affordable price allows vast amounts of robust data to be collected (Marr, 2018). Artificial intelligence makes machines mimic humans with an ability to sense, engage and learn by building perceptions of knowledge and communicating information in natural language processing.

AI is deployed to achieve certain goals and it is believed that AI can transform the traditional construction industry to catch up with the fast pace of digitalization. It is important to determine the capability and function of existing AI technologies to explore the potential

of deploying AI in the construction industry for more effective and efficient value chains. The following section will discuss machine learning and some examples of the capability of existing AI technologies including image recognition and speech recognition.

Machine Learning

Machine learning (ML) is a subfield of AI. It is a process where the computer differentiates regularity from training data and can automatically learn and improve without being explicitly programmed (Lucci & Kopec, 2015). ML algorithms are usually separated into three different methods, which are supervised learning, unsupervised learning, and reinforcement learning. Supervised learning makes machines make decisions based on the learning from labelled datasets in categories of classification and regression while unsupervised programme refers to machines learning essential structure in unlabelled datasets categorizing into clustering and dimension reduction techniques (Abioye et al., 2021). Reinforcement learning is learning the optimal behaviour in an environment by adjusting actions based on continuous feedback to maximise a reward (Abioye et al., 2021).

Functions of Existing AI Technologies

Image Recognition

Recognizing images can be an easy task for humans; however, it has been proven to be relatively hard for computers (Gevel, Broersen & Wolvius, 2017). Pre-programmed open-source algorithms and software libraries offered by Google and IBM such as Tensorflow have allowed individuals to construct their algorithms and visual recognition, hence making this more accessible to the public (Gevel, Broersen & Wolvius, 2017). Image recognition is useful for examining the traffic flow, tracking worker behaviours, and enhancing security in construction sites. Specific algorithms with facial landmarks can boost the ability of computers to differentiate the faces of people at the sites for enhanced safety and personalized service for telecommunication.

Speech Recognition

Speech recognition is one of AI's functions by translating spoken words into written words and it is widely used on Chatbots, virtual applications, and mobile devices (Gevel, Broersen & Wolvius, 2017). Users can enter data into a computer program without typing on a keyboard, with the aid of voice recognition (Corley & Ligon, 2004). The development of speech recognition started with 'Audrey' in 1952, which was capable of identifying digits spoken in a single voice (Corley & Ligon, 2004). The utilization of speech recognition documents information by allowing the progress of recording data faster and flexibly and it is particularly useful if workers are barely literate.

APPLICATION AREAS OF AI IN THE CONSTRUCTION INDUSTRY

The investment has been made for digitising different divisions within the construction workflow. The way of designing a project has been enhanced with BIM models, particularly when project data and the management processes have now been changed to the cloud-based application. Additionally, operations management has been improved to be more automated

and "sensorized". It has been found that AI-based applications have the potential to effectively tackle the characteristics of the construction with the availability of large volumes of heterogeneous data (Pan, & Zhang, 2021). Synchronization between AI and BIM can be the key to enhanced automation and digitalization. The following section will discuss various application areas and future opportunities for leveraging AI in the construction industry. They include risk mitigation, construction safety improvement, generative design, planning and scheduling.

Risk Management and Mitigation

AI can plan, identify, evaluate, monitor and predict potential risks in terms of safety, quality, time, and cost. Risk reduction and mitigation shall be employed in the construction practice to prevent undesirable accidents and failures. For instance, subcontractors are required to work on different tasks in parallel with thousands of issues being created under a continually changing environment. AI can automatically assign priority to issues by its nature using construction language analysis (Rajagopal et al., 2018). Algorithms can understand and predict complicated things by conducting risk assessments for urgent issues to be addressed immediately (Rajagopal et al., 2018). The identified issues will be escalated to the relevant department to obtain a superintendent's attention to conduct a review of the dashboard.

Additionally, AI systems can encapsulate all the risks associated with subcontractors working on a project by analysing their behaviours, current workloads and issue management (Rajagopal et al., 2018). The algorithm will then enable a risk score assigned to each subcontractor after identifying the risks posed to each subcontractor (Rajagopal et al., 2018). The project team and construction managers can therefore work closely with the subcontractors to reduce and mitigate the risks.

Construction Safety Improvement

Construction safety is a key concern across all job sites within the construction industry. Today, plenty of photos and videos are captured and recorded daily at construction sites and this increases a considerable amount of engineering data for analysis. Modern technologies equipped with sensors improve the functionality and operation of digital technologies. These installed sensors help monitor the construction progress and sites in aspects of materials, temperature, and engine condition (Walch, 2020). The AI-based programme monitors construction sites intelligently by analysing data in real-time and provides certainty to problems and malfunctions, hence preventing project delays and downtime (Walch, 2020).

Furthermore, there are plenty of work areas under high uncertainty, dangerous structures and heavy equipment movement, hence posing great hazards on sites. With the use of AI-enabled systems and supporting technologies such as Internet of Things (IoT) devices, cameras, and sensors, AI can benefit construction site management and monitor site conditions 24 hours a day. AI systems equipped with facial and object recognition technologies can detect worker risky behaviours and notify the construction team of potential hazards, thereby reducing liability, increasing efficiency and also improving the level of security on site (Walch, 2020).

Generative Design

Design teams such as architects, designers and engineers usually spend a long time working on the project design, verifying design parameters and ensuring the design complies with the building regulations and the expected functional requirements. A significant improvement is achieved by AI by comparing it with traditional scripting and allowing more parameters to be considered (Schober, 2020). Both the engineers and designers are only required to choose the best preferable design from the system's available alternative options.

Generative design has been considered a form-finding process that can simulate nature's evolutionary approach for designing purposes (Rajagopal et al., 2018). AI generative design software explores every possible solution available and generates design alternative options to meet the specified requirements and parameters including spatial requirements, materials, performance, and cost constraints (Schober, 2020). AI software would then start to learn from repetitions of the decisions made for improving design.

Generative design enables users to produce the most dynamic design based on the required specifications, thereby enabling a more efficient, cost-effective and high-quality design process (Schober, 2020). Apart from this, generative design has the potential to increase creativity by exploring various possible ways of designing projects such as shapes and curves, probing into innovative solutions that are rarely considered by designers and engineers (Schober, 2020).

Scheduling

Inaccurate or poor planning is a main factor in construction failures. Project delays often result from challenges associated with the planning phase and delays are pervasive in large-scale construction projects. Scheduling needs to select proper plans to allocate adequate time and resources to deliver the project deliverables within the required timeframe. Common heuristics and algorithms in AI can be used to identify solutions that fit the problem constraints and user needs by using search techniques, optimisation techniques and genetic algorithms (Abioye et al., 2021).

Quality Inspection

The manual observation and traditional inspection process is extremely time-consuming, costly, tedious and error-prone, subject to countless reassessments and reworks. For instance, to prevent clashes with utilities during the construction stage of urban infrastructure projects, the project team would sometimes take weeks or months to compare the planning documents with the onsite conditions (Schober, 2020). This process can be done quickly using AI since artificial neural networks in AI can execute and perform the clash detections in one day. In addition to identifying potential clashes, AI also offers solutions to improve and optimise the plans after the inspections.

Budgeting

Different types of optimisation algorithms are powerful tools to draw up more plausible cost strategies under the optimal trade-off among the project performance factors. AI-based estimation models are instrumental in offering an early prediction of construction costs and deep learning with BIM can aid in better predictions of other factors such as bankruptcy, success, energy, carbon efficiency and waste, giving a higher accuracy of the prediction results (Abioye et al., 2021).

Logistics Planning

Transportation route optimization can be achieved with sophisticated calculations of the shortest distance between locations considering different factors such as traffic capacity and delivery window. AI technology also benefits logistics planning by optimizing transportation routes and improving traffic navigation (Blanco et al., 2018). Reinforcement learning in AI is an algorithm with the ability to learn according to trial and error, which improves the effectiveness of the optimization process and provides solutions considering objective functions of the journey duration and fuel cost (Blanco et al., 2018). AI assesses unlimited alternatives and consolidations based on similar previous projects to develop the best path and automatically revise strategies over time (Blanco et al., 2018).

RESEARCH METHODS

A review of existing literature was carried out to identify the capability and application areas of AI in construction. The questionnaire survey was chosen in the study because it can collect first-hand data from a wider community across the construction industry, such as engineers, project managers, directors, etc. in a short time. Fateh, Nik Mat, et al. (2024) mentioned that online survey was used since respondents were expected to feel more at ease answering the survey than talking openly and honestly to interviewers because the topic might reveal weaknesses in the organization. In addition, the questionnaire also can gain better insights towards the general perception of the construction community towards existing application areas and future opportunities of AI in construction. A total of 100 participants in the construction industry in Malaysia were invited to participate in this questionnaire survey. The questionnaires were distributed electronically using Microsoft Forms through emails. The data was collected in April 2021 when the COVID-19 pandemic outbreak happened in Malaysia. The electronic survey method was deemed to be suitable, considering various restrictions imposed due to the pandemic at the time of data collection.

Results and Analysis

A total of 45 responses were collected, contributing to the 45% response rate. There are a variety of backgrounds of respondents including architect, consultant, contractor, designer, developer, engineer, project manager, quantity surveyor, subcontractors, site supervisors and others. As illustrated in Figure 1, quantity surveyors have the highest number of responses (15), followed by others (8), contractors (5), designers (4), and subcontractors (4).

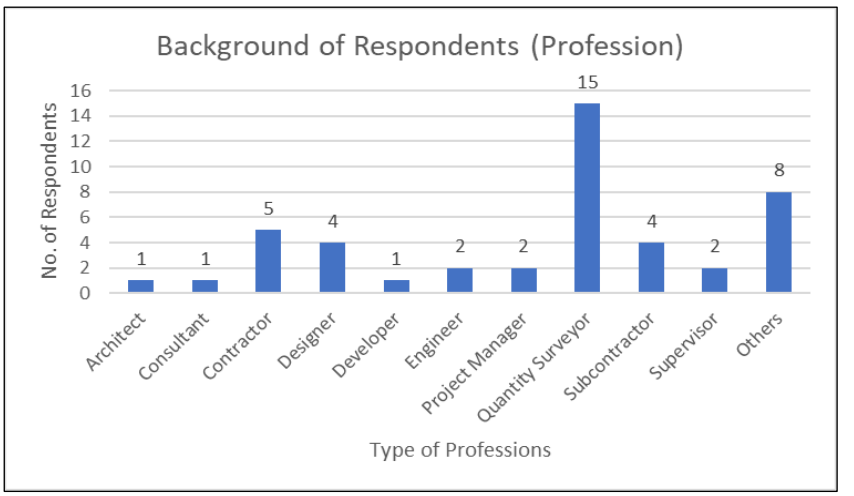

Figure 1. Background of The Respondents (Profession)

About 53% of respondents have a work experience of 1 to 5 years, followed by respondents with over 20 years (29%). The percentage of respondents with work experience of 11 to 15 years and 6 to 9 years is the same, standing at 9%. Figure 2 presents the work experience of respondents. This shows that the survey involved a high proportion of young workers as well as experienced professionals in the industry.

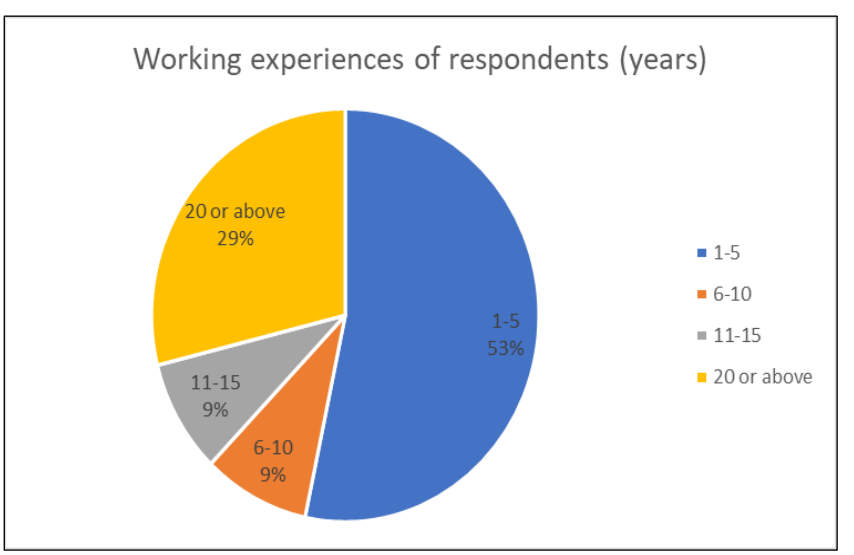

Figure 2. Working Experiences of Respondents (Years)

The respondents were asked to identify the applications of AI in construction projects. The results found that there is a significant relationship between progress monitoring and scheduling from this statistic. Progress monitoring and scheduling received the most votes, i.e. 24. Logistics is ranked second where it scores 21 votes. This is followed by surveying (20), budgeting (19), safety inspection (17), quality inspection (17), risk management (13) and others (3). Surprisingly, risk management received the lowest votes. The result is in contrast with the literature review that indicates AI helps mitigate and manage construction risks.

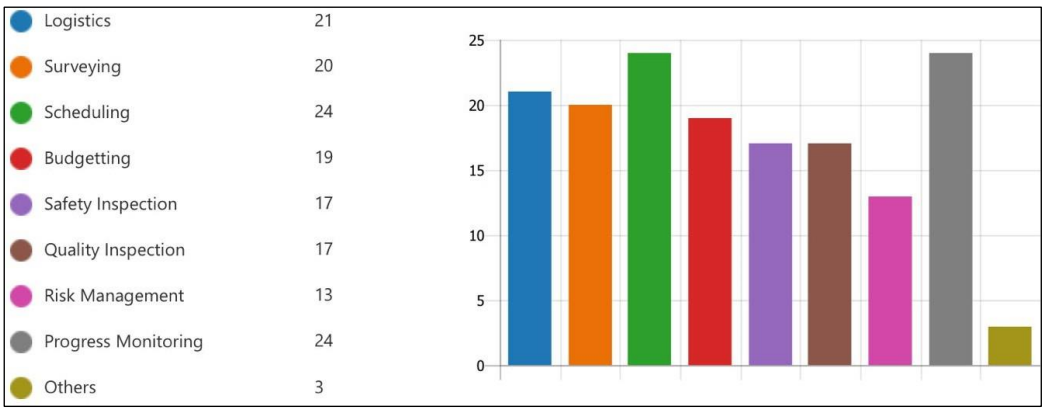

Figure 3. AI Applications Exist in The Construction Industry

The respondents were also asked if AI would affect their jobs positively or negatively. The result as presented in Figure 4 is encouraging, where about 98% of the respondents consider AI brings either positive or neutral impacts to their jobs in construction. Only 2% of respondents are sceptical about the adoption of AI in construction. The results illustrated a generally positive attitude amongst construction stakeholders towards the implementation of AI for improving construction performance.

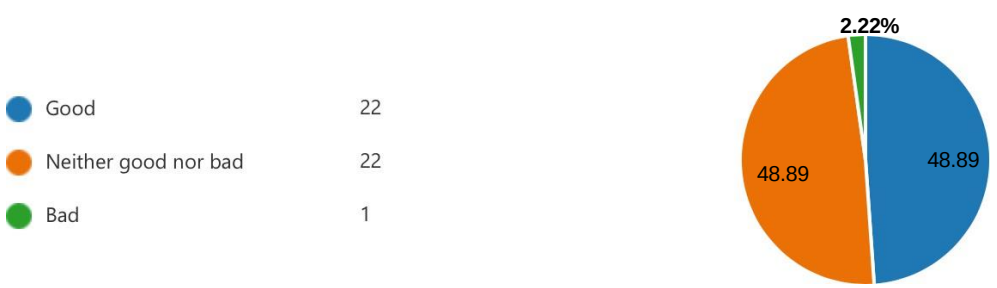

Figure 4. The Extent of AI Impacts The Construction Job

The questionnaire also investigated how likely the respondents will consider using artificial intelligence in their construction works. Figure 5 illustrates approximately 60% of respondents are very likely or somewhat likely to use AI to support their jobs. While about 27% of respondents hesitated to adopt AI, 6% of the respondents revealed that they were somewhat unlikely to use AI. No respondents perceived themselves as very unlikely to use AI in carrying out their work in the future. This result again shows that there will be an upward trend of AI applications in construction, considering the willingness of construction stakeholders to deploy AI in their future construction jobs.

Figure 5. Willingness to Adopt AI in Construction Works

The respondents then asked about the future opportunities of AI technologies in construction. According to Figure 6, AI has the potential to increase productivity (32) and improve scheduling (28), followed by surveying (27). Logistics, generative design and administrative tasks obtained the same number of votes, i.e. 26. AI is perceived to be helpful in the areas of quality control (25), claim management (23), safety improvement (23) and risk mitigation (23). Preventing cost overruns and talent retention are also recognised as a potential AI application in construction, with 22 votes and 19 votes respectively.

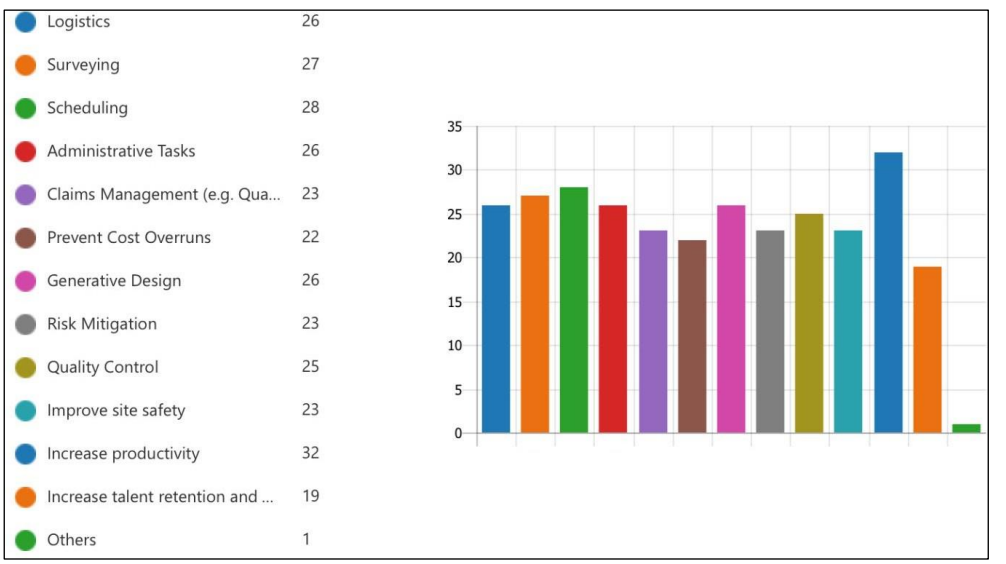

Figure 6. The Potential of AI Towards The Current Construction Industry

DISCUSSION

As revealed in the result, the power of AI in boosting the performance of the construction sector is greatly acknowledged amongst construction stakeholders. The adoption of AI in construction has gained increasing attention and people are generally positive towards a wider implementation of AI-empowered technologies in construction to increase construction productivity. The results present evidence that construction professionals appreciate the value and potential of AI, although the adoption rate of AI-enabled applications in the construction industry remains low. Omar et al. (2023) mentioned that large public investment in construction requires an advanced support system, to ensure the deliverable and give a significant impact on national growth. The findings show that there are numerous application areas to leverage AI in construction, with most application areas greatly acknowledged. Among them, progress monitoring and scheduling are the most prevalent application areas. The result supports Abioye et al. (2021) views on the use of AI-integrated BIM at the early design stage for project scheduling and planning. Abioye et al. (2021) also described that aggregating a large volume of images, videos and other data forms into AI technologies for site analytics can optimise site performance in all key areas including planning, design, safety, quality, schedule and cost. In addition, AI could also be integrated with blockchain technology, Internet-of-Things (IoT) and Building Information Modelling (BIM) for the development of a more holistic site analytics AI tool with real-time updates Abioye et al. (2021). The deployment of AI would make the supply chain of construction engineering and management more automated, efficient, intelligent, and value-driven.

CONCLUSION

AI will play a role in revolutionizing the construction industry, leading to more productive, automated, and reliable workflows in construction. The construction sector involves a lot of repetitive manual work that is prone to human errors. Integrating advanced AI techniques in construction can be the game changer to improve construction performance by carrying out designated goals effectively and efficiently. According to the study results, construction stakeholders generally perceived AI to impact construction jobs positively, and construction communities have a positive attitude towards a wider AI adoption in construction. This study also identified various application areas to leverage AI in construction. Progress monitoring and scheduling are among the popular application areas for deploying state-of-the-art AI solutions in the construction industry. By investigating state-of-the-art AI and future opportunities in construction, the study offers empirical results to support the development of AI in construction. The paper offers insights into understanding the stakeholder perceptions towards AI adoption and verifying that AI is not a theoretical subject in construction practice. The paper contributes to the body of knowledge of AI in the construction sector, hence assisting construction stakeholders to embrace this transformational technology for tackling different engineering and management problems. The power of AI to make the construction sector smarter and more efficient is greatly acknowledged.

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