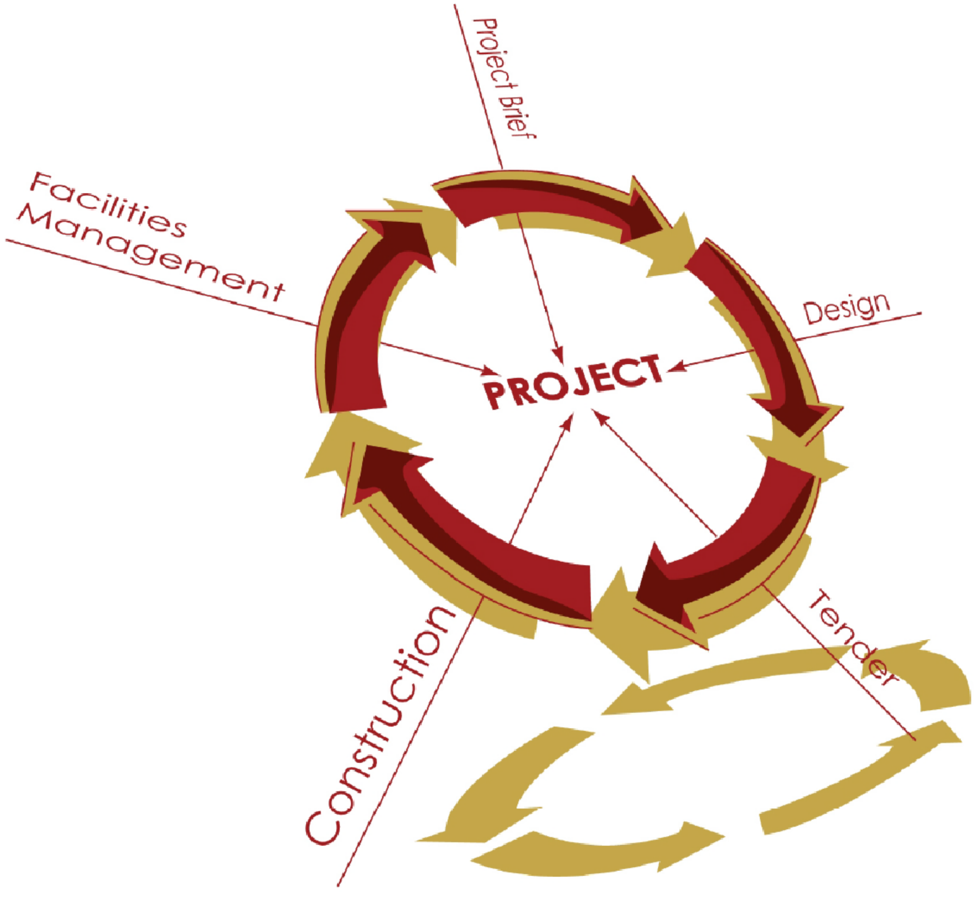
MCRJ SPECIAL ISSUE Volume 22 | No.2 | 2024 eISSN 2590 - 4140

Malaysian Construction Research Journal

1ST INTERNATIONAL VIRTUAL GO GREEN 2023 (i-VGG2023)

Building A Sustainable Tomorrow : The Role Of Digital Transformation In Leading The Way



CREAM CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA
CIDB MALAYSIA

MALAYSIAN CONSTRUCTION RESEARCH JOURNAL (MCRJ)

SPECIAL ISSUE Vol. 22 | No. 2 | 2024

1ST INTERNATIONAL VIRTUAL GO GREEN 2023 (i-VGG2023)
Building A Sustainable Tomorrow : The Role Of Digital Transformation In Leading The Way

The Malaysian Construction Research Journal is indexed in
Scopus Elsevier and ASEAN Citation Index (ACI)

eISSN No.: 2590 – 4140

Construction Research Institute of Malaysia (CREAM)
Level 14, CIDB 520, The MET Corporate Towers,
No. 20, Jalan Dutamas 2,
50480 Wilayah Persekutuan,
Kuala Lumpur, MALAYSIA.

Contents

Introduction v

Editorial Advisory Board vi

Editorial viii

DEVELOPMENT OF SAFETY AND HEALTH COSTS FORMULA (SaHeCF) FOR URBAN RAIL INFRASTRUCTURE PROJECTS IN MALAYSIA 1
Izatul Farrita Mohd Kamar, Asmalia Che Ahmad, Suraya Masrom and Nor Suzila Lop

CHEMICAL ENVIRONMENTS EFFECTS ON MECHANICAL PROPERTIES OF KENAF FIBRE REINFORCED PULVERISED FUEL ASH CONCRETE 18
Norazura Mizal Azzmi, Jamaludin Mohd Yatim, and Nazhatulzalkis Jamaludin, Nadira Ahzahar, Zuraihana Ahmad Zawawi and Siti Zubaidah Hashim

UNVEILING THE NATURE OF DEFECTS OCCURRENCES IN CONSTRUCTION PROJECTS 31
Najihah Rahimin, Haryati Mohd Isa, Thuraiya Mohd and Nur Azfahani Ahmad

OPERATIONAL SAFETY COMPLIANCE DURING THE OPERATIONAL AND MAINTENANCE PHASE OF CONSTRUCTED PETROL STATIONS 47
Mazlina Zaira Mohammad, Hafizuddin Zubir, Nor Syamimi Samsudin, Natasha Khalil and Azman Zainonabidin

BUILDING A SUSTAINABLE FUTURE: DESIGNING AN ENERGY-EFFICIENT PUBLIC HOSPITAL IN MALAYSIA 63
Jamaludin Muhammad, Amirul Amin Ismail, Muhammad Faris Arman, Mohammad Syathir Amini Shahbudin and Zaniman Sulong

UNVEILING THE DRIVERS OF FLASH FLOODS IN CONSTRUCTION SITES: INSIGHTS FROM FACTORS FOR RESILIENT URBAN DEVELOPMENT 78
Siti Nur Aishah Mohd Noor, Mohd Khairul Amri Ramly, Puteri Sidrotul Nabihah Saarani, Zailawati Khalid and Mohamad Badruzhisham Mohd Mazlan

CHALLENGES IN SELECTING THE APPROPRIATE TYPE OF INDUSTRIALISED BUILDING SYSTEMS (IBS) IN HOUSING PROJECTS: THE ROLE OF INTUITION AND HEURISTICS APPROACH 88
Mohd Rofdzi Abdullah, Mohd Najib Abd Rashid and Wan Nur Syazwani Wan Mohammad

DEBRIS FLOOD DISCHARGE ANALYSIS AS A BASIS FOR SABO DAM PLANNING ON THE LEPRAK RIVER AT SEMERU MOUNTAIN, EAST JAVA 100
Andrea Sumarah Asih, Wahyu Kurniawan and Jati Iswardoyo

FACTORS AFFECTING THE EFFICIENCY OF FACILITIES MANAGEMENT (FM) IN AGED CONDOMINIUM: A CASE STUDY OF KUALA LUMPUR 110
Farhan Md Dahlan, Ashrof Zainuddin, Mohd Hasrol Haffiz Aliasak, Siti Rosemawar Mohd Sahi and Norbaizura Abdul Wahab

MEASURING MAINTENANCE AND OPERATION IMPACTS OF HIGH-RISE RESIDENTIAL BUILDINGS TOWARDS SUSTAINABILITY 122
Martina Jasoffa Omar, Mazlina Zaira Mohammad, Nor Syamimi Samsudin, Natasha Khalil, Iryani Abdul Halim Choo and Nur Dalila Nadzri

AN OBSERVATION ON THE IMPLEMENTATION OF BIOPHILIC DESIGN STRATEGIES IN MALAYSIAN PLATINUM-RATED GREEN OFFICE BUILDINGS 147
Asniza Hamimi Abdul Tharim, Sitinur Kamilah Mohd Idris, Asmalia Che Ahmad, Edi Purwanto and Issa Tafridj

SPATIAL RISK ASSESSMENT OF SICK BUILDING SYNDROME IN A UNIVERSITY SPACE: A GIS-BASED PHYSICAL CONTEXT MAPPING APPROACH 163
Syed Mohammad Asyraf Syed Mohammad Anuar, Abdul Rauf Abdul Rasam, Nawfal Kamarul Bahrain, Mawar Masri, Jamalunlaili Abdullah and Colonius Atang

EXPLORING THE BARRIERS TO ECO-INNOVATION IMPLEMENTATION IN CONTRACTOR FIRMS 177
Siti Sarah Mat Isa, Nazirah Zainul Abidin, Wan Norizan Wan Ismail, Norhafizah Yusop and Norsyazwana Jenuwa

UNVEILING THE PATH TO SUSTAINABILITY: EXPLORING THE CURRENT PRACTICES OF CORPORATE REAL ESTATE SUSTAINABLE MANAGEMENT FOR GREEN OFFICE BUILDINGS 193
Nurul Sahida Fauzi, Timothy Tunde Oladokun, Siti Nadiah Mohd Ali, Huraizah Arshad, Nor Nazihah Chuweni and Nor Aini Salleh

EXPLORING CONCEPTUAL MODEL ON THE KEY CRITERIA AND COMPONENTS OF GREEN BUILDING CONSTRUCTION MATERIALS FOR HOTEL OPERATIONAL SUSTAINABILITY 205
Nur Adlina Ismail, Natasha Khalil, Suwaibatul Islamiah Abdullah Sani, Noor Akmar Shah Nordin and Husrul Nizam Husin

ANALYSIS OF MERCURY (Hg) HEAVY METAL IN RIVERS ARTISANAL GOLD MINING KALIREJO AREA, KOKAP DISTRICT, KULON PROGO REGENCY SPECIAL REGION OF YOGYAKARTA 223
Shilvyanora Aprilia Rande, A. A Inung Arie Adnyano and Hendro Purnomo

BIOPHILIC DESIGN TO ENHANCE THE HEALING ENVIRONMENT IN MALAYSIAN PRIVATE HOSPITALS: EXPERTS’ PERSPECTIVES 233
Nurul Zalifah Zakaria, Suriati Ahmad and Atikah Fukaihah Amir

PRIORITISATION OF INDICATORS FOR ASSESSING THE OPERATIONAL PERFORMANCE OF PUBLIC PRIVATE PARTNERSHIP (PPP) PROJECTS USING AHP MULTI-CRITERIA DECISION-MAKING METHODS 245
Nor Suzila Lop, Kharizam Ismail, Haryati Mohd Isa, Natasha Khalil and Ellyyanti Tahir

BIM-BASED PROJECT CONTRACTORS' PERSPECTIVE OF BUILDING INFORMATION MODELING (BIM) USES IN THE BIM EXECUTION PLAN 265
Wan Nur Syazwani Wan Mohammad, Shahela Mamter, Raja Nurulhaiza Raja Nhari, Nurhasyimah Ahmad Zamri, Hasni Suryani Mat Hasan and Norzaidi Haron

A MODEL FOR ASSESSING THE COMPETENCY OF FACILITY MANAGERS IN PRE-CONSTRUCTION HOSPITALS IN MALAYSIA 277
Norsyazwana Jenuwa, Wan Norizan Wan Ismail, Norhafizah Yusop, Siti Sarah Mat Isa and Mohd Saidin Misnan

Introduction

This special issue in Malaysian Construction Research Journal (MCRJ) is compiled in conjunction with the **1st International Virtual Go Green 2023 (i-VGG2023)** conference that was conducted virtually from 21st to 22nd September 2023. This conference was successfully hosted by the Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA Perak Branch in collaboration with Research Office, Industry, Community & Alumni Network (PJIMA), Yogyakarta National Institute of Technology (ITNY) Indonesia and Construction Industry Development Board (CIDB) Malaysia.

A total of 121 research papers were successfully presented at the conference themed "**Building a Sustainable Tomorrow: The Role of Digital Transformation in Leading the Way**". The theme underscores the importance of leveraging digital technologies to drive sustainability in the construction industry to become more resilient and adaptable structures. This is particularly important in the face of climate change, as buildings need to be designed and constructed to withstand changing environmental conditions. Aligning to The Construction 4.0 Strategic Plan (2021-2025) and National Policy on the IR 4.0 (Industry4WRD), digital transformation plays a pivotal role in driving sustainability within the construction industry. Inevitably, digital transformation supports the integration of sustainable practices such as designing energy-efficient buildings and incorporating green construction materials.

Hence, the objective of the i-VGG2023 conference is to achieve the development of research based on the green and sustainability agenda of United Nation Sustainable Development Goals (SDGs) at both national and international levels. At the same time, this conference provides a publication platform for academic members and coordinates targeted activities for the achievement of academic publication towards knowledge dissemination in the construction industry. It is hoped that the knowledge sharing through this publication helps to contribute ideas to the creation of a more sustainable and resilient built environment for future generations via embracing innovative technologies and practices.

Assoc. Prof. Sr Dr. Natasha Khalil
Editor
1st International Virtual Go Green 2023,
The College of Built Environment,
Universiti Teknologi MARA (UiTM) Perak,
Seri Iskandar Campus,
32610 Seri Iskandar, Perak,
MALAYSIA.

Editorial Advisory Board

Editorial

Welcome from the Editors

Welcome to this special issue in Malaysian Construction Research Journal (MCRJ) for the 1st International Virtual Go Green 2023 (i-VGG2023). We would like to express our sincere gratitude to our contributing authors, reviewers, organizers and readers.

This special issue in MCRJ for i-VGG2023 contains twenty (20) interesting papers covering the theme of "Building a Sustainable Tomorrow: The Role of Digital Transformation in Leading the Way". It is hoped that the readers would greatly benefit from the scientific content and quality of papers published in this issue.

Brief introduction of each article is given as hereunder:

Izatul Farritta Mohd Kamar et al., have developed a safety and health costs formula for urban rail infrastructure projects that consists variable factors of Client Costs, Construction Period, Employer Costs, Types of Accident Classification, Days of the Stop Work Orders, and the Location of Body Injury. The findings offer a reliable calculator that may assist stakeholders in estimating the costs related to safety and health in construction projects and plan insightful safety measures plan.

Norazura Mizal Azzmi et al., have investigated the effect of chemical environment on the mechanical characteristics of pulverized kenaf fibrous fuel ash concrete as construction materials at a volume percent of 0.75 with a particular emphasis placed on the consequence of acidic, alkaline and sulfate solutions. It is revealed that this concrete composite (KFPC, cement pastes with 25% fly ash replacement with kenaf fibre) exhibit exceptional mechanical performance and has flexural strength in both normal and aggressive conditions.

Najihah Rahimin et al., have analysed the prevalence of defects occurrences in construction projects through systematic literature review (SLR) approach. The study has discovered that the major causes are derived from design defects, material defects, workmanship defects, and maintenance defects, where eleven categories of defects are workmanship, design, maintenance, factory, lack of protection, material, documentation defects, nature, vandalism, mishandling by users' and wear and tear.

Mazlina Zaira Mohammad et al., have analysed a comparison study between the Behaviour Base Safety (BBS) elements in the construction industry that affected the safety culture practice in the operation and maintenance phase in petrol stations, as sample building cases. The outcomes of this study show the differences between among element of BBS, including which element of BSS was the most efficient approach and effective factor affecting based behaviour safety or safety performance in the workplace.

Jamaludin Muhammad et al., have identified the success criteria for the passive design approach commonly used by designers, especially architects, for local public hospital design construction projects. It considers various aspects such as building orientation, efficient layout, natural and artificial lighting, efficient Heating, Ventilation, and Air Conditioning (HVAC), and other mechanical systems. The findings highlight the potential benefits of an energy-efficient design, including reduced operational costs, improved patient comfort, and a positive environmental impact.

Siti Nur Aishah Mohd Noor et al., have unveiled the root causes of flash floods in construction sites where the causes encompass clogged drainage systems, rapid urban development, and the failure to construct proper damp or levee structures. The study has formulated strategies that are able to bolster the resilience of construction sites and curtail the adverse consequences of flash flood events.

Mohd Rofdzi Abdullah et al., have identified the significant decision-making approaches and behavioural patterns in selecting the Industrialised Building System (IBS) types for housing construction projects as Decision Support Tool (DST). The result revealed that there is a utilization of intuition from the top and middle managers from a large-scale contractor organisation as the ability to make decisions based on gut feelings or implicit knowledge, and experiences.

Andrea Sumarah Asih et al., have proposed a reference planning design for construction of sabo dam structure by analysing the sediment concentration and debris flood discharge at The Leprak River, East Java Indonesia, using Standar Nasional Indonesia (SNI). Based on the analysis results, the sediment concentration is 0.31, while the debris flood discharge is 262.041 m3 /s.

Farhan Md Dahlan et al., have determined the factors that contributed to the efficiency of Facilities Management (FM) practices in aging condominiums that pose a greater structural risk. The research concluded that three of the most critical factors affecting the efficiency of FM in aged condominiums were financial, learning and growth, and pre-conditions during the developer’s transition period.

Martina Jasoffa Omar et al., have identified the relationship between the maintenance and operation of high-rise residential buildings and sustainability issues due to the rising demand for high-rise residential buildings in developing countries. The correlation results are based on the three indicators of sustainability; economic, environment and social that focus on building maintenance cost, environmental impacts and the usage of recycle materials and renewable energy, and awareness on sustainability behaviours.

Asniza Hamimi Abdul Tharim et al., have identified the biophilic design strategies in Malaysia’s platinum-rated green office buildings and observed through GBI checklist for direct experience of nature, indirect experience of nature, and experience of space and place. The findings indicated that the lower zone of the office buildings has the highest score of biophilic elements in lighting, air, plants, colour, image, and ecological compared to the upper zone.

Syed Mohammad Asyraf et al., have investigated the spatial risk level of Sick-Building Syndrome (SBS) at university buildings using the Geographical Information System-Multi Criteria Decision-Making (GIS-MCDM) method and the JKR’s SBS criteria in a physical context. The finding has shown that some of the CBE's spaces were affected by SBS, especially in the central region of the administration building of block A, due to some physical effects with the leaky roof, poor air conditioning, and poor ventilation.

Siti Sarah Mat Isa et al., have explored the barriers of eco-innovation (EI) implementation faced by large contractor firms in the Malaysian construction industry through semi-structured interviews with G7 contractor firms. The results revealed that the barriers to EI derived from four factors; firm-specific barriers, cost difficulties, people-related barriers, and external pressures.

Nurul Sahida Fauzi et al., have analysed the current practices of Corporate Real Estate Sustainable Management (CRESM) for green office buildings through qualitative approach involving semi-structured interviews with construction experts. The analysis demonstrates the widespread implementation of Green Building Index (GBI) (as guiding element), Building Management Systems (BMS), Building Information Modelling (BIM), Performance Measurement Systems (PMS), and Sustainable Performance Measurement Systems (SPMS) which reflects the commitment of organizations to adhere to sustainable practices and optimize building.

Nur Adlina Ismail et al., have established a conceptual model of key criteria of green building construction materials that relates to the hotel's operational sustainability towards economic, environmental and social aspects. The findings finalised that there are 11 criteria of green building materials consists of Manufacturers' Identification, Materials Declaration, Life Cycle Assessment, Indoor Air Quality Performance, Toxic Disposable, Design Adaptability, Regional Materials, Durability, Reusable Design, Renewable Resources and Water Efficiency.

Shilvyanora Aprilia Rande et al., have analysed the condition of surface water against the content of dissolved Hg in the Plampang River flow from gold mining activities, where gold mining projects contribute to the demand for construction materials as mines are developed, and associated infrastructure is built. The study revealed that sediment and water samples close to community gold mining has a high concentration of mercury, thus indicates that the mercury content is eroded and revealed into river.

Nurul Zalifah Zakaria et al., have established the biophilic design elements checklist for Malaysian private hospitals through experts' perspectives, towards encouraging a better green hospital development. The findings revealed that natural light, water features, plants or landscape, pets' area, image of nature, natural materials, natural or soft colours, shape and form, prospects, refuge, complex and orderly design, culture and ecology are reliable items as biophilic design elements for hospital design.

Nor Suzila Lop et al., have analysed the relative importance weight for Key Performance Indicators (KPIs) in the procurement contract in measuring the operational performance of Public Private Partnership (PPP) construction projects using Analytical Hierarchy Process (AHP) approach. From the AHP analysis, the most important element is mechanical (0.274) and followed by electrical (0.236), operational element (0.193), civil, structural and architectural (0.135), telecommunication (0.076), landscape and ground (0.044), pest control and wildlife control (0.042).

Wan Nur Syazwani Wan Mohammad et al., have highlighted the key factors of Building Information Modelling (BIM) implementation that focus on the planning-to-design stage, based on the BIM execution plan from the perspective of the BIM-based project contractors. The findings showed that the planning phase via 4D modeling was remarked as the upmost significant use in the planning-to-the-design stage. The 4D modeling involves time-related information, installation periods and sequences, workflow rescheduling, construction visualization, material optimization, project coordination, and project safety.

Norsyazwana Jenuwa et al., have examined the relationship between facility managers' competence in the pre-construction hospitals with six relevant competencies; leadership and strategy, finance and business, operation and maintenance, communication, human factors, and real estate management, using the analysis technique of Modelling Structured Equations Partial Smallest Square Estimation (SEM-PLS). Out of six competencies, human factor competencies are strong predictors with the competency of the facility managers, followed by real estate management competencies, operational and maintenance competencies, and communication competency.

DEVELOPMENT OF SAFETY AND HEALTH COSTS FORMULA (SaHeCF) FOR URBAN RAIL INFRASTRUCTURE PROJECTS IN MALAYSIA

Izatul Farrita Mohd Kamar[1*], Asmalia Che Ahmad[1], Suraya Masrom[2] and Nor Suzila Lop[1]
[1]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Seri Iskandar Campus, 32610, MALAYSIA
[2]Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Perak Branch, Tapah Campus, 32610, MALAYSIA

**Corresponding Email: izatul739@uitm.edu.my*

Abstract
The rapid development of the Klang Valley Mass Rapid Transit (KVMRT) System has contributed to a substantial amount of costs related to safety and health issues. Numerous scholars have analysed the two recognised typologies of safety and health costs, namely, prevention costs and accident costs. However, studies on the prevention costs during the pre-construction stage of a project are quite rare and have mainly focused on the financial losses or accident costs incurred by the contractor and victim. Many of the rail construction companies or stakeholders lack knowledge and information concerning the calculation of the costs as the existing safety cost model was developed from the manufacturing sector. Moreover, models from the construction sector are limited to general construction. Therefore, the research aims to develop a safety and health costs formula for urban rail infrastructure projects. Using a quantitative research approach, a total of eight viaduct/guideway packages of the MRT 1 (SBK Line) project and ten viaduct/guideway packages of the MRT 2 (SSP Line) projects were examined to obtain data for the study and analysed using the Statistical Package for Social Sciences (SPSS) software. The study found that the Client Costs were affected by the Construction Period, the Employer Costs were related to the Types of Accident Classification, the total number of Days of the Stop Work Orders, and the Location of Body Injury. The Victim Costs were related to the number of days the victims were on Medical Leave. Finally, validation by simulation, the safety and health costs formula were successfully developed. The findings of the study offer a reliable calculator that may assist stakeholders in estimating the costs related to safety and health in construction projects, and, hence, enable them to plan their investments in terms of safety measures in a more insightful manner.

Keywords: *Safety and Health Costs; Costs Formula; Costs Weightage; Costs Calculation; Urban Rail Infrastructure Projects*

INTRODUCTION

The construction industry in Malaysia contributed enormously towards Malaysia`s national economic growth. The construction industry plays a main role in the country`s development as well as making more contributions towards economic growth and employment. However, compared to the other industries, the construction industry is considered unique because most of its activities often take place outdoors and under conditions that are not conducive to safety and health. The sites are frequently considered to be among the dangerous places for both workers and publics (Minglong et al., 2023; Choi et al., 2020; Misnan & Mohammed, 2007). Alcumus (2022) assesses that the average fatality rate in the construction sector is more than twice as high as that in all other industries.

Previous studies have shown that various losses have been incurred when accidents occurred (Davies & Teasedale, 1994; Jallon et al., 2011b; Goetsch, 2013; Pellicer et al., 2014;

Feng et al., 2015) and these losses may include costs to victims and their families as well as to employers and society (Mossink & De Greef, 2002). In addition, construction injuries not only give great cause for humanitarian concern but also the high cost of injury or death and this motivates a more sustaining safety performance in the construction industry (Rajendran 2009). In the event of an accident on a construction site, it involves a huge amount of cost. The same is true in the operation of urban railway projects. However, the quantification, evaluation and identification of many losses incurred in an accident are hidden and difficult to quantify, evaluate and identify (Teo & Feng, 2011; Feng et al., 2015; Pellicer et al., 2014). Furthermore, existing research indicates that employers commonly underestimate the true financial impact of such events (Ryan et al., 2019). Moreover, the existing model (for example, the Traditional cost model) is difficult to apply directly in construction because they were developed specifically for the manufacturing sector (López-Alonso et al., 2013). As a result, the objective of this research is to develop a safety and health costs formula for urban rail infrastructure projects in Malaysia. The findings from this research could heighten the importance of the effect of an accident on the stakeholders' company economic and budgeting.

ACCIDENT COSTS FORMULA AND CALCULATIONS

Accident costs are usually calculated with much uncertainty. The study of the costs of accidents was pioneered by Heinrich (1931) more than 80 years ago. Among the several sources of uncertainty in the calculation is in determining the right component of the costs. Several approaches using formula calculations were proposed for quantifying the actual total cost of an accident. Table 1 shows several accident costs that were formulated by previous researchers.

Aaltonen et al. (1996) developed the Accident Consequence Tree (ACT) Method, which is based on the fault tree method for calculating accident costs. The consequences of the accident to the injured worker, the company and the national economy were identified with the aid of the consequence tree. The ACT Method was applied to workplace accidents in 18 Finnish furniture factories of different sizes and product types. Tang (1997) revealed that the accident costs in the construction industry are divided into the financial costs of the construction accident and the social costs of the construction accident. The financial costs of the construction accidents represent the losses incurred by private investors, such as contractors, due to the occurrence of construction site accidents. Whilst social costs are any item that will result in the utilisation of national resources. If there were no accidents, the utilisation of these society's resources could have been saved. The costs are based on the society's point of view. The costs incurred by society are in a broader perspective and the costs are higher than the financial costs incurred by the employers.

On the other hand, the accident costs, which were formulated by Hammer and Price (2001), are more general, and not specific to any group that incurs the cost. The accident costs were not classified into direct costs and indirect costs, which are commonly recommended by other researchers. They classified the total accident costs as the total sum of the accident prevention costs + legal costs + immeasurable costs + immediate losses + insurance costs + other safety costs + rehabilitation cost + welfare cost. Poon et al. (2008) developed the accident costs formula from society's point of view. He defined social costs as any item that will result in the utilisation of national resources. These costs were incurred due to worker's injury and fatality and were separately formulated due to different accident severity.

Table 1. Accident Costs Formula and Calculation from Previous Researchers

Researcher	The Formula of Accident Costs
Aaltonen et al. (1996)	Total Costs = Individual Costs + Company Costs + National Economy The Accident Consequence Tree (ACT) Method was developed based on the fault tree method for calculating accident costs.
Tang (1997)	Accident Cost = Financial Cost + Social Cost Financial Cost: 1) Loss due to the injured person. - Compensation paid to the injured worker. - Disability compensation. 2) Loss due to the inefficiency of the worker. 3) Loss due to medical expenses 4) Loss due to fines and legal expenses 5) Loss of productivity of other employees 6) Loss due to damaged equipment or plant 7) Loss due to damaged material or finished work 8) Loss due to idle machinery or equipment Social costs are defined as the losses incurred by society due to the occurrence of construction site accidents.
Hammer and Price (2001)	Total Cost = Accident Prevention Costs + Legal Costs + Immeasurable Costs + Immediate Losses + Insurance Costs + Other Safety Costs + Rehabilitation Cost + Welfare Cost
Poon et al. (2008)	Social Cost = Daily Wage x 365 days x (retirement age 65 – injury age) x % disability/100 If the accident involves a fatality, it will be calculated by: Social Cost = Daily Wage x 365 days x (retirement age 65 – death age)
Gavious et al. (2009)	Total Cost = Cdirect + Cindirect + Cpayment + Cimmeasurable Where, the parameters that reflect the direct costs, indirect costs, payment costs and immeasurable costs are formulated as: Cdirect = Cdamage + Cmedical + Cfine + Cinsurance Cindirect = Ccapacity lost + Cschedule + Crecruit + Cwork time + Cwip + Cmang Cpayment = M (PaynewW1) $\sum_{i=e}^{W2} \mathrm{Bi} - \mathrm{NI} \times \mathrm{W2}$ Cimmeasurable = Creputation + Cmorale
KLIACS JKKP (2013)	Total Cost = individual cost + employer cost + stakeholder cost Where, Individual cost = immediate loss of earnings + loss of future earnings + permanent afflictions + health and rehabilitation costs + administrative costs + finding a new occupation cost + costs of housewives' work and relatives' work to take care of the injured workers Employer cost = Damage Cost + Medical Cost + Fine Cost + Insurance Cost + Search and Rescue Costs + Capacity Lost + Schedule Cost + Recruiting Cost + Work Time Cost + Work in Progress Cost + Management Cost + External Investigation Cost + Accident Report Cost + Payment Cost + Immeasurable Cost Stakeholder cost = Government cost + Consultants cost + Client cost
HSE (2014)	Total Cost = Individual Cost + Employer Cost + Government Cost Where, Individual cost = Loss of Income + Compensation Payments + Health and Rehabilitation Costs + Administrative Costs + Non-Financial Costs. Employer cost = Sick Pay Payments + Insurance Premiums + Production Disturbance Costs + Administrative and Legal Costs. Government cost = Costs arising from loss of earnings to the individual (benefits payments, reduction in tax and national insurance receipts) + Medical Treatment Costs and Rehabilitation Costs + Administration and Legal Costs

Researcher	The Formula of Accident Costs
Pellicer et al. (2014)	CC = [0.0745*BS] + [β*BC] + [EX*NH*10-6*ΣjkNAjk*CTjk] - [0.75*GS*EX*NH*10-6*Σjk(DLjk - 1)*NAjk] Where, CC = Total Expected Cost of Occupational accidents BS = Base Salary β = Ratio of safety budget invested in the prevention cost BC = Budget of the construction project EX = Exposure time at the construction site FI NH = Number of man-hours per million hours worked for the entire Spanish construction industry NA = Number of accidents in the entire Spanish construction industry CT = Cost of the accident per type GS = Daily gross salary DL = Days of medical leave j = accident type; k = severity of the accident

Gavious et al. (2009) proposed methods for the reliable estimation of the costs involved in industrial accidents in an organisation, especially concerning production loss. The industrial accident costs contained two major cost categories, which are direct costs and indirect costs. Researchers have considered all the parameters that affect costs when an accident occurs. The total cost of an industrial accident is the sum of its direct costs and indirect costs.

Nevertheless, KLIACS JKKP (2013) explained that the formula for the total costs associated with workplace injuries is made up of the three distinct groups to whom the cost falls, namely the accident victim, the victim's employer, and other stakeholders. This combination contributes to improving the ease of data collection and the quantity and quality of data collected. The stakeholders are responsible during the design stage of the construction. The client needs to invest in each safety prevention cost component that is stated in the bill of quantities. They also need to bear the consultant's fee based on certain charges. The relevant stakeholder, when an accident occurs, is the government. The government needs to pay the compensation cost to the victim. Combining the costs of these three groups gives the total cost as a whole.

The HSE (2014) took a different approach. The formula for the total cost associated with workplace injuries in Great Britain is made up of the three different groups that bear the cost, namely, individuals, employers, and the government. Combining the costs of these three groups gives the actual total cost of workplace injuries. Pellicer et al. (2014) developed a mathematical model as a method that would permit employers to compute the estimation for each cost category. This estimate should be applied during the construction project design phase and execution phase at the work site. However, the model still has a few limitations. Reducing the number of workers exposed to risks if the prevention costs increased, would substitute the dangerous occurrence at the construction site. Designing a reliable correlation between the prevention costs invested and the accidents that occur at the construction site is not easy. Multiple case studies are needed to obtain reliable data to propose such a correlation and must be validated by additional data. Moreover, in its current form, the model is not specific to any project type and does not define the project characteristics.

In short, the literature highlights the existing accident cost formulas across the globe, but their relations to the study environment for urban rail infrastructure projects are limited. The diffusion of a new cost formula could provide valuable information for future calculations when accidents occur at the MRT and LRT sites. To develop a systematic calculation for estimating the total cost of accidents with a focus on rail infrastructure projects, all the existing formulas that were developed by previous researchers are considered. Based on the previous studies, the formula for the total costs related to the accident is divided into employer cost and victim cost. The employer cost is further divided into two, direct accident cost and indirect accident cost. The direct accident cost is the cost that is accrued directly from the accident. The costs are typically covered by the Social Security Organisation (SOCSO) and an insurance company (KLIACS JKKP, 2013). While the indirect accident cost is the cost item that is not covered by the worker's compensation insurance. For the victim cost, the costs are those borne by the victim when the accident happened. Usually, the cost items incurred by the victim are from the indirect accident costs, which is uninsurable.

METHODOLOGY

The process for developing the safety and health costs formula is by applying the first stage (planning phase), the second stage (conducting phase), and the third phase (applying phase) as provided in Figure 1. The activities in each of the phases are reviewed as follows:

Stage 1: Planning Phase – Safety and Health Costs Input

A wide variety of parameters is necessary to calculate the safety and health costs for urban rail infrastructure projects. The determinants of the safety and health cost bearers, cost components, cost factors, and the cost categories of this study are involved in this planning stage. The safety and health cost parameters were determined and developed through the literature review, preliminary survey, and main survey. The responses to the safety and health cost inputs are to ensure that the model is correctly directed to the inputs.

Stage 2: Conducting Phase – Safety and Health Costs Process

In this phase, the critical phases for estimating the safety and health costs and the types of projects that are significant for safety and health costs were identified based on the preliminary survey results. In addition, the potential informants for the main study were specified to get more accurate data (safety and health costs incurred) for the selected project. For the main survey of this study, the Safety and Health Costs Survey (SHCS) form was distributed to the potential informants, i.e., the contractors engaged in work packages for urban rail infrastructure projects. After each of the costs related to the safety and health costs incurred by the stakeholders was collected, the data were analysed. Identification of the safety and health costs components that are commonly incurred by the cost bearers of urban rail infrastructure projects was achieved in this phase. The study focused on two types of safety and health costs, namely prevention costs and accident costs (direct and indirect costs).

The analysis of data was conducted after the safety and health costs input were determined, which involved making sense of the data in terms of the outlined inputs at the beginning of the formula's development. Further, the safety and health cost formula and cost weightage for each safety and health cost component were developed to ensure this formula can be applied in estimating the safety and health costs for urban rail infrastructure projects.

Stage 3: Applying Phase – Safety and Health Costs Output

In the final stage of the formula's development, the application phase of this formula involves reporting the findings of the safety and health costs formula. The findings were documented and the valuable input from the respondent's response sets is the basis for action. The action towards improving this formula as an estimating tool for the safety and health costs incurred in urban rail infrastructure projects was directed to the relevant management that was accountable for accomplishing the actions.

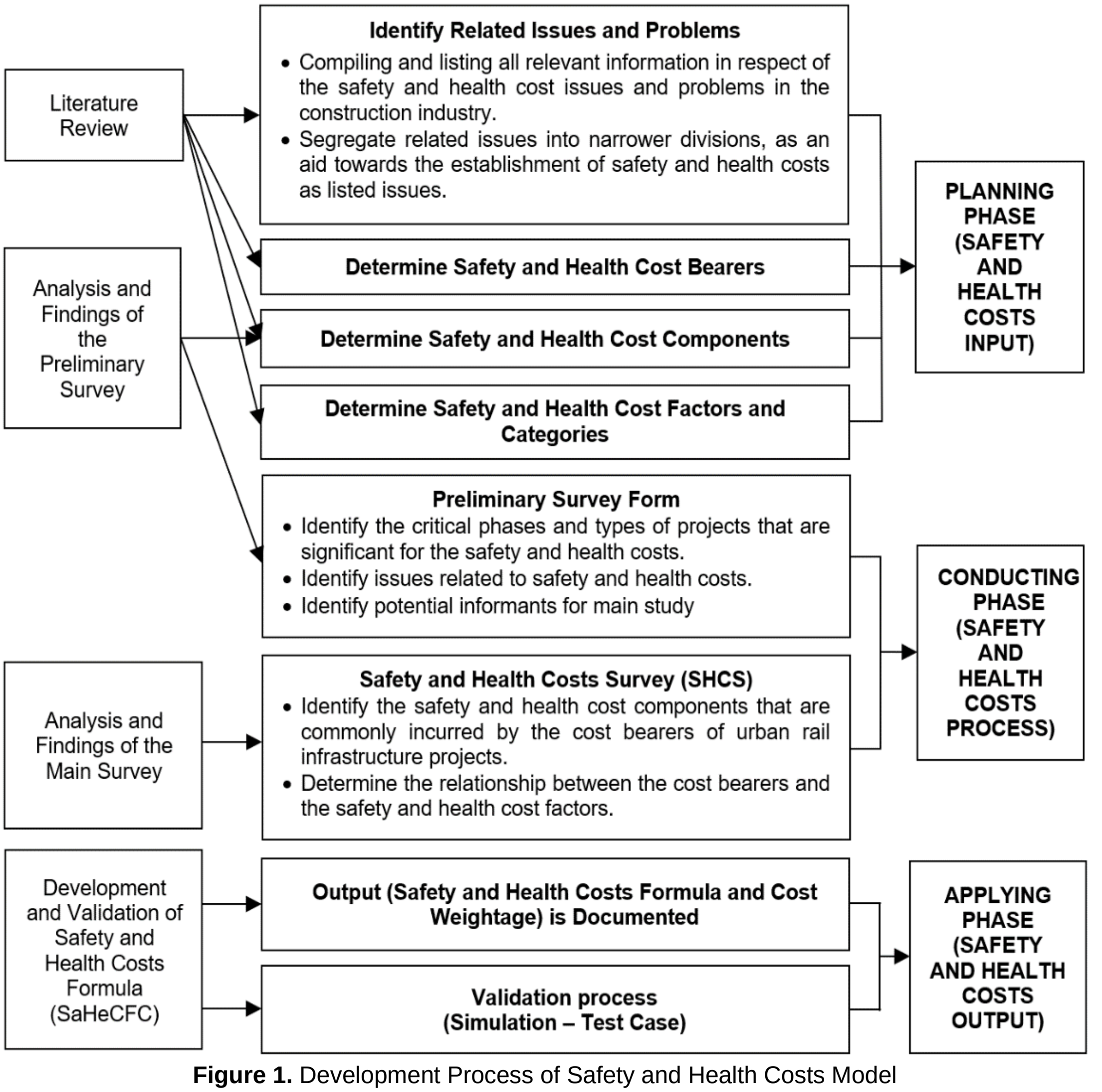


Figure 1. Development Process of Safety and Health Costs Model

The activities in the applying phase consist of the documentation of safety and health cost formulas and cost weightage for each safety and health cost component. The safety and health cost formulas were developed based on the previous study, namely, divided into client costs, employer costs, and victim costs. While the novelty of this research was the development and determination of the cost's weightage for each safety and health cost component and category. The cost weightage is important to help the stakeholders in estimating each of the cost components incurred for the prevention costs and accident costs. Moreover, the cost weightage also illustrates the level of hazard for each type of accident involved at the MRT site. Finally, the formula was validated by the simulation (formula testing) to measure the reliability of the formula.

RESULTS AND DISCUSSION

Development of Safety and Health Costs Formula

To develop a systematic safety and health costs calculation for urban rail infrastructure projects, all the existing formulas that were developed by previous researchers were considered. Therefore, the formulas for the total cost related to safety and health costs for urban rail infrastructure projects were divided into weighted client costs, weighted employer costs, and weighted victim costs. The weighted client costs are the costs incurred by the client in the pre-construction phase. These costs are known as the prevention costs. While the weighted employer costs include the accident costs, both direct and indirect. The direct costs are the costs that are accrued directly from the accident. The costs are typically covered by the Social Security Organisation (SOCSO) and insurance companies. While the indirect costs are the cost items that are not covered by the worker's compensation insurance.

For the weighted victim cost, the costs incurred by the victim when accidents happen are from the indirect costs, which is uninsurable. This combination contributes to improving the ease of data collection and the quantity and quality of the data collected. The costs were formulated based on the regression analysis and results. The safety and health cost factors that influence the weighted client costs, weighted employer costs and weighted victim costs were examined in this formula. The weighted client costs have a significant relationship with the weighted construction period. While the weighted employer costs are affected by the weighted accident classification and the weighted days of the stop work order and the weighted location of body injury. Only the weighted number of days for medical leave has a significant relationship with the weighted victim costs. The weighted safety and health costs were assigned to reflect the importance of the cost for each safety cost component and category against the overall safety and health costs. The weighted safety and health costs equation is given as follows:

$$SHCw = WCC + WEC + WVC$$

SHC_w is the weighted Safety and Health Costs
WCC is the weighted Client Costs
WEC is the weighted Employer Costs
WVC is the weighted Victim Costs

For the Client Costs, the weighted Client Costs (WCC) equation is given as:

$$WCC = ACC\ (W_1\alpha_1)$$

Where:
ACC is the average Client Costs
$W_1\alpha_1$ is the weighted Construction Period

The weighted Employer Costs (WEC) equation is given as:

$$\mathrm{WEC} = \frac{\mathrm{AEC}\ (\mathrm{W}_{2\alpha 1} + \mathrm{W}_{2\alpha 2} + \mathrm{W}_{2\alpha 3})}{3}$$

Where:

AEC is the average Employer Costs
$W_2\alpha_1$ is the weighted Type of Accident Classification
$W_2\alpha_2$ is the weighted Days of Stop Work Order
$W_2\alpha_3$ is the weighted Location of Body Injury

The weighted Victim Costs (WVC) equation is given as:

$$\mathrm{WVC} = \mathrm{AVC}\ (W_3\alpha_1)$$

Where:

AVC is the average Victim Costs
$W_3\alpha_1$ is the weighted Days of Medical Leave

Development of Cost Weightage for Each Safety and Health Cost Component and Category

The cost weightage for each safety and health cost component was classified into specific cost categories. The cost weightage of each component and category was calculated based on the historical data gathered from the MRT 1 (SBK Line) Projects and MRT 2 (SSP Line) Projects. The historical data gathered from both projects were the prevention costs and the accident costs incurred by the MRT 1 (SBK Line) Projects. The data were gathered from experts in the related fields. The development indicators from other research, such as the Occupational Safety and Health Costs (OSH) Calculator were also referred to as a benchmark for this study. The OSH Calculator was selected due to the similarity of the studies, which focus on the construction industry. However, the OSH Calculator does not include the prevention costs and no specific cost weightage is determined for each safety and health cost component and category.

The weight of each safety and health cost component and category were calculated by the mean calculation from the historical data. Moreover, the integration between the safety and health cost components and cost categories with the weightage items is an important part of this research to forecast the precise safety and health costs incurred for future projects. Thus, Tables 2-6 show the list of the assigned cost weightage for each safety and health cost component and category incurred by the client, employer, and victim after going through a thorough identifying process.

a) Weighted Client Costs (WCC)

Table 2 shows details of the cost weightage for the prevention cost components incurred by the client. From the data analysis and findings of the preliminary survey (semi-structured interviews) and main survey (questionnaire), there are 11 components involved for the Prevention Costs. The weighted client costs were influenced by the weighted construction period. The weighted construction period is divided into two cost categories, which are less than 50 months and more than 50 months. These categories are based on the construction period awarded to the work packages contractor. The weightage scale for the construction period (more than 50 months) is higher than the weightage scale for the construction period (less than 50 months) (weight=1.31) and (weight=0.39), respectively. The results show that longer construction periods will increase the prevention costs due to the cost of the resources (human, plant, and materials) involved in the project.

This contrasts with the findings of Lopez-Alonso et al. (2013), who studied 40 construction works in progress in southern Spain. The results found that the costs of accident prevention were affected by the types of accident and directly varied according to the total number of workers, the average number of subcontractors, and the health and safety budget involved. Moreover, Feng (2015) found that safety investment is affected by the project hazard and safety culture levels, which means that those factors can be used as a formula for cost prediction and can be tailored to an individual building project.

Table 2. Weighted Construction Period ($W_1\alpha_1$) for Client Costs

No.	Prevention Cost Components	Construction Period Cost Categories	
		<50 Months	>50 Months
		Weightage	Weightage
1.	Insurance Costs	0.023	0.014
2.	PPE and Training Costs	0.027	0.056
3.	Evaluation and Monitoring Costs	0.073	0.075
4.	OSH Management & Documentation Costs	0.012	0.006
5.	Safe Working Area Costs	0.036	0.058
6.	Special Work Condition Costs	0.785	0.686
7.	Electrical Works Costs	0.003	0.005
8.	Plant Costs	-	0.052
9.	Facilities on Site Costs	0.010	0.025
10.	Housekeeping Costs	0.002	0.017
11.	Emergency Response Costs	0.028	0.006
	Sub Total	1.00	1.00
	Construction Period Weightage	0.39	1.31

b) Weighted Employer Costs (WEC)

Three cost factors affected the weighted employer costs, namely, the weighted Types of Accident Classification, weighted Days of Stop Work Order, and the weighted Location of the Body Injury. Table 3 shows details of the cost weightage for the weighted Types of Accident Classification. The cost categories of the Accident Classification are based on NADAPOD (2004), which are the accident Class 1, Class 2, Class 3, and Class 8. The highest weightage scale is accident Class 1 (weight=5.635) and the lowest weightage scale is accident Class 2 (weight=0.204). While the highest weightage scale for the types of cost component is the Damage/Repair Costs component (weight=0.423) for the accident Class 1.

This shows that employers incur high costs from fatalities due to the cost of hospital bills. Moreover, employers also must spend some money for the victim, which includes the cost of returning the victim’s body to his country, the cost of escort staff, including their transportation, accommodation, and all expenses during their task and the ex-gratia payment to the victim’s family. While the Damage/Repair Costs component contributes to the highest cost weightage for the accident Class 1 (Fatality) due to the highest cost incurred from the machine and equipment damage and the cost to repair including the cost of labour.

Table 3. Weighted Types of *Accident Classification* ($W_2\alpha_1$) for Employer Costs

No.	Direct and Indirect Accident Cost Components	Types of Accident Classification Cost Categories			
		Accident Class 1	Accident Class 2	Accident Class 3	Accident Class 8
		Weightage	Weightage	Weightage	Weightage
1.	First-Aid Treatment Costs	0.001	0.012	0.010	-
2.	Hospital Costs	0.020	0.348	0.370	-
3.	Damage/Repair Costs	0.423	-	0.073	0.653
4.	Fine Costs	0.008	-	-	-
5.	Accident Report Costs	0.0004	0.010	0.008	0.006
6.	Replacement Costs	0.001	-	-	-
7.	Administration Costs	0.007	0.177	0.093	0.132
8.	Schedule Costs	0.002	-	0.009	-
9.	Productivity Loss Costs	0.347	0.067	0.146	0.077
10.	Ex-Gratia Costs	0.163	-	0.130	-
11.	Management Costs	0.014	0.387	0.118	0.105
12.	Corrective Action Costs	0.014	-	0.042	0.027
	Sub Total	1.000	1.000	1.000	1.000
	Accident Classification Weightage	**5.635**	0.204	0.294	0.341

Table 4 shows details of the cost weightage for the Days of Stop Work Order. Three cost categories were determined for the Days of Stop Work Order, which are 0-14 days, 15-30 days, and more than 30 days. The highest weightage scale (weight=35.162) for the Days of Stop Work Order is for more than 30 days. The highest weighted cost scale (weight=0.617) is for the Ex-Gratia Costs. This shows that large costs are incurred by the employer if the number of days for the stop work order is more than 30 days. When the work stops on-site, it will affect the costs of the employer.

Table 4. Weighted Days of Stop Work Order ($W_2\alpha_2$) for Employer Costs

No.	Direct and Indirect Accident Cost Components	Days of Stop Work Order Cost Categories		
		0-14 Days	15-30 Days	>30 Days
		Weightage	Weightage	Weightage
1.	First-Aid Treatment Costs	0.005	0.001	0.0005
2.	Hospital Costs	0.129	0.104	0.002
3.	Damage/Repair Costs	0.351	0.014	0.539
4.	Fine Costs	-	0.054	-
5.	Accident Report Costs	0.006	0.002	0.0001
6.	Replacement Costs	0.001	-	-
7.	Administration Costs	0.110	0.014	0.001
8.	Schedule Costs	0.003	0.016	-
9.	Productivity Loss Costs	0.127	0.149	0.393
10.	Ex-Gratia Costs	0.111	0.617	0.051
11.	Management Costs	0.021	0.029	0.002
12.	Corrective Action Costs	0.036	0.001	0.012
	Sub Total	1.000	1.000	1.000
	Stop Work Order Weightage	0.355	1.645	35.162

Table 5 reveals the weighted table for the weighted Location of the Body Injury. The cost weightage was gathered from the cost incurred when the workers accident based on location of body injury. The table shows that the neck is the highest weightage scale (weight=35.162). While the lowest weightage scale is for injury to the lower limbs of the body (weight=0.234). Previous research found that commonly working with the hands above shoulder height and increased workloads on the shoulder and neck muscles were more frequent in workers with both acute and chronic shoulder and neck pain.

This finding further reinforces the notion found in previous studies concerning the costs of an accident incurred by the employer. Jallon et al. (2011b) revealed that the accident category and the number of days lost are the factors that should be included in the calculation of indirect accident costs. Similar findings have been observed in other studies (Tang et al., 2018; Forteza et al., 2017; Ministry of Health Malaysia, 2017; Safe Work Australia, 2015) that revealed that all these factors were significantly influential to in terms of the total accident costs (direct and indirect costs).

Table 5. Weighted Location of Body Injury ($W_2\alpha_3$) for Employer Costs

No.	Direct and Indirect Accident Cost Components	Cost Categories (Location of Body Injury)						
		Head	Neck	Trunk	Upper Limb	Lower Limb	Multiple Locations	General Injuries
		Weight	Weight	Weight	Weight	Weight	Weight	Weight
1.	First-Aid Treatment Costs	0.008	0.0005	0.002	0.017	0.010	0.007	0.0002
2.	Hospital Costs	0.084	0.002	0.188	0.306	0.276	0.544	0.002
3.	Damage/Repair Costs	0.022	0.539	0.010	0.153	-	-	0.638
4.	Fine Costs	0.110	-	-	-	-	-	-
5.	Accident Report Costs	0.003	0.0001	0.001	0.013	0.010	0.005	0.006
6.	Replacement Costs	0.008	-	-	-	-	-	-
7.	Administration Costs	0.042	0.001	0.019	0.145	0.151	0.109	0.134
8.	Schedule Costs	0.049	-	-	-	-	-	-
9.	Productivity Loss Costs	0.261	0.393	0.124	0.123	0.318	0.025	0.077
10.	Ex-Gratia Costs	0.236	0.051	0.626	-	0.009	-	-
11.	Management Costs	0.138	0.002	0.018	0.165	0.201	0.310	0.116
12.	Corrective Action Costs	0.038	0.012	0.013	0.77	0.025	-	0.026
	Sub Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Location of Body Injury Weightage	0.648	35.162	1.770	0.193	0.234	0.328	0.338

Shalini (2009) concluded that the number of days admitted in the hospital is related to the severity of the accident in measuring the economic costs of an occupational accident. Furthermore, Waehrer et al. (2007) described the costs of occupational injuries that were presented as three influential factors, namely, the industry level, worker characteristics, and the event of the injury.

However, these results can be contended by the Occupational Safety and Health (OSH) Calculator research, developed by the Department of Occupational Safety and Health. The OSH calculator identifies a different factor that significantly affects the accident costs, which is the zone (location of accident) factor (KLIACS JKKP, 2013). Nevertheless, this factor is not suitable for this research due to the location of the projects being in the same zone, which is in Kuala Lumpur and the Klang Valley.

c) Weighted Victim Costs (WVC)

Only one cost factor affects the weighted victim costs, i.e., the weighted Days of Medical Leave. Table 6 shows details of the cost weightage for the weighted Days of Medical Leave. The cost categories of the Days of Medical Leave are 0-3 days, 4-7 days, 8-14 days, 15-30 days, and more than 30 days. The highest weightage scale is the days more than 30 days (weight=10.494). While the lowest weightage scale (weight=0.024) for the Days of Medical Leave is from 0-3 days. Therefore, the longer Days of Medical Leave affect the victim's costs. Medical leave indicates the seriousness of the injuries. However, many of the workers did not take medical leave at all. Taking medical leave might give them a bad image and employers might not hire or pay them in the future.

This result is parallel to the study of Feng et al. (2015), where a longer period of absence of the victim due to severe injuries may result in a higher indirect cost of the accident. Commonly, a longer period of absence of the victim will affect the employer if the medical leave wages are covered. However, based on the data collected from the safety personnel, most of the victims injured on the MRT project were foreign workers. Due to this situation, the cost borne by the foreign worker will increase whenever they are unable to work on site. Hence, the cost is calculated based on the victim’s salary per day times the days of unpaid leave.

This finding is consistent with the findings of the final report prepared by the European Commission, where the labour costs were estimated by the number of accidents, the number of days lost, and the unit daily labour cost (European Commission, 2004). In addition, based on the accident cost model developed by the Health and Safety Executive (HSE) UK, the number of days absent from work were included in the unit costs of workplace incidents report. The report was used for appraisal of HSE interventions (HSE, 2013).

Whilst in Singapore, medical leave wages are not covered by the insurance policy, but by the Work Injury Compensation Act under the Ministry of Manpower (MOM) Singapore (Feng et al., 2015). Similarly, in Malaysia, the Social Security Organisation (SOCSO) only covers the medical leave wages for the local labourers (KLIACS JKKP, 2013).

Table 6. Weighted Days of Medical Leave ($W_3\alpha_1$) for Victim Costs

No.	Indirect Accident Cost Components	Days of Medical Leave Cost Categories				
		0-3 days	4-7 days	8-14 days	15-30 days	>30 days
		Weightage	Weightage	Weightage	Weightage	Weightage
1.	Cost Losses by the Victim	0.024	0.268	0.434	2.149	10.494

Simulation Process (Test Cases)

The simulation was conducted on a similar urban rail infrastructure project, which is the Light Rail Transport Line Extension Project (LRT 2). This project was extended for the Ampang and Kelana Jaya lines, which are in the Klang Valley. Four work package contractors (WPC), namely AMG (Package A), AMG (Package B), KLJ (Package A) and KLJ (Package B) were selected as samples for the simulation process. Other projects that were selected included the MRT 2 (SSP Line) Projects. From the above projects, a total of 30 reportable accident cases, which are Class 1 (Fatality), Class 2 (Permanent Disability), Class 3 (Temporary Disability), and Class 8 (Dangerous Occurrence) were successfully identified.

The information on the project background and the factors influencing the safety and health costs were determined, which include the Construction Period of the project, the Types of Accident Classification, the Days of Stop Work Order, Days of Hospital Admission, Days of Medical Leave and Location of the Body Injury. Details regarding the data identified for the simulation process are shown in Table 7.

Table 7. Detailed Information for the LRT Line Extension Project and MRT2 (SSP Line) Project

Project Name	Construction Period (Day)	Accident Classification	Stop Work Order (Day)	Hospital Admission (Day)	Medical Leave (Day)	Location of The Body Injury
AMG (Package A)	27	Class 1	14	-	-	Trunk
AMG (Package B)	36	Class 2	3	3	9	Trunk
AMG (Package B)	36	Class 3	-	-	3	Lower Limb
AMG (Package B)	36	Class 8	4	-	-	No Injury
AMG (Package B)	36	Class 8	5	-	-	No Injury
AMG (Package B)	36	Class 8	-	-	-	No Injury
KLJ (Package A)	30	Class 3	-	-	-	Head
KLJ (Package A)	30	Class 8	-	-	-	No Injury
KLJ (Package A)	30	Class 8	-	-	-	No Injury
KLJ (Package A)	30	Class 8	-	-	-	No Injury
KLJ (Package B)	45	Class 1	5	-	-	Head
KLJ (Package B)	45	Class 1	78	-	-	Neck
KLJ (Package B)	45	Class 2	2	7	30	Lower Limb
KLJ (Package B)	45	Class 2	2	7	30	Upper Limb
KLJ (Package B)	45	Class 3	2	6	20	Upper Limb
KLJ (Package B)	45	Class 3	1	2	62	Lower Limb
KLJ (Package B)	45	Class 3	1	-	10	Lower Limb
KLJ (Package B)	45	Class 3	2	6	20	Lower Limb
KLJ (Package B)	45	Class 3	2	7	30	Upper Limb
KLJ (Package B)	45	Class 3	1	-	4	Upper Limb
MRT 2 (SSP Line) Project	53	Class 1	14	-	-	Trunk
MRT 2 (SSP Line) Project	53	Class 8	-	-	-	No Injury
MRT 2 (SSP Line) Project	53	Class 8	-	-	-	No Injury
MRT 2 (SSP Line) Project	53	Class 8	-	-	-	No Injury
MRT 2 (SSP Line) Project	53	Class 8	-	-	-	No Injury
MRT 2 (SSP Line) Project	53	Class 8	-	-	-	No Injury
MRT 2 (SSP Line) Project	53	Class 1	30	-	-	Head
MRT 2 (SSP Line) Project	53	Class 1	30	4	4	Trunk
MRT 2 (SSP Line) Project	53	Class 3	1	-	14	Upper Limb
MRT 2 (SSP Line) Project	53	Class 3	1	-	14	Upper Limb

Analysis of The Simulation Results

Table 8. Results of the Independent-Samples T-Test on the Proposed Safety and Health Costs Model

Project Name	Actual Cost (RM)	Simulation Cost (RM)	Paired Differences		t	df	Sig. (2-tailed)
			Mean	Std. Error Difference			
AMG (Package A)	20,997,309.00	9,782,176.73	.04603	.07760	.593	58	.555
AMG (Package B)	65,618,526.00	9,680,980.78					
AMG (Package B)	65,604,555.00	9,653,429.89					
AMG (Package B)	65,605,213.00	9,656,228.73					
AMG (Package B)	65,743,345.00	9,656,228.73					
AMG (Package B)	65,607,248.00	9,656,228.73					
KLJ (Package A)	31,838,833.00	9,661,180.53					
KLJ (Package A)	31,838,433.00	9,656,228.73					
KLJ (Package A)	31,840,433.00	9,656,228.73					
KLJ (Package A)	31,830,433.00	9,656,228.73					
KLJ (Package B)	7,421,448.00	9,761,171.35					
KLJ (Package B)	9,350,961.00	11,058,955.21					
KLJ (Package B)	7,397,647.00	9,654,231.73					
KLJ (Package B)	7,396,277.00	9,653,464.15					
KLJ (Package B)	7,422,711.00	9,655,149.07					
KLJ (Package B)	7,428,911.00	9,665,682.30					
KLJ (Package B)	7,383,877.00	9,653,909.69					
KLJ (Package B)	7,392,681.00	9,655,916.65					
KLJ (Package B)	7,395,881.00	9,655,149.07					
KLJ (Package B)	7,385,085.00	9,652,947.85					
MRT 2 (SSP Line) Project	13,127,328.00	32,515,279.83					
MRT 2 (SSP Line) Project	13,056,267.00	32,389,359.92					
MRT 2 (SSP Line) Project	13,036,267.00	32,389,359.92					
MRT 2 (SSP Line) Project	13,033,267.00	32,389,359.92					
MRT 2 (SSP Line) Project	13,036,267.00	32,389,359.92					
MRT 2 (SSP Line) Project	12,214,389.00	32,518,425.02					
MRT 2 (SSP Line) Project	12,214,389.00	32,518,425.02					
MRT 2 (SSP Line) Project	12,355,169.00	32,539,744.02					
MRT 2 (SSP Line) Project	12,137,864.00	32,386,273.30					
MRT 2 (SSP Line) Project	12,137,369.00	32,386,273.30					

Table 8 tabulates the accidents cost data run on the actual data of the safety and health costs and the simulation of the safety and health costs from the proposed model. An independent samples t-test was used to analyse the reliability of the formula. This test was considered after the data were transformed to confirm the normality. There was strong evidence (t=0.593, p=>0.50) that there is no significant difference between the actual safety and health costs and the simulated safety and health costs. This finding further reinforced the notion that the proposed Safety and Health Costs Formula (SaHeCF) is reliable for use by the industry as a calculator to estimate the cost of safety and health from pre-construction up to the construction phase for KVMRT projects specifically and for urban rail infrastructure projects generally.

CONCLUSION

This study has followed a rigorous research process by using multiple data collection. However, there were limitations which were associated with limited scope of study. The primary limitation is that the main surveys are only carried out for the MRT 1 (SBK Line) and MRT 2 (SSP Line) Project. The study covered the viaduct/guideway package for both projects. The surveys did not include other work packages due to the limitations of data, time, finances, and resources. Further investigation needs to be done covering a bigger regional scale, covering the whole of Malaysia is necessary as the findings could be further extended. The safety and health costs formula development process are a significant contribution to the research. The development of the safety and health costs formula is divided into three phases – planning phase (safety and health costs input), conducting phase (safety and health costs process) and applying phase (safety and health costs output). The research aims to develop a safety and health costs formula for urban rail infrastructure projects The safety and health cost formulas cover the costs incurred by the client, employer and victim. The client incurs the safety and health costs under the prevention costs, while in the event of an accident, the costs are incurred by the employer and victim. Moreover, the weightage system is aimed at making the score for each of the safety and health cost components and categories quantitatively as an outcome of this research. The cost weightage was obtained from the mean value for each cost component and category under the prevention costs components and accident costs components. For the cost formula verification, the simulation was carried out and analysed using an independent samples t-test procedure. The purpose of the formula testing was to establish the reliability of the formula for future use by industry stakeholders. The applicability of the safety and health costs formula (SaHeCF) as a calculation model in estimating safety and health costs has generated a new method that can be applied in the construction of urban rail infrastructure projects. It will help the relevant stakeholders and related government agencies, such as the Department of Safety and Health (DOSH) Malaysia, Mass Rapid Transit (MRT) Corporation Sdn Bhd, Prasarana Berhad, Construction Industry Development Board (CIDB), Project Delivery Partner (PDP); MMC-Gamuda KVMRT Sdn Bhd and MRCB-GK Sdn Bhd to apply a new safety and health costs model for future urban rail infrastructure projects.

ACKNOWLEDGEMENTS

We wish to thank and acknowledge the fund support of research grant from MyRA Research Grant (PhD Graduate) (Project code: 600-RMC/GPM LPHD 5/3 (061/2021)) funded by the Universiti Teknologi MARA, Perak Branch.

REFERENCES

Aaltonen, M. V. P., Uusi-Rauva, E., Saari, J., Antti-Poika, M., Rasanen, T., & Vinni, K. (1996). The accident consequence tree method and its application by real-time data collection in the Finnish furniture industry. *Safety Science*, *23*(1), 11–26.

Alcumus, Top ten Health and Safety Risks in Construction, Alcumus Group Ltd, https://www.alcumus.com/en-gb/insights/blog/top-ten-health-and-safety-risks-in-construction/, accessed date: May 2022.

Choi, J., Gu, B., Chin, S., Lee, J.-S., 2020. Machine learning predictive model based on national data for fatal accidents of construction workers. *Autom. Constr*., 110.

Davies, N.V. and Teasedale, P. (1994). *The Costs to the British Economic of Work Accidents and Work-Related Ill-Health*. London: HMSO.

European Commission. (2004). *Statistical analysis of socio-economic costs of accidents at work in the European Union*. Retrieved on 25 August 2018, from https://moodle.adaptland.it/pluginfile.php/7859/mod_resource/content/0/Communit%C3%A0_Europe_07_2004_statistical_costs_of_accidents.pdf.

Feng, Y. (2015). Mathematical models for determining the minimum level of voluntary safety investments for building projects. *Journal of Construction Engineering and Management*, *141*(7), 1-11.

Forteza, F. J., Carretero-Gomez, J. M., & Sese, A. (2017). Occupational risks, accidents on sites and economic performance of construction firms. *Safety Science, 94*, 61–76.

Gavious, A., Mizrahi, S., Shani, Y., & Minchuk, Y. (2009). The costs of industrial accidents for the organization: Developing methods and tools for evaluation and cost-benefit analysis of investment in safety. *Journal of Loss Prevention in the Process Industries*, *22*(4), 434–438.

Goestsch, D. L. (2013). *Construction Safety and Health* (2nd Edition). New Jersey, USA: Pearson Education.

Hammer, W., & Price, D. (2001). *Occupational Safety Management and Engineering* (5th Edition). New Jersey: Prentice Hall.

Heinrich, H. W. (1931). *Industrial Accident Prevention*. New York: McGraw-Hill.

HSE (2014). *Costs to Britain of workplace fatalities and self-reported injuries and ill health 2015/16.* Retrieved on 22 June 2017, from http://www.hse.gov.uk/statistics/.

Jallon, R., Imbeau, D., & De Marcellis-Warin, N. (2011b). Development of an indirect-cost calculation model suitable for workplace use. *Journal of Safety Research*, *42*(3), 149–164.

KLIACS JKKP. (2013). *Kajian Mengenai Kos Kemalangan Di Tempat Kerja Bagi Sektor Pembinaan*. Unpublished report.

Lopez-Alonso, M., Ibarrondo-Davila, M. P., Rubio-Gamez, M. C., & Munoz, T. G. (2013). The impact of health and safety investment on construction company costs. *Safety Science*, *60*, 151–159.

Minglong, Z., Nariman, G., Mani, P., Boon, C.S., & Sira, Y. (2023). A construction accident prevention system based on the Internet of Things (IoT). *Safety Science*, 159, 1-14. https://doi.org/10.1016/j.ssci.2022.106012

Ministry of Health Malaysia. (2017). *Health Indicators 2017: Indicators for Monitoring and Evaluation of Strategy Health for All.* Retrieved from http://www.moh.gov.my/images/gallery/publications/Petunjuk Kesihatan 2017.pdf.

Misnan, M. S., & Mohammed, A. H. (2007). Development of safety culture in the construction industry: A conceptual framework. In *23rd Annual ARCOM Conference, 3-5 September 2007* (pp. 13–22). Belfast, UK.

Pellicer, E., Carvajal, G. I., Rubio, M. C., & Catala, J. (2014). A method to estimate occupational health and safety costs in construction projects. *KSCE Journal of Civil Engineering*, *18*(7), 1955–1965.

Poon, S.W., Tang S. L., & Wong, K.W. (2008). *Management and Economics of Construction Safety in Hong Kong.* Hong Kong: University Press.

Rajendran, S., Gambatese, J. a., & Behm, M. G. (2009). Impact of Green Building Design and Construction on Worker Safety and Health. *Journal of Construction Engineering and Management*, *135*(10), 1058–1066.

Ryan, W. A., Carol, K.H.H., Bo, X. (2019). Construction accidents in Australia: Evaluating the true costs. *Safety Science*, 120, 886–896. https://doi.org/10.1016/j.ssci.2019.07.037

Safe Work Australia. (2015). The Cost of Work-related Injury and Illness for Australian Employers , Workers and the Community: 2012-13. Retrieved on 5 September 2017, from https://www.safeworkaustralia.gov.au/system/files/documents/1702/

Shalini, R. T. (2009). Economic cost of occupational accidents: Evidence from a small island economy. *Safety Science*, *47*(7), 973–979.

Tang, S. L. (1997). *Financial and social costs of construction accidents*. Retrieved on 1 September 2016, from http://www.irbnet.de/daten/iconda/CIB600.pdf.

Teo, E. A.-L., & Feng, Y. (2011). The indirect effect of safety investment on safety performance for building projects. *Architectural Science Review*, *54*(1), 65–80.

Waehrer, G. M., Dong, X. S., Miller, T., Haile, E., & Men, Y. (2007). Costs of occupational injuries in construction in the United States. *Accident Analysis and Prevention, 39*(6), 1258–1266.

CHEMICAL ENVIRONMENTS EFFECTS ON MECHANICAL PROPERTIES OF KENAF FIBRE REINFORCED PULVERISED FUEL ASH CONCRETE

Norazura Mizal Azzmi[1*], Jamaludin Mohd Yatim[2], and Nazhatulzalkis Jamaludin[1], Nadira Ahzahar[1], Zuraihana Ahmad Zawawi[1] and Siti Zubaidah Hashim[1]
[1]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, Malaysia
[2]Department of Structures and Materials, Faculty of Civil Engineering, University Teknologi Malaysia

**Corresponding Email: noraz026@uitm.edu.my*

Abstract
This study investigates the effect of the chemical environment on the mechanical characteristics of pulverized kenaf fibrous fuel ash concrete with a volume percent of 0.75, with a particular emphasis placed on the consequence of acidic, alkaline and sulfate solutions. The study also explores the effect of compressive and flexural characteristics of composites and a considerable reduction in each strength was seen; nevertheless, kenaf composites exhibited greater strength stability. The weakening of the fibre/matrix interface caused by environmental factors are identified using scanning electron microscopy (VPSEM). The increase in mechanical performance over a prolonged period when exposed to various of environments was attributed to the addition of 25% fly ash.

Keywords: *Mechanical properties; kenaf fibre; strength; fly ash*

INTRODUCTION

Green products are valuable alternatives for the mitigation of carbon footprint nowadays. Concretes are the most common choice for construction materials in Malaysia due to the availability of local resources for raw materials components, they are easier to handle and cost-saving materials. Regardless of its popularity in materials selection, the conventional mixture of cement, aggregate and water have profound impact to the greenhouse gas (GHG) emissions. Manufacturing of cement produces 7% of the global carbon dioxide (CO_2) emission (M.B. Ali, 2011). Thus, the increase the concentration of CO_2 in the atmosphere, gradually lead to global warming and climate change issues. Bio-fibre concrete offers many advantages as sustainable construction materials to combat carbon emissions. (Brabha H.N., 2019; Mohammad H.B., 2020). Bio-fibres are extracted from natural resources like plants, animals, and minerals (A. Vinod, 2020). Biofibres are organic materials and categorized into plant fibre and animal fibre. These fibres function as reinforcement in the polymer matrices and structural application. Numerous studies are carried out on biobased materials in concrete mixture to enhance its diverse properties and promote green materials for construction industries that are more energy and resource efficient (Mehta et al., 2002; Ana, 2019; Soudabeh, 2020). Plant biofibre offers remarkable properties for low cost, low density, considerable strength, and biodegradability that are friendly to the environment. Plant cultivation are renewable resources with minimal impact on greenhouse gas emissions and global warming (Mabrouk, 2017). On the other hand, the drawback of biofibre is the deterioration of the fibre in the alkaline environment of ordinary Portland cement (OPC) concrete (Jianqiang, 2017). There is continuous improvement on concrete mixture to develop different properties and overcome the shortcomings. However, pre-treatment of fibre is the effective solution to this problem, the modification of biofibre before using cementitious materials will further assist to achieve sufficient bonding strength improving the composite (Abbas et al., 2022). Therefore, this research aims to investigate the performance of kenaf fibre reinforced pulverised fuel ash concrete compared to normal concrete as composite material in building construction.

MATERIAL AND EXPERIMENTAL DETAILS

Materials

Kenaf is one of biofibre extracted from Kenaf plant stem which is extensively produced as industrial raw materials for sustainable value. Kenaf bast is enriched with cellulose fibre, which possesses a higher tensile strength compared to other cellulose fibres (Mnica Ardanuy, 2015). Its high-water absorbent capability has a substantial effect on the mechanical and physical properties such as compressive and flexural behaviour, stress–strain responses, and density (S. Gwon et al., 2022; Flávio de Andrade Silva, 2011). This includes the fresh state properties like setting time, rheology, and heat of hydration (N. A. Johansen, 2009). (Seongwoo Gwon, 2021). This study investigates the incorporation of kenaf fibre as a strengthening component in concrete with the aim of enhancing its mechanical and physical characteristics. In Figure 1(a), the visual representation displays the kenaf fibre, while Figure 1(b) illustrates the presence of kenaf fibre within hardened concrete, thereby assuming the role of a binder for the coarse and fine aggregates that constitute the matrix composite.

(a) (b)

Figure 1. (a) KenafFibre and (b) Kenaf Fibre with Concrete

The absorption of water by Kenaf fibre is significantly influenced by its hydrophilic characteristics, necessitating the implementation of appropriate treatment methods. The previous study by Babatunde et al. (2018), investigated the efficacy of a chemical reaction in the elimination of hydrogen bonding within the intricate network structures of cellulosic fibres, thereby facilitating the removal of undesirable impurities such as dirt and lignin. A 5% solution of sodium hydroxide was prepared by diluting it with distilled water. Subsequently, the fibres were subjected to immersion in this solution for a duration of three hours, maintaining the room temperature. This treatment aimed to effectively remove lignin, oil, and dirt contaminants from the fibres. Subsequently, the fibrous material underwent a thorough rinsing process with water, followed by complete immersion in water for a duration of 24 hours. Following the 24-hour duration, the liquid undergoes a transformation, manifesting a brownish hue as a consequence of chemical reactions. Subsequently, the fibrous materials are subjected to an additional rinsing process until the aforementioned coloration gradually diminishes. In order to achieve optimal results, it is imperative to subject the fibre to a desiccation process spanning approximately 48 to 72 hours, at ambient conditions, prior to its subsequent division into segments measuring 25 millimetres in length.

The two types of binders were used in this study as shown in Table 1 are ASTM Type I Portland cement conforming to ASTM C150 (OPC) and ASTM Class F. The pulverized fly ash (PFA) was collected from Tanjung Bin Power Plant, Pontian, Johor conforming to ASTM C618 Class F since the sum of SiO_2, $Al2O_3$ and Fe_2O_3 exceeds 70% which produces low calcium content (Abubakar & Baharudin, 2012). Chemical composition of OPC and PFA indicates the difference in the Calcium Oxide, Silicon Dioxide and Aluminium Oxide composition. For comparison purposes, the following four mix proportions were adopted: (a) OPC mixes as a control mix (b) OPC with kenaf fibre, KFC (c) cement paste with 25% fly ash replacement (in mass percentage), PFAC (d) cement pastes with 25% fly ash replacement (in mass percentage) with kenaf fibre, KFPC.

In the specimen preparation process, the raw materials were mechanically mixed and then cast into steel mould with 100mm×100mm×100mm dimension for cube concrete and 100×100×500mm dimension timber moulds for prism concrete. After 24 hours, the specimens were demoulded and cured in water for 28 days. Table 2 shows the mix proportions of KFC and KFPC mixtures by SI unit weight per cubic metre (kg/m^3). The method for producing concrete mixes known as Concrete Mix Design (DOE) involves establishing the appropriate ratios of cement, sand, and aggregates for the concrete mixture in order to achieve the required level of concrete strength. Kenaf fibre 0.75% of volume fraction was selected as an optimum value in this study compared to previous study using 0.5%, 1% and 1.5% volume fraction of kenaf fibre (Azzmi & Yatim, 2018). Superplasticizers such as Rheobuild 1100 was selected for this research because they have been shown to improve the workability of concrete. Figure 2 (a) depicts the sample of Ordinary Portland Cement (OPC), whereas Figure 2 (b) illustrates the sample of Pulverised Fuel Ash Cement (PFA), which exhibits a darker colour compared to the OPC.

Table 1. Chemical Composition of OPC and PFA

Oxide Composition	OPC	PFA
Calcium Oxide (CaO)	62.4	7.21
Silicon Dioxide (SiO_2)	20.4	47.10
Aluminum Oxide (Al_2O_3)	5.20	30.00
Iron Oxide (Fe_2O_3)	4.19	7.34
Magnesium Oxide (MgO)	1.55	1.52
Sulphur Trioxide (SO_3)	2.11	0.49
Manganese Oxide (MnO)	0.15	-
Equivalent Alkalis (Na_2O+0.658K_2O)	0.14	2.09
Loss of ignition	2.36	2.19

Table 2. Concrete Mix Proportions

Constituent Material (Kg/m^3)	Ordinary Portland Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	Water	Kenaf Fibre 0.75%	Super Plastizer
Proportions OPC	463	-	800	867	250	-	4.63
Proportions PFAC	347.3	115.7	800	867	250	-	4.63
Proportions KFC (Kenaf fibre +OPC)	463	-	800	867	250	9	4.63
Proportions KFPC (Kenaf fibre+25% PFA)	347.3	115.7	800	867	250	9	4.63

(a) (b)

Figure 2. (a) Ordinary Portland Cement (OPC) and (b) Pulverised Fuel Asih Cement (PFA)

Mix Proportions and Experimental Details

In this study, the samples of OPC, KFC, PFAC, and KFPC concrete were prepared for three extreme environmental solutions. The mass loss of samples was measured after 90,180 and 365 days of curing in 2% acid sulphuric solution based on standard ASTM C1898-20 (2000), 5% sodium hydroxide solution adopted from ASTM C1202 (1997), and 10% magnesium sulphate solutions from the standard in ASTM C1202 (2003). In this study, several solutions conditions were utilized to simulate the impact of sulphate on concrete samples in a harsh environment, as would occur in natural ground conditions. The initial weight of the specimens and the weight of the specimens after immersion were measured to determine the strength loss caused by sulphate deterioration. The average results of three samples were considered for evaluation. All specimens were compared to specimens that had been cured in water referred to the British Standard in 1881:Part lll: (1983).

Mechanical Properties Results

The deterioration of concrete specimens was investigated by evaluating the strength distortion factor expressed in percentage was measured by days of immersion and was calculated using the Equation below;

$$\text{SLF} = \frac{\text{Fcw} - \text{Fca}}{\text{Fcw}} \text{ x } 100\% \tag{1}$$

Where:

SLF = Strength loss factor after immersion in acid sulphuric solution
Fcw = The average compressive strength of companion specimen cured in water
Fca = The average compressive strength of the specimen after immersion in acid sulphuric solution.

The formula to determine the compressive strength of the immersion samples was determined using the following formula in accordance with BSEN 12390-3:2009, and the formula for determining the flexural strength of the immersion samples was determined using the following formula in accordance with BSEN 12390-5:2009.

Acidic Solution

Figure 3 illustrates that the compressive strength of all types of mixtures decreases when the samples immersed in the acidic content. The compressive strength of companion concrete specimens was subjected to a curing period of 365 days in water, in order to establish a comparative analysis with specimens immersed in an acidic solution. The compressive strength of concrete mixtures without fibre reinforcement, which include ordinary Portland cement (OPC) and pulverized fuel ash cement (PFAC), exhibit a significant decline when subjected to an acidic environment. The specimen underwent uniaxial stress, leading to increased fracture in mixes of ordinary Portland cement (OPC) and pulverized fuel ash cement (PFAC). The samples experienced significant degradation of the C–S–H and O–H phases due to the presence of sulfuric acid. KFC and KFPC had a lower compressive strength than OPC and PFAC and were still higher than that of concrete mixtures containing fibres within. When the concrete matrix was degraded and acid was attacked, the fibres of concrete held the brittleness of the concrete together.

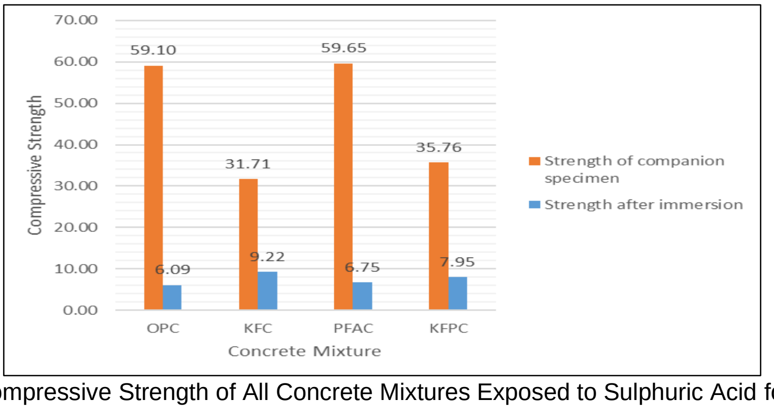


Figure 3. Compressive Strength of All Concrete Mixtures Exposed to Sulphuric Acid for 365 Days

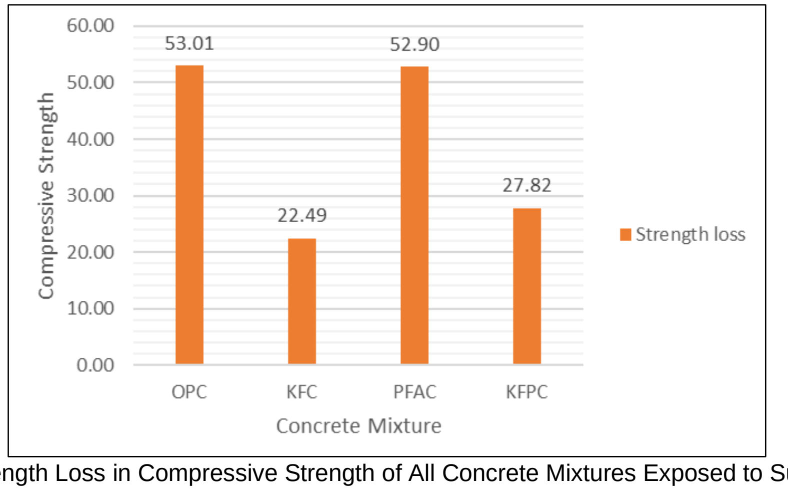


Figure 4. Strength Loss in Compressive Strength of All Concrete Mixtures Exposed to Sulphuric Acid for 365 Days

In Figure 4, the concrete flexural strength exhibits a comparable response to acid immersion. The pozzolan effect of the blended fly ash in the concrete provides reasoning for KFPC's maximum strength after immersion in acid for 365 days. Concrete pores are occupied by $Ca(OH)_2$, which slows the acid attack's deterioration process. The durability of KFPC in an acid attack is also attributed to the high tensile strength of kenaf fibre, which is likely in normal conditions (Azzmi & Yatim, 2018; Azzmi et al., 2018; Reju & Jidxji Jacob, 2012).

The flexural strength of the specimens is shown in Figure 5, and it demonstrates a decrease in the strength of all samples. After immersion, the KFPC samples have the maximum strength with 4.10 Mpa, compared to the PFAC samples, which have 3.86 Mpa, and the KPF samples, which have 3.03 Mpa. The OPC samples had the lowest strength of2.30 Mpa.

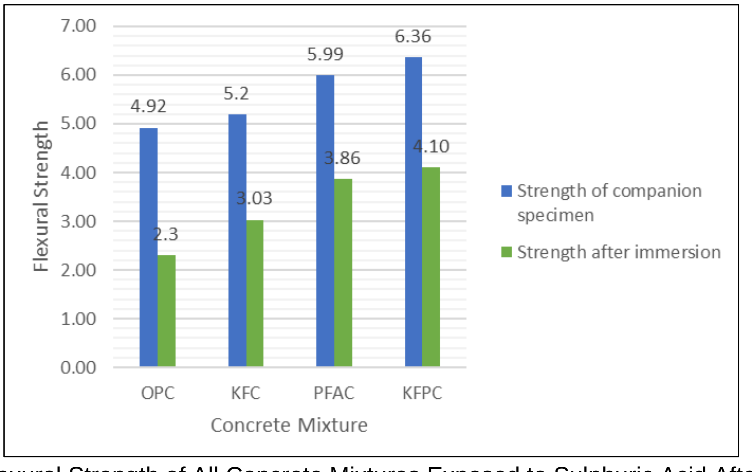


Figure 5. Flexural Strength of All Concrete Mixtures Exposed to Sulphuric Acid After 365 Days

As shown in Figure 6, the flexural strength loss is essentially comparable for all concrete combinations. Results with the lowest recorded number comes from the PFAC concrete combination, which does not contain any fibre, followed by the KFC concrete mixture, which contains both OPC and fibre. The OPC mixes show the largest loss of flexural strength, with a value of 2.62. (Taha et al., 2015) KFPC concrete based on PFA and fibre has a strength of 2.26 after immersion and has the strongest compressive strength of all mixes. The results indicated enhanced bending strength and that the KFPC could withstand a chemical reaction triggered by sulfuric acid.

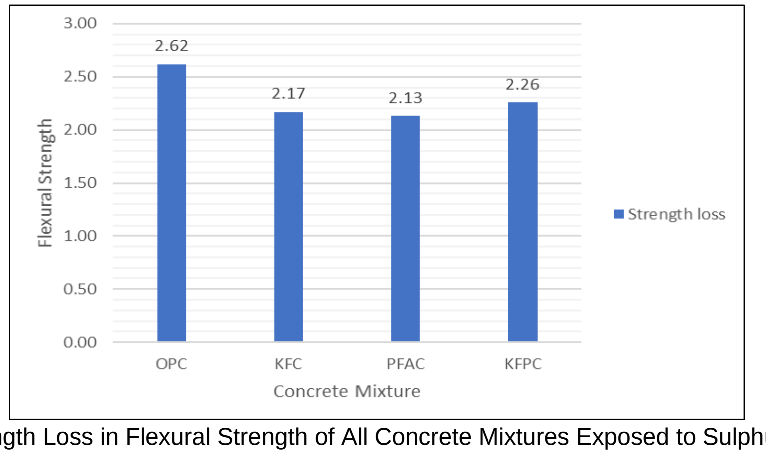


Figure 6. Strength Loss in Flexural Strength of All Concrete Mixtures Exposed to Sulphuric Acid After 365 Days

The compressive strength of KFC and KFPC concrete mixes reduced after 365 days of immersion in alkaline solution or sodium hydroxide (NaOH) compared to companion concrete, as shown in Figure 7. The compressive strength of fibre-covered cube samples was known to rise less than OPC and PFA concrete; however, immersion in alkaline increased concrete performance. Prior to being used in the concrete composite, the fibre was treated with NaOH solution, making it more compatible with the alkaline environment after three hours of immersion during treatment. Adding PFA to concrete mixes also increased the bonding of the fibre-matrix composite, which resulted in an improvement in the compressive strength.

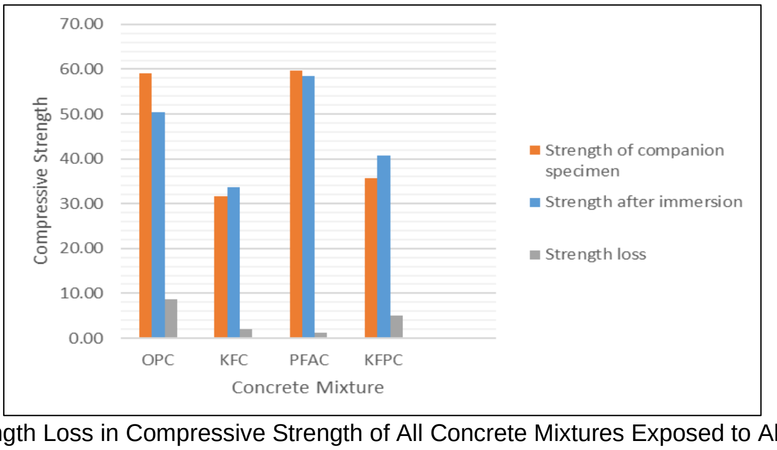


Figure 7. Strength Loss in Compressive Strength of All Concrete Mixtures Exposed to Alkaline Solution

The loss of flexural strength, as illustrated in Figure 8, indicates that strength in the flexural increases following immersion in an alkaline solution. The graph of four concrete mixes depicts the increase in flexural strength in OPC, PFAC, and KPFC combinations. Exposure to an alkali solution of sodium hydroxide (NaOH) resulted in the expected Alkali-Silica Reaction (ASR) in this situation. Because of the increased alkalinity, the rate of PFA pozzolanic reaction has increased, resulting in increased C-S-H production. This would explain the increase in flexural strength as compared to when the material is typically cured by water (Duraman ,2019). However, the alkaline action was incompatible with the strength decrease in the KFC mixes due to fibre within.

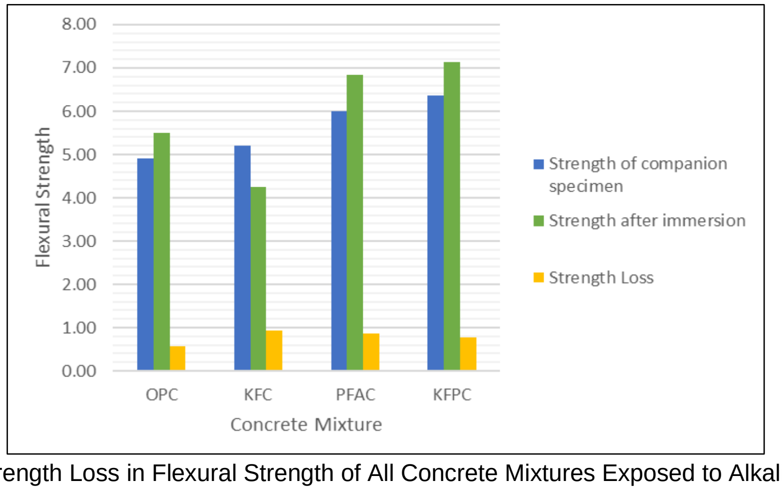


Figure 8. Strength Loss in Flexural Strength of All Concrete Mixtures Exposed to Alkaline Solution

Sulphate Solution

Figure 9 compares the strength loss of a companion specimen cured in water to the strength loss of a specimen immersed in a magnesium sulphate solution. In contrast to the test specimen, which was harmed by sulphate, curing in water at normal room temperature benefited the companion specimens. At the end of a 365-day testing period, the strength of concrete specimens immersed in sulphate solution is compared to the strength of companion concrete cured in water. In the situation of strength loss, the difference in strength between the companion specimen and those immersed in solution is considered.

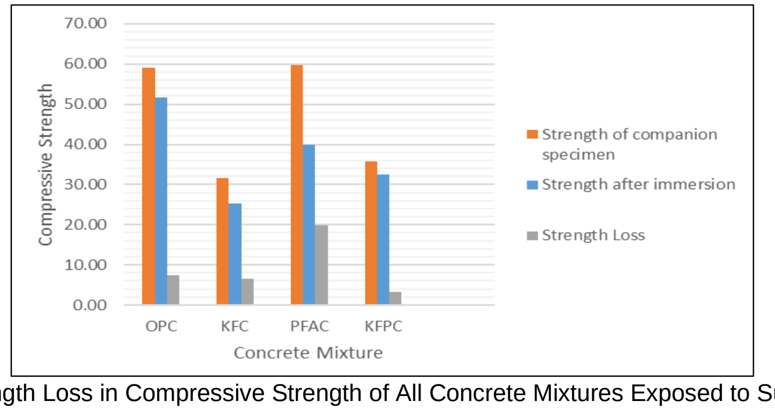


Figure 9. Strength Loss in Compressive Strength of All Concrete Mixtures Exposed to Sulphate Solution

Figure 10 demonstrates that the entire specimen experienced a loss of strength. On the PFAC sample, the loss was seen to be greater than in the kenaf fibre and PFA cement samples. For instance, a strength decreases of 19.8 was recorded for PFAC, 6.53 for KFC, and 3.28 for KFPC specimens. The value of 7.35 indicates that the loss of OPC samples is greater than that of KFC and KFPC samples. It is believed that immersion in sulphate solution for an extended period contributed to the overall sample's loss of strength. The reaction of sulphate ion leads to the formation of thaumasite and portlandite from the C-S-H phases (Bellmann & Stark, 2007). The thaumasite content can be reduced by decreasing the calcium and silica component of the concrete mixture. Due to the formation of ettringite and gypsum by OPC specimens during the cement hardening process, the inclusion of pozzolana cement of fuel ash prevented surface cracking and deterioration.

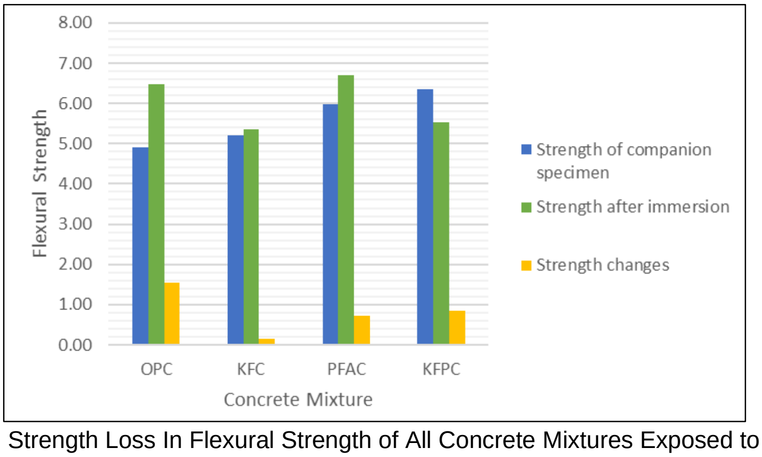


Figure 10. Strength Loss In Flexural Strength of All Concrete Mixtures Exposed to Sulphate

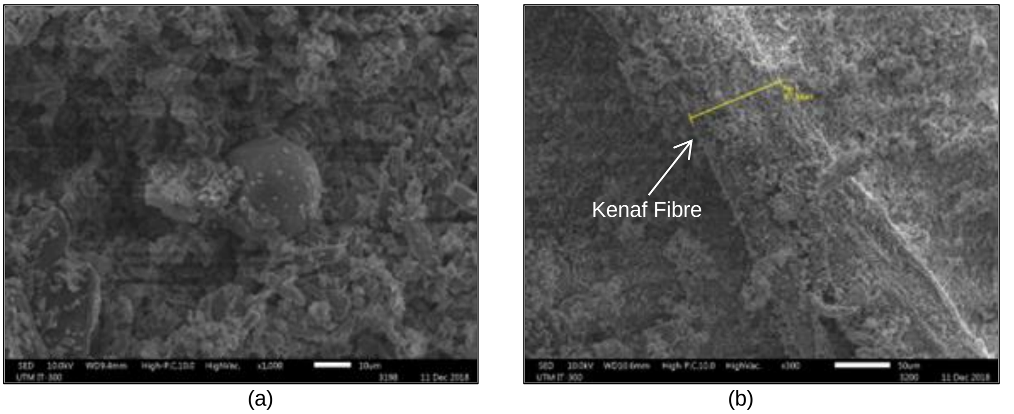
Figure 10 shows that the flexural strength of the OPC, KFC, and PFAC increases with time. After 365 days, all of the mixtures gained strength because of the sulphate's activity. The values were found to be greater in OPC and PFAC combinations devoid of fibres, while KFPC specimens exhibited negligible SLFs. This research findings on flexural strength are consistent with those of the prior study (Jena & Panigrahi, 2019; Okoye et al., 2016). In the absence of fibres, PFA is seen to replace CH in the form of calcium silicate hydrate, rendering CH inaccessible to sulphate, gypsum, and ettringite, hence decreasing specimen permeability and preventing the sulphate ion from penetrating the concrete.

However, the addition of kenaf fibres that are incompatible with cement paste contributes to the weakening of the material by creating gaps. When mineral mixtures are present in cement, they significantly reduce C_3A (dilution effect) and react with portlandite (CH) to produce calcium silicate hydrate (C-S-H). They also exhibit increase in density and decrease in permeability. Researchers discovered that when magnesium sulfate attacks, Mg+2 ions drive the decalcification of C-S-H, resulting in Mg-S-H. Consequently, the presence of portlandite (CH), which traps magnesium ions such as the mineral brucite, may be beneficial (Bezzar, 2017).

MICROSTRUCTURE ANALYSIS

Results in Acid Solution

PFAC concrete samples with fly ash but no fibre within decreased in size; however, the concrete particles did not fall compared to OPC. The KFPC samples were seen to grow owing to absorption while remaining in form, resulting in the outer layer of concrete peeling off. The Variable Pressure Scanning Electron Micrograph (VPSEM) of KFPC in acid solution is shown in Figure 11 (a). The samples were subjected to a high magnification of 100,000 times in order to evaluate their surface structure. This was followed by a comprehensive analysis of their composition. The fibre was added to increase the bridging effect of the KFPC fibre matrix. However, after 365 days in an acid solution, the fibre swelled and deteriorated in a specific area of the fibre. Despite this, KFPC was deemed a more durable material that uses natural fibre and waste composite than standard concrete. The capacity of treated fibre in composite was greater because the flexural strength did not decrease as much as regular concrete.



(a) (b)

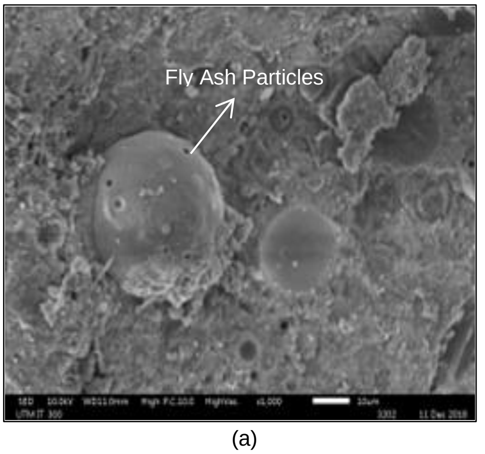
Figure 11. VPSEM of KFPC in Acid Solution

Figure 11 (b) displays VPSEM images of KFPC concrete samples following 365 days of exposure to a severe sulphuric acid assault. When sulphuric acid solutions were applied to the PFA matrix, gypsum production was reduced. When compared to PFA concrete, the OPC samples produced more gypsum due to the higher concentration of $Ca(OH_2)$ present. The C-S-H bonds were degraded, and different gypsums were produced as a consequence of the chemical reaction between sulfuric acid and calcium. Furthermore, the SEM images showed that the microstructure contained deposits of calcite ($CaSO_3$) and white calcium salt ($CaSO_4$) as well as multiple layers of gypsum. (Charkhtab et al., 2021).

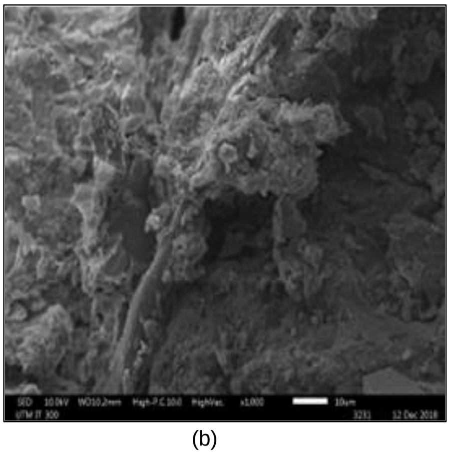
Results in Alkaline Solution

VPSEM was used to examine the performance of KFPC samples in an alkaline environment of 5% NaOH for 365 days. Additionally, the fibre was treated with the same solution to eliminate fibre impurities and improve its compatibility with concrete. Figure 12 shows that the flexural strength of the KFPC samples increased after immersion in sodium hydroxide. As seen in Figure 10, the pores in the dense concrete created with KFPC were previously filled with fly ash particles, and the porous concrete was filled with kenaf fibre. The weight gain that occurred after immersion permits the fibre to rupture at various spots throughout the samples.

Figure 12 (a and b) shows that the gypsum particles stick to the fibres, weakening the interface between the fibres and the matrix, reducing the strength and load-bearing capacity of the test specimens of concrete. It could be related to the growth of fragile crystals around the fibres, which impeded the formation of a solid bond between the fibres and cement paste. Gypsum and white sediments are produced when the C-S-H bonding dissolves, reducing the density of concrete and resulting in mass loss, according to Charkhtab et al. (2021).



(a)

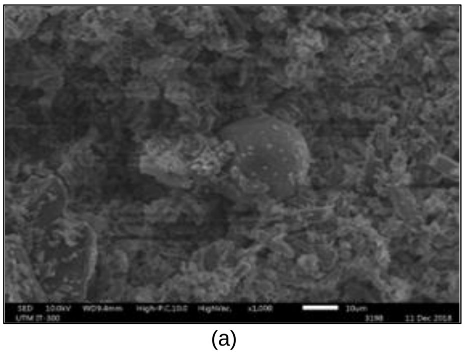


(b)

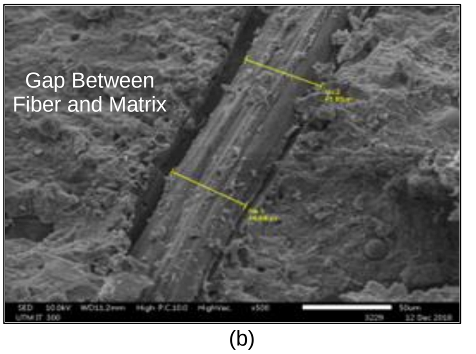
Figure 12. VPSEM of KFPC in Alkaline Solution

Results in Sulphate Solution

As can be seen in Figure 13 (a), the VPSEM findings for KFPC concrete compositions of PFA and fibre subjected to sulphate solutions are displayed. The VPSEM picture depicts how specimens change in nature while immersed in sulphate. When exposed to sulphate, the OPC-based concrete's spherical spaces progressively fill up with newly precipitated products. As the pozzolanic action of PFA and subsequent development of additional hydration products such as C-S-H gel took place in the PFA-containing mixes over time, there were less spaces for freshly precipitated products because of exposure to sulphate in these combinations. As a result, concrete specimens have shown improved strength and durability. Flexural strength subsequent to immersion in sulphate exposure led to the formation of microcracks.



(a)



(b)

Figure 13. VPSEM of KFPC in Sulphate Solution

Gaps were discovered in between the kenaf fibre and concrete matrix in Figure 13 (b). When mineral mixtures are present in cement, they significantly reduce C_3A (dilution effect) and react with portlandite (CH) to produce calcium silicate hydrate (C-S-H). They increase in density and decrease in permeability. When magnesium sulfate attacks, Mg+2 ions drive C-S-H decalcification, resulting in Mg-S-H. Therefore, the presence of portlandite (CH), which binds magnesium ions in the brucite mineral, may be useful.

CONCLUSION

The findings of the experimental study led to a few conclusions, which are as follows:

- The KFPC has strong resistance to acid attack in comparison to regular and PFA concrete; nevertheless, the strength reduced as the time of immersion increased to 365 days.
- Subsequent to being immersed in alkaline solutions, the KFPC samples showed an increase in their mechanical strength.
- According to the findings of the development of microcracks, the incorporation of kenaf fibre into OPC and PFA did not result in an improvement in the performance of the concrete when exposed to sulphate solution.
- The substance of the chemical assault on the concrete was validated by VPSEM analysis subsequent to immersion. KFPC was able to withstand a harsh environment because of its minimal strength loss after exposure.
- The capability of KFPC to exhibit flexural strength in both normal and aggressive conditions demonstrates that this concrete composite exhibits exceptional mechanical performance.

AKNOWLEDGEMENT

The authors would like to express their special thanks to Universiti Teknologi MARA (UiTM), Universiti Teknologi Malaysia (UTM) and National Kenaf and Tobacco Board for facilitating the research until completed.

REFERENCE

A. Hakamy, F. S. (2015). Effect of calcined nanoclay on microstructural and mechanical properties of chemically treated hemp fabric-reinforced cement nanocomposites. *Construction and Building Materials*, 882-891.

A. Mehta, R. S. (2017). Sulfuric acid resistance of fly ash based geopolymer concrete. *Construction Building Materials*, *146*, 136-143.

A. Vinod, M. S. (2020). Renewable and sustainable biobased materials: An assessment on biofibers, biofilms, biopolymers and biocomposite. *Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2020.120978,* 2683-2694. doi:https://doi.org/10.1016/j.jclepro.2020.120978

Abbas, A.-G., Aziz, F., Abdan, K., Mohd Nasir, N., & Norizan, M. (2022). Kenaf Fibre Reinforced Cementitious Composites. *Fibers,* 1-24. doi:https://doi.org/10.3390/fib10010003

Ana Antunes, P. F. (2019). Rice husk-earth based composites: A novel bio-based panel for buildings refurbishment. *onstruction and Building Materials, 221,* 99-108. doi:https://doi.org/10.1016/j.conbuildmat.2019.06.074

ASTM Type I Portland cement conforming to ASTM C150 (Standard specification for Portland cement) and ASTM Class F fly ash conforming to ASTM C618 (Standard Specification for Coal Fly Ash and Raw Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete).

Azzmi, N. M., & Yatim, J. M. (2018). Kenaf Fibrous concrete: Mechanical Properties with different fibre volume fraction. International Journal on Advanced Science, Engineering and Information Technology, 8(4), 1036–1042.

Azzmi, N. M., Yatim, J. M., Hamid, H. A., Aziz, A. A., & Adole, A. M. (2018). Mechanical properties of pulverised fuel ash concrete Kenaf fibrous. In MATEC Web of Conferences 250 (Vol. 05007).

Babatunde, O. E., Yatim, J. M., Razavi, M., Yunus, I. M., & Azzmi, N. M. (2018). Experimental Study of Kenaf Bio Fibrous Concrete Composites. Advanced Science Letters, 24(6), 3922–3927. https://doi.org/10.1166/asl.2018.11512

Bellmann, F., & Stark, J. (2007). Prevention of thaumasite formation in concrete exposed to sulphate attack. *Cement and Concrete Research*, *37*(8), 1215–1222.

Bezzar, M. A. and A. (2017). Magnesium Sulphate Attacks on Mortars - Influence of Temperature, Type of Sand and Type of Cement. Journal of Engineering Science and Technology Review, 10(1), 10–17. https://doi.org/10.25103/jestr.103.07

Brabha Hari Nagaratnam, M. A. (2019). Strength and microstructural characteristics of palm oil fuel ash and fly ash as binary and ternary blends in Self-Compacting concrete. *Construction and Building Materials, 202*, 103-120. doi:https://doi.org/10.1016/j.conbuildmat.2018.12.139.

Charkhtab, S., Madandoust, R., Jamshidi, M., & Nikbin, I. M. (2021). Mechanical properties of fly ash-based geopolymer concrete with crumb rubber and steel fiber under ambient and sulfuric acid conditions. Construction and Building Materials, 281, 122571. https://doi.org/10.1016/j.conbuildmat.2021.122571

Duraman, S. B., & Haji Omar, M. F. H. (2019). Durability of pulverised fuel ash (PFA) concrete exposed to acidic and alkali conditions. MATEC Web of Conferences, 258, 05015.

Flávio de Andrade Silva, B. M. (2011). Effect of fiber shape and morphology on interfacial bond and cracking behaviors of sisal fiber cement-based composites. Cement and Concrete Composites, 814-823

I.M. Nikbin, M. A. (2018). Environmental impacts and mechanical properties of lightweight concrete containing bauxite residue (red mud). *Journal of Cleaner Production, 172*, 2683-2694. doi:https://doi.org/10.1016/j.jclepro.2017.11.143

Jena, S., & Panigrahi, R. (2019). Mechanical and Durability Properties of Fly Ash Geopolymer Concrete with Silica Fume. Journal of The Institution of Engineers (India): Series A, 100(4), 697–705. https://doi.org/10.1007/s40030-019-00400-z

Jianqiang Wei, C. M. (2017). Degradation of natural fiber in ternary blended cement composites containing metakaolin and montmorillonite. *Corrosion Science*, 42-60.

M.B. Ali, R. S. (2011). A review on emission analysis in cement industries. *Renewable and Sustainable Energy Reviews, 15*(5), 2252-2261. doi:https://doi.org/10.1016/j.rser.2011.02.014.

Mabrouk Maache, A. B. (2017). Characterization of a novel natural cellulosic fiber from Juncus effusus L. *Carbohydrate Polymers*, 163-172.

Mehta P.K. (2002). Greening of the concrete industry for sustainable development. *Concrete International, 24*, 23-28.

Mohammad H B, a. R. (2020). Natural Kenaf Fiber and LC3 Binder for Sustainable for Sustainable Fiber-Reinforced Cementitious Composite: A Review. *Applied Sciences, 10(1), 357., 10* (Special Issue Low Binder Concrete and Mortar). doi:http://dx.doi.org/10.3390/app10010357

Mònica Ardanuy, J. C. (2015). Cellulosic fiber reinforced cement-based composites: A review of recent research. Construction and Building Materials, 115-128.

N.A. Johansen, M. M. (2009). New method for determination of absorption capacity of internal curing agents. Cement and Concrete Research, 65-68.

Okoye, F. N., Durgaprasad, J., & Singh, N. B. (2016). Effect of silica fume on the mechanical properties of fl y ash based-geopolymer concrete. Ceramics International, 42(2), 3000–3006. https://doi.org/10.1016/j.ceramint.2015.10.084

Omar Faruk, A. K.-P. (2012). Biocomposites reinforced with natural fibers: 2000–2010. *Progress in Polymer Science*, 1552-1596.

Reju, R., & Jiji Jacob, G. (2012). Investigations on the chemical durability properties of Ultra High Performance Fibre Reinforced Concrete. International Conference on Green Technologies (ICGT), 181–185.

S. Gwon et al. (2022). Internal curing of cement composites using kenaf. Journal of Building Engineering, 1-15. Soudabeh Dezhampanah, I. N. (2020). Environmental performance and durability of concrete incorporating waste tire rubber and steel fiber subjected to acid attack. *Journal of Cleaner Production, 268*, 1-21. doi:https://doi.org/10.1016/j.jclepro.2020.122216

Taha Mehmannavaz, Mohammad Ismail, P. Forouzani, I. O. Hassan, S. M. S. & M. S. (2015). Performance Of Aerated Concrete Incorporating By- Product From Agro-Industry In Sulphuric Acid. *Malaysian Journal of Civil Engineering 27 Special Issue, 177*(1), 170–177.

UNVEILING THE NATURE OF DEFECTS OCCURRENCES IN CONSTRUCTION PROJECTS

Najihah Rahimin[1], Haryati Mohd Isa[1,2*], Thuraiya Mohd[3] and Nur Azfahani Ahmad[4]
[1]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, Perak, Malaysia
[2]Department of Quantity Surveying, College of Built Environment, Universiti Teknologi MARA, Perak Branch, Perak, Malaysia
[3]Department of Real Estate Management, College of Built Environment, Universiti Teknologi MARA, Perak Branch, Perak, Malaysia
[4]Department of Building Surveying, College of Built Environment, Universiti Teknologi MARA, Perak Branch, Perak, Malaysia

**Corresponding Email: harya966@uitm.edu.my*

Abstract
Construction defects are always of great concern in the industry because they cause delays before handover and raise maintenance costs when buildings are occupied. Despite numerous studies on the nature of defects occurring, it has been difficult to systematically review this research problem due to the absence of review techniques, making it difficult for researchers to replicate or interpret the results. Therefore, this study performs a systematic literature review (SLR) on the nature of defects occurrences of construction defects in construction projects. The review process included four key methodological steps, namely systematic searching strategies based on identification, screening, and eligibility on several established databases such as Scopus, ScienceDirect, Google Scholar, Emerald Insight, and Web of Science, followed by data extraction and analysis. Four main themes were discovered based on the types of construction defects: (1) architectural defects, (2) structural defects, (3) mechanical defects, and (4) electrical defects. These four themes were divided into twenty-two sub-themes. Lastly, four themes were discovered based on the causes of construction defects: (1) design defects, (2) material defects, (3) workmanship defects, and (4) maintenance defects.

Keywords: *Nature; defects; construction; projects*

INTRODUCTION

In recent years, defects have become increasingly prevalent in the construction sector in Malaysia (Alomari, 2022; Sellakutty et al., 2017). Even with new advancements in construction technology, building defects persist. Indeed, it is the building's most frequent issue in Malaysia (Hong (2016); Sambasivan & Soon (2007); Sravani & Chandgude, 2020). These defects arise from various factors, including poor workmanship, construction materials, and faulty design.

Nordin (2010) asserted that 53% of the designed and constructed public buildings, audited from 2009 to 2010, are still undergoing preparations for delivery to the client due to defects. These issues not only lead to cost overruns but also hinder the buildings to function correctly. The National House Buyers Association (2023) reported that the majority of the defects issues that occurred in residential projects in Malaysia range from complex structural issues, which threaten the integrity of buildings, to simple items relating to aesthetics. Consequently, these issues have a detrimental impact on the quality and life-cycle costs of the properties.

Jorgensen (2009) and Hassan et al. (2022) argued that most of the defects lack precise documentation (Ilozor et al., 2004; Pheng & Wee, 2001). As a result, identical issues recur in subsequent projects, even those undertaken by the same contractor, and the client is ultimately responsible for fixing them at their own expense (Hassan et al., 2022). Sandanayake et al. (2021) stated that minimising defects is a crucial yet challenging process. Identifying significant gaps and trends in defect occurrences requires a range of procedural steps before performing a systematic analysis and implementing an established framework (Lee et al., 2020). Some defects led to the appearance of other defects. Thus, preventing the primary defects can consequently avoid the appearance of many defects, as certain defects cause the emergence of other defects. To prevent more defects from arising, it is crucial to identify the causes of building defects at an early stage (Ilozor et al., 2004; Alomari, 2021; Borku, 2021).

Defect types, causes, and categories can be identified by meticulously tracking and categorising defects. These significant findings can serve as lessons learned to assist the project team in determining what went wrong, subsequently improving cost-efficiency as well as quality (Wardhana & Hadipriono, 2003; Ilozor et al., 2004; Carillo, 2006; Le & Bronn, 2007).

Despite the abundance of available studies on construction defects (Atkinson, 1998; Josephsen & Hammarlund, 1999; Pheng & Wee, 2001; Chong & Low, 2005; Sommerville, 2007; Zietsman, 2008), there has been limited research on defects in relation to work discipline and their environs. Given this gap, the current research aims to conduct a systematic literature review (SLR) focusing on the nature of defects occurrences in construction projects. Through this approach, the authors' empirical evidence can be justified to identify the gaps and guide the direction for future research in this field. In progressing the review, the authors were guided by the main research question: What are the types, causes, and categories of construction defects occur in construction projects?

LITERATURE REVIEW

Type of Construction Defects

The term 'defects' refers to shortcomings in design and construction practices or inadequacies arising from normal wear and tear (Lambers et al., 2023; Alomari, 2021; Yacob et al., 2019; Isa et al., 2011; Olanrewaju et al., 2010). Atkinson (2002) categorised defects into two categories depending on when they first manifest. Physical or patent defects occur when the building materials, the structure, or the project documents fall short of the standards set by the contract, the law, or best practice. Process defects, on the other hand, emerge when the construction process is performed in a way that results in an enormous loss of resources or time compared to an optimal process. While hidden/latent defects are not visible and can only be discovered during the occupancy stage, patent defects are readily apparent to be found during the building inspection.

Chong and Low (2005) stated that accessing an occupied building can be challenging to gather information on the defects' occurrence. This challenge arises because such information is rarely disclosed to the public until it is severe enough to prompt complaints from the tenants to the authorities. Hassan (2009) and Nordin (2010) revealed that the most defective elements for the RMK9 projects are due to architectural defects. However, this is refuted by Amin (2010), who claims that architectural components are more exposed than other components. Thus, tenants are more likely to report architectural defects than mechanical defects.

Hassan et al. (2022) stated that the most common types of defects occurring in buildings in Malaysia include water seepage, cracks, and defects in finishes. Furthermore, Olanrewaju et al. (2010) classified defects into three categories: very important defects, significant defects, and minor defects. Examples of very important defects encompass flooding of the property, cracking of a structural element, short-circuit of the electrical system, causing fire, or leakage of the roof sheathing. Construction defects affect many viewpoints of a project and can result in structural, legal, and financial consequences; rectifying them is essential. Impact on construction time and cost, sustainability and productivity, customer satisfaction, defect types and causes, implications for legal responsibility and prevention, and societal repercussions are a few of the noteworthy and vital aspects of construction defects (Tayeb et al., 2020; Koch and Schultz, 2019; Robert, 2016).

According to Gonzalez (2023) and Chris (2021), significant construction defects can significantly affect a building's integrity, usability, and attractiveness. Such defects can include, for example, mechanical issues, electrical problems, inadequate thermal and moisture protection, structural integrity issues like unstable foundations, the concrete and masonry division, and carpentry. Additionally, water intrusion causes property damage and toxic mould exposure, design errors like poorly planned roofs resulting in water penetration, poor drainage, or inadequate structural support, material defects like failure due to defective or damaged building materials, and defects in construction like poor drainage and waterproofing. On the other hand, defects that are visible and simply identified during construction, with clear team responsibility and low cost of correction, may be considered minor construction defects. Undersized beams, paint coating applications, and inadequately reinforced concrete are a few instances of minor defects in construction (Gonzalez, 2023; Chris, 2021).

Causes of Construction Defects

Josephson (1999) believes that the causes of the faults can be avoided or remedied to prevent their reoccurrence. Nevertheless, the industry has taken a while to acknowledge the defects issue. Understanding the factors contributing to building defects is crucial for understanding the triggered issues. Hanafi et al. (2018) noted that diverse processes can lead to and have an impact on building defects. In general, mechanical agents, biological agents, chemical agents, and natural disasters are the primary culprits of flaws in a building brought on by defective agents.

The causes of construction defects in Malaysia vary and can be attributed to several factors (Tayeb et al., 2020) and (Hassan et al., 2022). Among the identified factors are shortage of budget, insufficient design, poor workmanship, inadequate maintenance, inadequate contractor, poor site management, wrong method of construction, poor quality materials, human errors, and work processes. Conversely, poor workmanship, subpar construction materials, insufficient supervision and management, design mistakes, land movement, and materials that do not meet the required standards are among the prevalent triggers for construction defects Tayeb et al. (2020).

Bakri & Mydin (2014) and Khan et al. (2021) stated that wall cracks are the primary cause of most structural defects due to overload and building settlement. Moreover, Borku (2020) claimed that poor building practices, poor construction methods, inadequate workmanship, or insufficient site supervision probably instigated defects occurrences. Khan et al. (2021) noted that natural disasters and the defects they cause are unpredictable, potentially resulting in structural damage ranging from minor cracks to collapse. Thus, it is crucial to concentrate on the root causes of faults at various stages of a building project (Khan et al., 2021).

Categories of Construction Defects

Isa et al. (2014) categorised defects into ten categories, namely workmanship, design, maintenance, lack of protection, material, documentation, nature, vandalism, mishandling by users, and wear and tear.

Table 1. Categories of Defects

Defects Category	Description
Workmanship	Improper joints, improper handling of the components and improper installation
Design	Poor decisions in design i.e., specification of materials, layout and integration between different materials and systems
Maintenance	Materials systems that are not maintained properly or non-existent during occupancy of the building
Lack of protection	Deficiencies in the construction process that result in inadequate protection against various elements, leading to defects in the building project
Material	Poor material quality
Documentation	Wrong or incomplete specification
Nature	Due to unpredictable nature
Vandalism	Due to deliberate destruction
Mishandling by users'	Due to human error
Wear and tear	Gradual damage upon daily usage of an item over time

(Source: Isa et al., 2014)

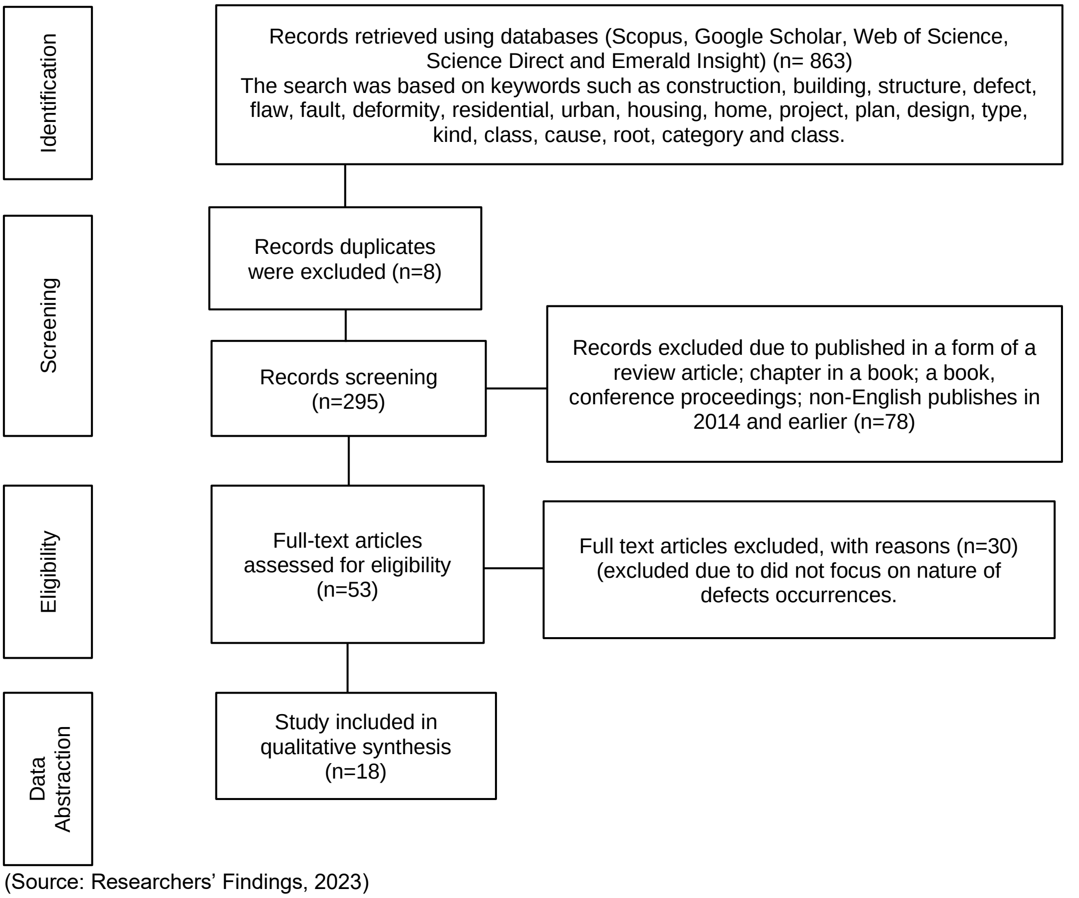
Workmanship faults include those that result from improper handling, improper installation, improper material mixing, and improper joints or gaps, which the contractors typically cause. Meanwhile, poor design decisions made by the designers are due to design defects. Next, maintenance defects involve material systems that require adequate maintenance or are non-existent during the building occupancy period. Then, lack of protection defects results from inadequate protection being provided or poor/non-maintenance of the equipment. The use of low-quality materials in the project results in material defects by the designers or contractors. The next defect category is documentation defects, which occur due to incorrect or incomplete specifications during the pre-contract or construction stage. In addition, unpredictable nature and deliberate destruction contribute to natural defects and vandalism defects. Finally, wear and tear defects occur due to gradual damage upon daily usage of an item over time.

Hanafi et al. (2018) categorised construction defects into two types, namely structure and non-structure. Structure defects are defined as physical damage to the designated load-bearing elements of the building caused by the failure of load-bearing elements to the extent that the building becomes risky to the occupants. Non-structural defects exist in building components such as roofs, walls, columns, beams, windows, doors, floors, stairs, and apron. However, it does not involve safety, yet it must be restored to maximise the building's functionality (Suffian, 2013) and (Hanafi et al., 2018). In addition, Lee et al. (2018) added that there are eight different types of faults, including poor work performance, water problems, surface concerns, abrasion, separation, inappropriate fitting, missing mission, and cracked.

RESEARCH METHODOLOGY

SLR was utilised to identify the types, causes, and categories of construction defects. SLR utilises systematic, transparent, and reproducible methods at each level of the procedure to locate and compile all pertinent research (Higgins et al., 2011) and (Shaffril et al., 2021). It is a method for synthesising scientific data to address a specific research issue in a clear, repeatable manner while attempting to incorporate all published data on the subject and evaluating the quality of this data (Petticrew, 2001; Liberati et al., 2009; Lame, 2019).

Figure 1 shows the flow diagram of the study in the systematic searching strategies process, namely identification, screening, eligibility and exclusion, and data abstraction.



(Source: Researchers' Findings, 2023)

Figure 1. The Flow Diagram of The Study

Phase 1: Identification of Literature

Identification of literature is a method to search for any potential synonyms, associated terms, and variations for the research's main keywords, which include the type of defects, causes of defects, and categories of defects. It aims to provide the selected database with more options for discovering additional relevant articles for the review. Shaffril et al. (2021) claimed that the identification process involved using a thesaurus online, keywords from previous research, keywords from Scopus, and expert suggestions.

Wijewickrama et al. (2021) mentioned that related words, such as synonyms, related terms, and variations of the main keywords, were searched to obtain a thorough reading of the existing literature. On the five major databases, Scopus, ScienceDirect, Web of Science, Emerald Insight, and Google Scholar. The use of Boolean operators, phrase searching, truncation, wild cards, and field code functions enable the authors to construct on the existing keywords and produce comprehensive search strings. Table 2 provides information on how to search these five databases: Scopus, ScienceDirect, Web of Science, Emerald Insight, and Google Scholar, resulting in a total of 863 for the nature of construction defects.

Table 2. Search String 1-Nature of Construction Defects

Database	Keywords
Scopus	TITLE-ABS-KEY (((“construction” OR “building” OR “structure” AND “defect” OR “flaw” OR “fault” OR “deformity” AND “residential” OR “urban” OR “housing” OR “home” AND “project” OR “plan” OR “design” AND “type” OR “kind” OR “class" AND “cause” OR “root” OR “source" AND “category” OR “class” OR “classification”)))
ScienceDirect	TS = KEY (((“construction” OR “building” OR “structure” AND “defect” OR “flaw” OR “fault” OR “deformity” AND “residential” OR “urban” OR “housing” OR “home” AND “project” OR “plan” OR “design” AND “type” OR “kind” OR “class" AND “cause” OR “root” OR “source" AND “category” OR “class” OR “classification”)))
Web of Science	TS = KEY (((“construction” OR “building” OR “structure” AND “defect” OR “flaw” OR “fault” OR “deformity” AND “residential” OR “urban” OR “housing” OR “home” AND “project” OR “plan” OR “design” AND “type” OR “kind” OR “class" AND “cause” OR “root” OR “source" AND “category” OR “class” OR “classification”)))
Emerald Insight	TITLE-ABS-KEY (((“construction” OR “building” OR “structure” AND “defect” OR “flaw” OR “fault” OR “deformity” AND “residential” OR “urban” OR “housing” OR “home” AND “project” OR “plan” OR “design” AND “type” OR “kind” OR “class" AND “cause” OR “root” OR “source" AND “category” OR “class” OR “classification”)))
Google Scholar	TS (((“construction” OR “building” OR “structure” AND “defect” OR “flaw” OR “fault” OR “deformity” AND “residential” OR “urban” OR “housing” OR “home” AND “project” OR “plan” OR “design” AND “type” OR “kind” OR “class" AND “cause” OR “root” OR “source" AND “category” OR “class” OR “classification”)))

(Source: Researchers’ Findings, 2023)

Table 2 shows the search string for the nature of construction defects from the five database search engines. English-published articles were searched by including the keywords in their titles or abstracts: ("construction" OR "building" OR "structure" AND "defect" OR "flaw" OR "fault" OR "deformity" AND "residential" OR "urban" OR "housing" OR "home" AND "project" OR "plan" OR "design" AND "type" OR "kind" OR "class").

Phase 2: Screening of The Identified Literature

This phase focuses on automatically screening articles based on the appropriate criteria using the database's sorting function. The screening procedure is designed to remove any duplicate, irrelevant, and non-English articles. By using these particular databases as a search engine, only articles from the timeline between 2014 and 2023 were selected as one of the inclusion criteria. In this phase, 53 were reviewed, and only 18 were found to be eligible for this nature of construction defects paper's review.

Phase 3: Eligibility and Exclusion

In this third process, the author will manually check the retrieved articles to ensure they satisfy the requirements. The initial stage in this approach entailed reading the titles and abstracts of the articles. After a thorough analysis, only 18 papers were selected for the SLR. The content of another study proved to be unrelated to the paper's objective.

Phase 4: Data Abstraction

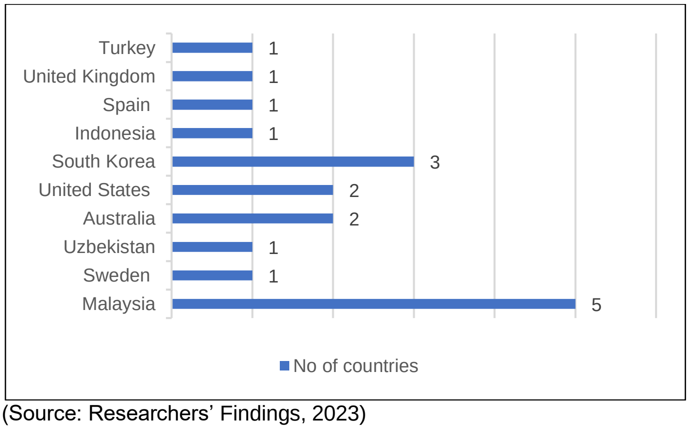
The final phase was the data abstraction. Figure 1 shows the flow diagram of the study before the data abstraction phase based on the data from the 18 selected literature.

FINDINGS AND DISCUSSION

The data from the literature was analysed and summarised in Table 3 to Table 5. The data abstraction is about the nature of construction defects, where the nature of construction defects refers to the types, causes, and categories of construction defects that occurred.

Background of The Selected Studies

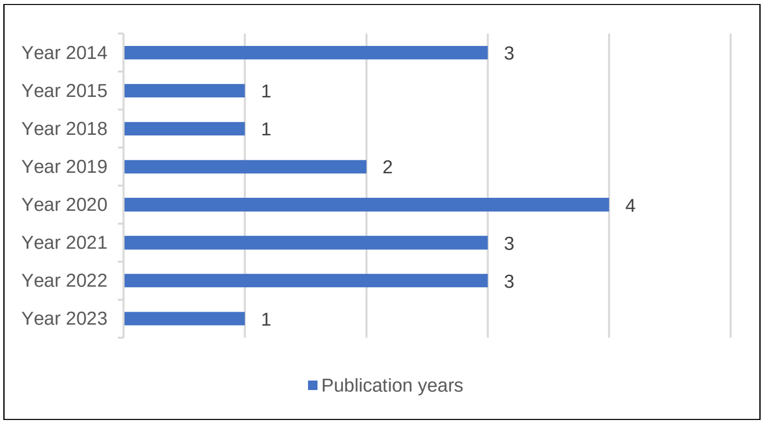
From the 18 articles, a total of five papers focused their studies in Malaysia (Olanrewaju et al., 2022; Dzulkifli et al., 2022; Talib, R. B. et al., 2021; Abdul-R. et al., 2014 and Sulieman M. et al., 2014) Next, three papers in South Korea (Lee S. et al., 2018; Park, J. et al., 2020 and Lee et al., 2020) also two papers in Australia (Cardellicchio et al., 2021 and Sandanayake et al., 2022). Then, two papers in the United States (Vandemark et al., 2020 and Aljassmi H et al., 2014). Meanwhile, one paper from the United Kingdom (Hopkin T. et al., 2019), Spain (Serrano et al., 2020), Indonesia (Pamungkas et al., 2021), Uzbekistan (Khotamov et al., 2023), Turkey (Cogurcu M., 2015) and Sweden (Zalejska et al., 2019).



(Source: Researchers' Findings, 2023)

Figure 2. Countries Where the Selected Studies Were Conducted

For publication, it is found that three articles were published in 2014 (Aljassmi H. et al., 2014; Sulieman M. et al., 2014 and Abdul-R. et al., 2014), each article in the year 2015 and year 2018 (Cogurcu M., 2015) and (Lee S. et al., 2018). Two articles were published in 2019 (Zalejska et al., 2019 and Hopkin T. et al., 2019), four articles in 2020 (Park J. et al., 2020; Lee et al., 2020; Serrano et al., 2020 and Vandemark et al., 2020). Then, every three articles published in year 2021 and year 2022 (Pamungkas et al., 2021; Talib, R. B. et al., 2021 and Cardellicchio et al., 2021) and (Olanrewaju et al., 2022; Sandanayake et al., 2022 and Dzulkifli et al., 2022). Lastly, only one article published in the year 2023 which is (Khotamov et al., 2023).



(Source: Researchers' Findings, 2023)

Figure 3. Publication Years of Selected Studies

Type of Construction Defects

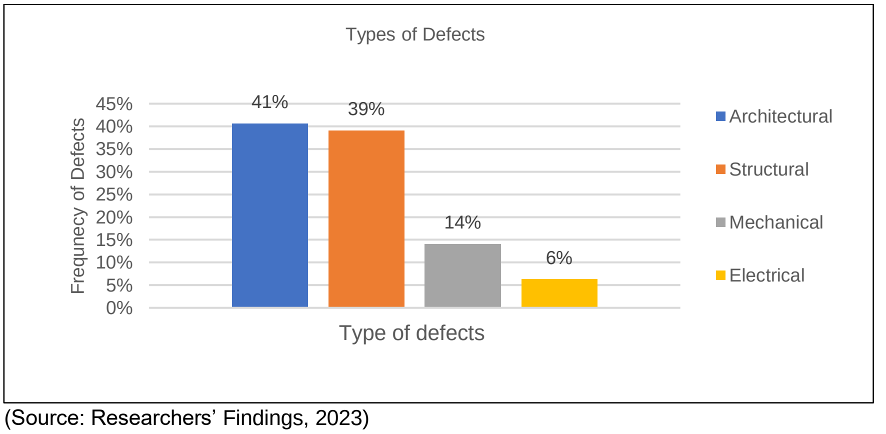
Table 3 shows the types of construction defects that have been abstracted from the literature obtained.

Table 3. Types of Construction Defects

Type of Construction Defects	Khotamov et al., 2023	Olanrewaju et al., 2022	Sandanayake et al., 2022	Dzulkifli et al., 2022	Pamungkas et al., 2021	Talib, R. B et al., 2021	Cardellicchio et al., 2021	Park, J et al., 2020	Lee et al., 2020	Serrano et al., 2020	Vandemark et al., 2020	Zalejska et al., 2019	Hopkin T et al., 2019	Lee S et al., 2018	Cogurcu M 2015	Aljassmi H et al., 2014	Sulieman M et al., 2014	Abdul-R et al., 2014
Architectural Defects																		
Non-structural cracks in finishes	√	√		√		√		√	√			√		√			√	√
Stains	√			√														
Discolouration of paints				√														
Detachment				√					√									
Leakage		√				√			√	√	√			√			√	
Peeling paint						√											√	
Incomplete work			√									√						
Structural Defects																		
Cracks	√	√		√				√		√		√		√	√		√	√
Spalling				√				√			√							
Corrosion				√				√										
Water leakage				√		√				√	√							√
Damp						√					√							√
Poor drainage		√									√							
Mechanical Defects						√												
Defective mechanical component						√												
Excessive noise						√				√								

Type of Construction Defects	Khotamov et al., 2023	Olanrewaju et al., 2022	Sandanayake et al., 2022	Dzulkifli et al., 2022	Pamungkas et al., 2021	Talib, R. B et al., 2021	Cardellicchio et al., 2021	Park, J et al., 2020	Lee et al., 2020	Serrano et al., 2020	Vandemark et al., 2020	Zalejska et al., 2019	Hopkin T et al., 2019	Lee S et al., 2018	Cogurcu M 2015	Aljassmi H et al., 2014	Sulieman M et al., 2014	Abdul-R et al., 2014
Malfunctioning								✓										
Loose														✓				
Water supply system failure														✓				
Faulty fixtures						✓												
Electrical Defects				✓														
System breakdown				✓														
Electrical Sparks/Shocks				✓													✓	
Supply stoppage				✓														

(Source: Researchers' Findings, 2023)



(Source: Researchers' Findings, 2023)

Figure 4. Types of Defects

These types of defects are classified into four elements, namely architectural, structural, mechanical, and electrical. It is supported by Chong and Low (2015), who state that defects can divided into work disciplines such as architectural, structural, mechanical, electrical, and biomedical, depending on the type of project. Architectural is highlighted as the most defective element with 41% defects occurrence, followed by 39% structural defects and 14% mechanical defects. Electrical defects are the least defective element with only 6% defects occurrence. Architectural defects encompass issues that occur on walls, floor and finishes, doors and fittings, windows and fittings, ceiling finishes, staircase, and roof. Cracks that appear or penetrate structural elements of buildings, such as beams, are called structural defects.

Mechanical defects occurred at elements of infrastructure, plant and machinery, tools and components, and heating and ventilation. In comparison, electrical defects are defects that occur in electrical systems, such as power supply and distribution, telecommunications, computing instrumentation, control systems, and others.

Causes of Construction Defects

Table 4 shows the causes of construction defects abstracted from the literature obtained. Construction defects can result from a singular root cause with the greatest impact on generating the construction defects or by combining many causes. Existing research that attempts to prevent defects by analysing the relationship between root causes and failure causes has provided insight that effective quality control performance can be achieved on construction sites.

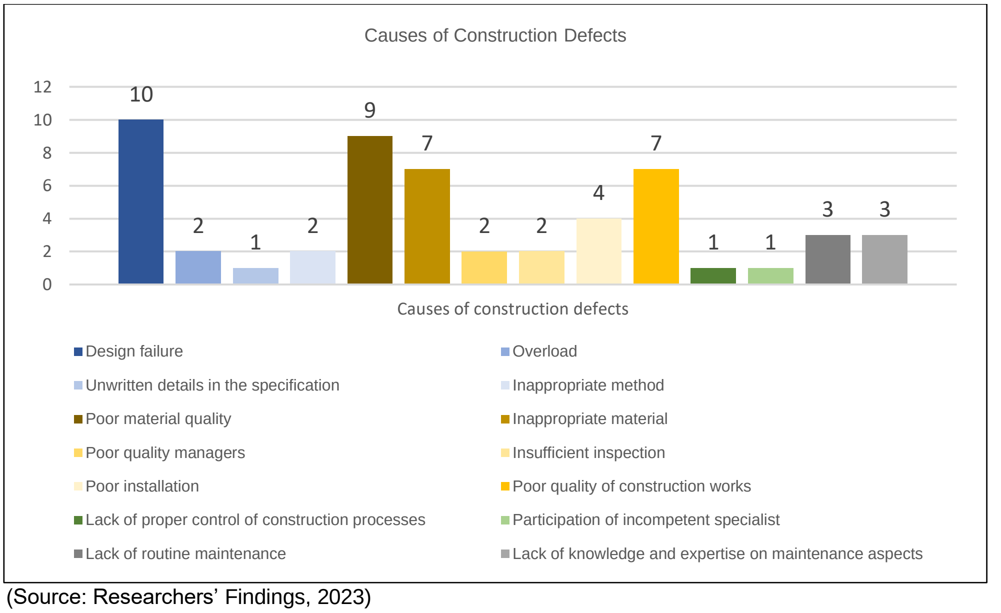
Table 4. Causes of Construction Defects

Causes of Construction Defects	Khotamov et al., 2023	Olanrewaju et al., 2022	Sandanayake et al., 2022	Dzulkifli et al., 2022	Talib, R. B et al., 2021	Cardellicchio et al., 2021	Park, J et al., 2020	Lee et al., 2020	Serrano et al., 2020	Vandemark et al., 2020	Zalejska et al., 2019	Hopkin T et al., 2019	Lee S et al., 2018	Cogurcu M 2015	Aljassmi H et al., 2014	Sulieman M et al., 2014	Abdul-Rahman et al., 2014
Design Defects																	
Design failure	✓	✓		✓	✓			✓	✓	✓			✓	✓		✓	
Overload					✓									✓			
Unwritten details in the specification							✓										
Inappropriate method			✓				✓										
Material Defects																	
Poor material quality	✓	✓	✓	✓				✓	✓				✓			✓	✓
Inappropriate material		✓	✓				✓	✓					✓			✓	✓
Workmanship Defects																	
Poor quality managers							✓										✓
Insufficient inspection							✓										✓
Poor installation							✓		✓							✓	✓
Poor quality of construction work	✓		✓					✓	✓				✓			✓	✓
Lack of proper control of construction processes	✓																
Participation of incompetent specialist	✓																
Maintenance Defects																	
Lack of routine maintenance	✓	✓	✓														
Lack of knowledge and expertise on maintenance aspects	✓	✓	✓														

(Source: Researchers' Findings, 2023)

Various causes of construction defects are established in the literature. From the above table, four themes of causes of construction defects occurrence are categorised: design defects, material defects, workmanship defects, and maintenance defects.

Hanafi et al. (2018) stated that building defects are caused by different processes and are affected by several factors. The workmanship defect theme has more subjects than the other two themes. Design failure contributed the most significant frequency of 10, while unwritten details in specification contributed to the most minor frequency. Regarding materials defects, there are only two subjects: poor material quality with a frequency of 9 and inappropriate material with a frequency of 7.



(Source: Researchers' Findings, 2023)

Figure 5. Causes of Construction Defects

Lastly, poor quality of construction work has the largest frequency for workmanship defects on the causes of construction defects. Lack of proper control of construction processes and participation of incompetent specialists have the least frequency with only a frequency of 1. Several elements, some readily apparent to the human eye and others acutely undiscovered within the building, are believed to contribute to structural defects (Alomari, 2022; Amin, 2010). Some construction flaws that directly impact a structure's performance can result from poor design or construction. Additionally, poor architectural design, inadequate manufacturing, the use of inferior materials or equipment, and a failure to adhere to plans and specifications can all result in construction defects (Summerlin & Ogborn, 2006; Alomari, 2022).

Categories of Construction Defects

Table 5 shows the 11 categories of construction defects which have been abstracted from the literature obtained. Workmanship flaws include errors in handling, installation, mixing of materials, and failing to provide adequate joints or gaps. Meanwhile, design flaws result from the designers' bad design choices. Contractors typically bring on these flaws. The use of low-quality materials in the project can result in material defects, and these defects may be attributed to either the designers or the contractor. Lack of protection flaws are those that result from inadequate protection being provided, and poor maintenance or non-maintenance of equipment or services come under this category. Additional six categories of faults are included, including documentation defects, manufacturing defects, nature defects, vandalism defects, user misuse, and wear-and-tear defects.

Table 5. Categories of Construction Defects

Categories of Construction Defects	**Khotamov et al., 2023**	**Olanrewaju et al., 2022**	**Sandanayake et al., 2022**	**Dzulkifli et al., 2022**	**Talib, R. B et al., 2021**	**Cardellicchio et al., 2021**	**Park, J et al., 2020**	**Lee et al., 2020**	**Serrano et al., 2020**	**Vandemark et al., 2020**	**Zalejska et al., 2019**	**Hopkin T et al., 2019**	**Lee S et al., 2018**	**Cogurcu M 2015**	**Aljassmi H et al., 2014**	**Sulieman M et al., 2014**	**Abdul-Rahman et al., 2014**
Workmanship defects	√	√	√	√	√		√	√	√				√			√	√
Design defects	√	√	√	√	√		√	√	√	√			√	√		√	
Maintenance defects		√			√												
Factory defects	√		√		√												
Lack of protection defects					√												√
Material defects		√	√	√	√		√	√	√				√			√	√
Documentation defects					√												
Nature defects					√									√			
Vandalism defects					√												√
Mishandling by users' defects					√												
Wear & tear defects	√			√	√												

(Source: Researchers' Findings, 2023)

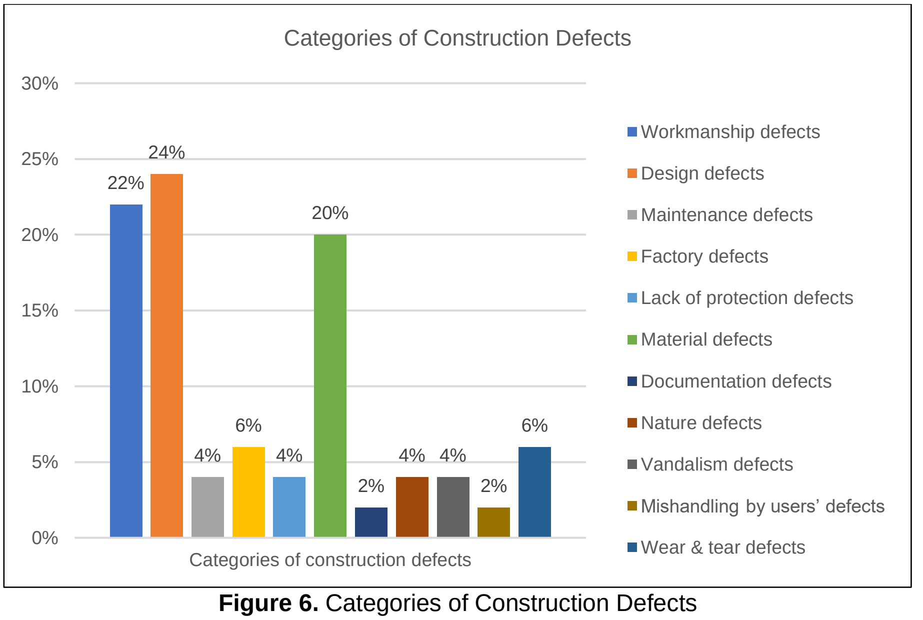


Figure 6. Categories of Construction Defects

Based on Figure 6, design defects have the most significant percentage of categories of construction defects, with 24%. Many researchers from previous studies agreed that design defects contribute to the most significant construction defects. Documentation defects, on the other hand, have the lowest percentage, only 2%, among the categories of construction defects. In contrast, workmanship defects and material defects followed with the second largest percentage with 22% and 20%. These categories of defects have been mentioned by

Isa et al. (2014) and Lee et al. (2018) in their research, in which Isa et al. (2014) categorised defects into five main categories of defects.

CONCLUSION

Since it is virtually always possible to predict when defects in construction projects will occur, more effort must be put into improving all parties involved, especially the professional team, to reduce the probability of defects. The current study has systematically reviewed earlier research on the nature of defects. This method allows for the discovery of gaps and presents chances for further research by challenging any claims of rigour in some of these studies. In this study, employing an SLR approach, 18 articles were appraised for their quality. There are four themes in the types of defects, namely architectural defects, structural defects, mechanical defects, and electrical defects. Furthermore, there are three themes for causes of defects, namely design defects, material defects, and workmanship defects. Eleven categories of defects are workmanship, design, maintenance, factory, lack of protection, material, documentation defects, nature, vandalism, mishandling by users' and wear and tear.

With the discovery of this nature of construction defects, the parties concerned can use this data to prevent construction defects from occurring in the future. The Malaysian construction industry is still concerned with defects issues. Responsible parties like building surveyors prevent the signs of flaws that frequently appear in residential projects. They must first determine the types, causes, and classifications of defects. From here, the project team will be able to determine acceptable solutions to defects problems. Proactive and thorough awareness of the nature of defects is also necessary to efficiently manage building problems. As a result, future initiatives can avoid having the same problems.

ACKNOWLEDGEMENT

The researchers would like to thank Universiti Teknologi MARA for providing the necessary support to enable the successful implementation of this research.

REFERENCES

Adlee, N. F., Misiran, M., Yusof, Z. M., Sapiri, H., & Amit, N. (2022). Perception on Malaysia fundmyhome crowdfunding initiative for Affordable Housing. The 5th Innovation and Analytics Conference & Exhibition (IACE 2021). https://doi.org/10.1063/5.0092730

Ahzahar, N., Karim, N.A., Hassan, S.H. and Eman, J. (2011). A study of contribution factors to building failures and defects in construction industry. Procedia Engineering, 20(3), 249-255

Alomari, O. M. (2022). Identification and Categorization of Building Defects. Civil Engineering and Architecture, 10(2), 438–446. https://doi.org/10.13189/cea.2022.100204

Atkinson, A.R. (2002). The pathology of building defects; a human error approach. Engineering Construction and Architectural Management, 9(1), 53-61

Borku, W. (2021). Impact factor: 4.295 Causes of defects in building costruction projects and its recommended remedial measures: A case study in Tepi Town, Southern Ethiopia. In International Journal of Advance Research. www.IJARIIT.com

Carrillo, P. (2006). Lessons learned practices in the engineering, procurement and construction sector. Engineering, Construction and Architectural Management, 12(3), 236-250

Chong, W.K., and Low, S.P. (2005). Assessment of defects at construction and occupancy stages. Journal of Performance of Constructed Facilities, 19(4), 283-289

Daud, A., & Ishak, M. F. (2018). Defect on high-rise government office buildings in Kelantan. In Built Environment and Technology

Dzulkifli, N., Sarbini, N. N., Abidin, N. I., & Ibrahim, I. S. (2022). Analysis of building defects at residential colleges: a case study at higher education facilities. ASEAN Engineering Journal, 12(4), 31-39. doi:10.11113/aej.V12.18142

Gonzalez, K. (2023, August 18). Construction Defects: Why They Happen & How To Prevent Them. Workyard. https://www.workyard.com/construction-management/construction-defects

Hanafi, M. H., Umar, M. U., Razak, A. A., Rashid, Z. Z. A., Noriman, N. Z., & Dahham, O. S. (2018). Common Defect of Colonial Buildings in Malaysia. IOP Conference Series: Materials Science and Engineering, 454(1). https://doi.org/10.1088/1757-899X/454/1/012186

Hanafi, M.H., Umar, M.U., Razak, A.A., Rashid, Z.Z.A., Noriman, N.Z. and Dahham,

Hassan, F., Haryati M.I., Che Mat, M., Ithnin, Z., and Sapisey, Z. (2009). Report on defects during defects liability period for public hospital projects in Malaysia. Kuala Lumpur

Hassan, S. H., Hamid, M. S. A., Zaini, M. F., Senin, S. F., Zakariah, Z., & Hashim, M. Z. (2022). Building Defects Assessment Framework for Malaysian Construction Projects. In Structural Integrity (Vol. 23). https://doi.org/10.1007/978-3-030-85646-5_22

Hong, C. H. (2016). Investigation of defects in new buildings in Malaysia.

Hopkin, T., Lu, S. L., Sexton, M., & Rogers, P. (2019). Learning from defects in the UK housing sector using action research: A case study of a housing association. Engineering, Construction and Architectural Management, 26(8), 1608–1624. https://doi.org/10.1108/ECAM-04-2018-0146

Ilozor, B.D., Okoroh, M.I. and Egbu, C.E. (2004). Understanding residential house defects in Australia from the State of Victoria. Building and Environment, 39(3), 327-337

Isa, H. M., Hassan, F. P., Ismail, Z., & Takim, R. (2011). Tracking architectural defects in the Malaysian hospital projects. ISBEIA 2011 - 2011 IEEE Symposium on Business, Engineering and Industrial Applications. https://doi.org/10.1109/ISBEIA.2011.6088825

Jorgensen, K. (2009). Failures and Defects in the Building Process: Applying the Bow-Tie Approach. In Construction Facing Worldwide Challenges (pp. 19-20). CIB.

Josephson, P.E., and Hammarlund, Y. (1999). The causes and costs of defects in construction: a study of seven building projects. Automation in Construction, 8(6), 681-687

Khotamov, A., & Kadabayeva, S. (2023). A new method for assessing the physical wear of apartment buildings with defects included. E3S Web of Conferences, 371, 03016. https://doi.org/10.1051/e3sconf/202337103016

Lambers, R., Cheung, F., & Skitmore, M. (2023). Risk management strategies for common residential construction defects: the case of Queensland, Australia. International Journal of Construction Management. https://doi.org/10.1080/15623599.2023.2252293

Lame, G. (2019). Systematic literature reviews: An introduction. Proceedings of the International Conference on Engineering Design, ICED, 2019-August, 1633–1642. https://doi.org/10.1017/dsi.2019.169

Le, M. A. T., & Brønn, C. (2007). Linking experience and learning: Application to multi-project building environments. Engineering, Construction and Architectural Management, 14(2). https://doi.org/10.1108/09699980710731272
Lee, K., Hong, G., Sael, L., Lee, S., & Kim, H. Y. (2020). Multidefectnet: Multi-class defect detection of building façade based on deep convolutional neural network. Sustainability (Switzerland), 12(22), 1–14. https://doi.org/10.3390/su12229785
Lekan, A., Clinton, A., Stella, E., Moses, E., & Biodun, O. (2022). Construction 4.0 application: Industry 4.0, internet of things and Lean Construction Tools' application in Quality Management System of residential building projects. Buildings, 12(10), 1557. https://doi.org/10.3390/buildings12101557
Meyers, C. (2021, November 26). Types of Construction Defects. FindLaw. https://www.findlaw.com/realestate/construction-defects/types-of-construction-defects.html
Mohamed Shaffril, H. A., Samsuddin, S. F., & Abu Samah, A. (2020, October 23). The ABC of systematic literature review: the basic methodological guidance for beginners. Quality & Quantity, 55(4), 1319–1346. https://doi.org/10.1007/s11135-020-01059-6
Nordin, O. (2010) Lesson Learnt from RMK9 for RMK10 Projects: Analysis on Project Failures and Defects, Kuala Lumpur unpublished
O.S. (2018). Common Defect of Colonial Buildings in Malaysia. IOP Conference Series: Materials Science and Engineering, 454, p.012186.
Olanrewaju, A. L. A., Khamidi, M. F., & Idrus, A. (2010). Quantitative analysis of defects in Malaysian university buildings: Providers perspective. Journal of Retail and Leisure Property, 9(2). https://doi.org/10.1057/rlp.2010.2
Olanrewaju, A. L., Tan, Y. Y., & Soh, S. N. (2022). Defect characterisations in the Malaysian affordable housing. International Journal of Building Pathology and Adaptation, 40(4), 539–568. https://doi.org/10.1108/IJBPA-11-2018-0095
Pamungkas, A., Larasati, K. D., & Iranata, D. (2021). Architectural and structural requirements on building permits to reduce earthquake risk. the case of Surabaya, Indonesia. Journal of Settlements and Spatial Planning, 12(2), 107–118. https://doi.org/10.24193/jssp.2021.2.04
Park, J., & Seo, D. (2022). Defect Repair Cost and Home Warranty Deposit, Korea. Buildings, 12(7). https://doi.org/10.3390/buildings12071027
Park, J., Cha, Y., Al Jassmi, H., Han, S., & Hyun, C. (2020). Identification of defect generation rules among defects in construction projects using association rule mining. Sustainability, 12(9), 3875. https://doi.org/10.3390/su12093875
Pheng, L. S., & Wee, D. (2001). Improving maintenance and reducing building defects through ISO 9000. Journal of Quality in Maintenance Engineering, 7(1). https://doi.org/10.1108/13552510110386865
Sambasivan, M., & Soon, Y. W. (2007). Causes and effects of delays in Malaysian construction industry. International Journal of Project Management, 25(5). https://doi.org/10.1016/j.ijproman.2006.11.007
Sandanayake, M., Yang, W., Chhibba, N., & Vrcelj, Z. (2022). Residential building defects investigation and mitigation – a comparative review in Victoria, Australia, for understanding the way forward. Engineering, Construction and Architectural Management, 29(9), 3689–3711. https://doi.org/10.1108/ECAM-03-2021-0232
Sellakutty, D., & Rajendran, R. (2017). A Review On Construction Defects. International Journal of Informative & Futuristic Research, 4(8), 7079–7084. https://www.researchgate.net/publication/316561407

Serrano, P. D. S., Merino, M. D. R., & Sáez, P. V. (2020). Methodology for continuous improvement projects in housing constructions. Buildings, 10(11), 1–16. https://doi.org/10.3390/buildings10110199

Sommerville, J. and J. McCosh, 2007. Defects in new homes: an analysis of data on I, 696 new UK houses. Structural Survey, 24(1): 6-21.

Sravani T, D. S. . (2020). Assessment on Various Construction Defects and. 7(18), 4239–4245. https://doi.org/10.31838/jcr.07.18.521

Suffian, A. (2013). Some common maintenance problems and building defects: Our experiences. Procedia Engineering, 54. https://doi.org/10.1016/j.proeng.2013.03.009

Talib, R. B., Sulieman, M. Z. (2021). Identifying Building Defects: From Construction Cases in Malaysia. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 12(11), 12A11J, 1-12. http://doi.org/10.14456/ITJEMAST.2021.220

Tayeh, B. A., Maqsoom, A., Issa Abu Aisheh, Y., Almanassra, M., Salahuddin, H., & Irshad Qureshi, M. (1959). Factors affecting defects occurrence in the construction stage of residential buildings in Gaza Strip. https://doi.org/10.1007/s42452-020-1959-1

VanDemark, L., & Clevenger, C. M. (2020). Site Civil Issues within Construction Defect Litigation. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 12(3). https://doi.org/10.1061/(asce)la.1943-4170.0000418

VanDemark, L., Clevenger, C. M., & Click, M. (2021). Building Envelope Issues within Construction-Defect Litigation. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 13(4). https://doi.org/10.1061/(asce)la.1943-4170.0000484

Wardhana, K., & Hadipriono, F. C. (2003). Analysis of Recent Bridge Failures in the United States. Journal of Performance of Constructed Facilities, 17(3). https://doi.org/10.1061/(asce)0887-3828(2003)17:3(144)

Wijewickrama, M. K. C. S., Chileshe, N., Rameezdeen, R., & Ochoa, J. J. (2021). Quality assurance in reverse logistics supply chain of demolition waste: A systematic literature review. Waste Management & Research, 39(1), 3-24. https://doi.org/10.1177/0734242X20967717

Yacob, S., Shah Ali, A., & Peng Au-Yong, C. (2019). ESTABLISHING RELATIONSHIP BETWEEN FACTORS AFFECTING BUILDING DEFECTS AND BUILDING CONDITION. In Journal of Surveying, Construction and Property (JSCP) (Vol. 10). http://ejournal.um.edu.my/publish/JSCP/31

Zietsman, R. (2008). Defects in the construction industry – then and now. 5 th Postgraduate Conference on Construction Industry Development, Bloemfontein, South Africa

OPERATIONAL SAFETY COMPLIANCE DURING THE OPERATIONAL AND MAINTENANCE PHASE OF CONSTRUCTED PETROL STATIONS

Mazlina Zaira Mohammad[1*], Hafizuddin Zubir[2], Nor Syamimi Samsudin[3], Natasha Khalil[3] and Azman Zainonabidin[3,4]
[1]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA (UiTM) 40450, Shah Alam, Selangor, MALAYSIA
[2]Octagon Maju Holding Sdn Bhd, No.9, Industrial Park, Jalan Sutera 1/5A, Bukit Angkat, 43000 Kajang, Selangor, MALAYSIA
[3]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610, Seri Iskandar, Perak, MALAYSIA.
[4]Arkitek Azman Zainonabidin,19A, Persiaran Dataran 2, Bandar Seri Iskandar,32610 Seri Iskandar, Perak MALAYSIA

**Corresponding Email: mazlinazaira@uitm.edu.my*

Abstract
The improvement of management employer and safety management system commitment and awareness in workplace safety and health, the decrease in injuries and potentially dangerous incidents, and the improvement in working environment will influence employees to comply with safety rules in operational and maintenance phase of petrol station industry. Yet, it was shown that human behaviour is what contributes to building accidents the most. Therefore, the purpose of this study to compare between the five Behaviour base safety (BBS) elements affecting the safe working environment and to determine the efficient approach of each BBS element has been practice in the petrol station industry. This research utilised a quantitative method, and weighting priority placed based on collected data. Based on the elements of BBS surveyed respondents have high safety compliance and work safely during operational and maintenance phase. The outcomes of this study show the differences between among element of BBS, including which element of BSS was the most efficient approach and effective factor affecting based behaviour safety or safety performance in the workplace. In a conclusion, this study shows that BBS elements namely a safety management system, management commitment, safe behaviour, co-worker influence, and employee engagement can help improve the level of compliance with safety regulations among employees.

Keywords: *Behaviour base safety; Department of Occupational Safety and Health; Occupational Safety and Health Act (OSHA); Relative Importance Index*

INTRODUCTION

The construction industry in Malaysia significantly contributes to the nation's economic growth. Safety in the workplace is a paramount concern, especially in the construction sector. Enhancing safety has become a top priority due to the inherent high-risk work and hazards associated with construction projects. The safety and well-being of employees are of utmost importance to ensure their productivity and prevent accidents. Construction industry accidents, whether involving workers or employers, can have severe consequences, including physical or mental impairments, and can also impose a substantial financial burden on construction budgets. This issue underscores the significance of employee behavior and compliance with the Occupational Safety and Health Act (1994) (OSHA) in shaping the safety culture and reducing accidents(Abdullah et al., 2016). The Occupational Safety and Health Act (1994) aims to instill a culture of safety and health among all employees and employers in Malaysia.

Notably, human behavior plays a pivotal role in construction accidents. Hence, it is the responsibility of employees to adopt a comprehensive approach focusing on both the physical working environment and the behavioral aspects, attitudes, and beliefs of employees, all of which influence safety behaviors and ultimately compliance (Zin and Ismail, 2012). To effect a paradigm shift in the construction industry towards safety improvement, Salem et al. (2007) advocate the Behavioral-Based Safety (BBS) approach as the most effective program. BBS draws upon the principles of behavioral science, as conceptualized by Skinner (Geller, 2005). and leverages psychological insights to reduce workplace accidents and injuries. It centers on understanding individual actions, analysing the motivations behind these actions, and applying preventive measures to enhance specific behavioral processes (Geller, 2005).

In the contemporary context, the safety and health of employer's are intertwined, and insecure workplaces heighten the risk of accidents and injuries, which can detrimentally impact health. The BBS approach stands out as an effective strategy for mitigating unwanted incidents in the workplace, with the core assertion that the human factor predominantly contributes to accidents and injuries (Geller, 2005).

Numerous research studies have explored BBS in the construction industry, addressing various elements and approaches affecting safety culture. As considered by Samsudin et al., 2023, in construction industry has been classify into four main phases which are design planning, construction, operational and maintenance, demolition or renovation. Consequently, the data are extensive and often challenging to synthesize. This study aims to pinpoint key elements of BBS that can enhance compliance with safety regulations among employees. Specifically, the study delves into the elements of safety management systems, management commitment, safe behaviors, peer influence, and employer engagement. The overarching goal is to discern the differences in how these five BBS elements impact the safety environment in the petrol station industry during both operational and maintenance phase. Furthermore, this research endeavors to determine the most efficient approach for each BBS element practiced in the petrol station industry and ultimately recommend the most effective BBS elements for implementation during operational and maintenance phase.

This study's objectives are geared towards understanding which BBS elements contribute to an efficient approach and heightened compliance with safety regulations in the petrol station industry. By identifying these crucial elements, improvements can be made to elevate the overall level of safety compliance in the industry, benefiting not only the sector as a whole but also individual employees.

An Overview During Operational and Maintenance Phase in Petrol Station Industry

The construction industry is a significant driver of development and economic growth in countries, including Malaysia (Samsudin et al., 2022). A nation's progress is reflected in the construction of essential infrastructure and physical facilities, making the construction industry intricately linked with a country's economic development. Within this sector, workplace safety emerges as a paramount concern, particularly due to the high-risk nature of construction work and associated hazards (Samsudin et al., 2023). Enhancing safety has become a priority, as the construction industry is inherently exposed to precarious working conditions.

The annual construction of new petrol stations is a common practice across Malaysia, driven by the budget allocation of various clients, including industry giants such as Petron, Shell, Petronas, BHPetrol, and Caltex. Over the past decades, the petrol station industry in Malaysia has experienced significant growth, with multiple companies entering the market and competing fiercely to establish new stations. Notably, Shell and Petron have set ambitious targets to build approximately 1000 petrol stations in Malaysia. Despite the immense growth opportunities, safety concerns are shared across the industry, as constructing and maintaining petrol stations pose similar high-risk challenges. These include exposure to gas and vapor from petrol or diesel, live electrical components, traffic management, confined space work, and elevated work, among other hazards. Furthermore, each client has specific safety regulations, necessitating consultants and contractors to attend safety training sessions organized by their respective clients.

Accidents in the construction sector, whether involving employees or employers, can have severe consequences, such as debilitating injuries that restrict physical or mental functions, or even fatalities. These incidents can place a considerable financial burden on construction budgets. The presence of this problem underscores the importance of employees' behavior and their compliance with the Occupational Safety and Health Act (1994) (OSHA) in shaping the safety culture and reducing accidents (Abdullah et al., 2016). The primary objective of the Occupational Safety and Health Act (1994) is to cultivate a safe and healthy work culture among all employees and employers in Malaysia (DOSH, 1994). The act emphasizes self-compliance as a fundamental concept, rooted in the responsibility of ensuring the safety, health, and welfare of all employees in the workplace (Samsudin, Khalil and Zainonabidin, 2022). The introduction of a culture of safety at work represents a systematic approach toward achieving accident-free workplaces.

In particular, the roles of employers and employees with commendable safety behavior are pivotal in ensuring compliance with safety regulations in the construction sector and fostering occupational safety and health improvements (Zin and Ismail, 2012). The literature highlights several common reasons provided by employers for non-compliance, including a lack of awareness of OSHA 1994, limited time for addressing occupational safety and health issues, insufficient resource allocation for occupational safety and health, underestimating the importance of OSH, and a misplaced belief in the "accidents will not occur to me" syndrome. Conversely, employees' non-compliance is often attributed to factors such as limited knowledge of safety and health laws, challenges in adhering to OSH rules and regulations, frustration with compliance, and a similar "accidents would not occur to me" syndrome (Zin and Ismail, 2012). Hence, ensuring that employers enforce safety rules and regulations while promoting employee involvement in safety initiatives is crucial for preventing accidents, near-misses, and injuries during work (Aryee and Hsiung, 2016).

Behavioural Based Safety (BBS)

Most of the companies in Malaysia that introduced the BBS normally have another branch or parent organization in other countries that have already adopted BBS and are seeking to introduce the program in this region (Osman, Awang and Yusof, 2015). BBS is a tool for recognizing and improving employee behaviours to reduce workplace accidents. BBS's fundamental is behaviourisms based which integrates broad principles from sound ergonomics and positive reinforcement (Nasyrah Ibrahim et al., 2015).

BBS tends to generate greater interest in the construction or manufacturing sector and has the tremendous benefit of involving the employee of the particular person, as well as the commitment of the company to avoid injuries in the workplace (Pathak, 2018). According to Salem et al. (2007), the behavioural approach is especially important in solving safety concerns because it relies on human psychology at work. Two key aspects have supported BBS over other methods, concentrating on employee conduct that is believed to be the key cause of injury and disease and promoting employee participation in safety problems as safety is not seen alone. There are four basic steps in the BBS approach namely identification, observation, intervention, referral, and monitoring (Ismail et al., 2012).

BBS technique can be treated in operational and maintenance phase and it's known as an interventional process to correct employer's unsafe behaviour and reduce the accident rate (Zerguine et al., 2016). This study shows that, the general process of BBS was to identify unsafe behaviours, develop appropriate observation checklists, provide training or educate everyone, conduct behavioural observation and lastly provide feedback for improving the behaviour employee and reduce the incidence rate at company level. Zerguine et al. (2016); shows that 8 main categories were the factor cause unsafe behaviour, it is individual factors, site condition, workgroup, contractor, supervision, project management, organizations, and society.

METHODOLOGY

In this study, a comprehensive approach was taken to collect and analyse data to explore safety compliance during operational and maintenance phase of petrol stations based on the elements of behavioral-based safety. The methodology consisted of several key steps, as outlined below.

1. Expert Content Validity:

The study initiated with a series of expert interviews aimed at obtaining validation for the questionnaire used in the research. The content validity involved the consensus agreement of each element with experts in the field of petrol station operational and maintenance phase. Specifically, five experts with roles such as Safety Holder Officer, Safety Manager, and Project Manager from contracting firms involved in operational and maintenance of petrol station were validated. Their insights and feedback were instrumental in refining the questionnaire and ensuring its relevance to the industry.

2. Questionnaire Survey:

Subsequently, a structured questionnaire survey was conducted to collect primary data essential for achieving the study's objectives. The survey was designed to examine the safety compliance in the operational and maintenance phase of petrol stations, with a focus on behavioral-based safety exposure. The questionnaire was distributed among employees actively engaged in petrol station operational and maintenance phase. The target population to identify the safety compliance via behavioural-based safety exposure.

3. Use of Secondary Data:

In addition to the primary data collected through the questionnaire, secondary data sources were consulted to identify the elements of Behavioral-Based Safety (BBS) and other relevant information. This secondary data was leveraged to design a questionnaire that would yield accurate and comprehensive insights into the subject matter. Secondary data sources included published literature from journals, articles, websites, research theses, and newspapers.

4. Target Population:

The target population for this study consisted of employees involved in petrol station operational and maintenance, with a minimum age requirement of 18 years. The questionnaire survey was distributed among this specific group to gain insights into safety compliance in the petrol station industry through the lens of behavioral-based safety exposure.

5. Questionnaire Structure:

The questionnaire was structured into three main sections:

- **Section A:** This section gathered general background and demographic information about the respondents.
- **Section B:** The variables related to unsafe behavior and safety-related injury incidents were assessed using a Likert scale, including response options such as "1:Strongly Disagree (SD)," "2:Disagree, D," "3:Neither Agree nor Disagree," "4:Agree, A" and "5:Strongly Agree, SA" The Likert scale utilized in this section was adapted from the study of Zhou et al. (2008).
- **Section C:** This section focused on determining the efficient approach for each of the BBS elements and, lastly, recommended the most effective BBS elements to be implemented in petrol stations during operational and maintenance.The Likert scale survey had been used in section B which is to determine the efficient approach each of BBS elements and lastly section C to recommend the most effective BBS elements to be implemented at a petrol station during operational and maintenance phase.

6. Data Collection and Analysis:

To collect responses, a Google Form was distributed to 100 intended participants via email and the WhatsApp application. Out of these, 60 respondents successfully completed and submitted the questionnaire, constituting 60% of the total targeted responses. The collected data were analysed using the Social Sciences Statistical Service (SPSS) version 22.0 software. The analysis aimed to determine the frequency of responses provided by the participants.

7. Reliability Study:

A reliability study was conducted to measure the internal consistency of the questionnaire. Cronbach's Alpha, a commonly used reliability coefficient, was calculated to assess the questionnaire's internal consistency. This coefficient ranges from 0 to 1, with higher values indicating greater internal consistency of the scale items (Koonce and Kelly, 2014).

8. Ranking Analysis:

Finally, Relative Importance Index (RII) was employed to determine the ranking of the most efficient approach for each BBS element and to identify the most effective BBS elements. This analysis provided valuable insights into which BBS elements were considered the most crucial for ensuring safety compliance in the petrol station industry during operational and maintenance phases. Lastly RII to determine the ranking of the most efficient approach for each element BBS and the most effective BBS elements. Referred to Mahesh (2012), the formula of RII is stated (Equation 1) below:

$$\text{Relative Importance Index, } \mathrm{RII} = \frac{\sum \mathrm{W}}{\mathrm{A}} \times \mathrm{N} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5\mathrm{N}} \qquad (1)$$

W is the weight given to each likers scale by the respondent and ranges from 1 to 5.

The W ranges is 1. Strongly Disagree, 2. Disagree, 3. Neither agree or Disagree, 4. Agree, and 5. Strongly Agree.

A is the highest weight = 5
N is the total number responses collected

DATA ANALYSIS AND FINDINGS

The internal consistency of the questionnaire used in this research was assessed using Cronbach's Alpha in the SPSS software, resulting in a value of 0.839. According to George and Mallery (2019). this value indicates "good" internal consistency. The survey collected demographic information from the respondents, including age, gender, highest education level, years of experience, organization category, client involvement in the petrol station industry, and position within the organization.

Based on the demographic data in Section A, the majority of respondents fell within the 25 to 34 age group (65%), were male (58%), held an advanced degree (76.7%), had 1 to 5 years of work experience (46.7%), and occupied positions such as executive, engineer, safety health officer, and others (63.3%). Furthermore, a significant portion of the respondents worked in the capacity of contractors (61.7%).

Section B of the questionnaire was designed to assess respondents' awareness of safety compliance, workplace environment, standard procedures related to work, and other elements. The primary objective of this section was to determine the efficient approach of each Behavioral-Based Safety (BBS) element practiced in the petrol station industry during both operational and maintenance phases.

The example of RII for B10 in Table 1 is calculated based on the Equation 1 shown as below. The other RII components and for the other table also are calculated similar as the example. The value is different depends on the number of respondents for each component that likert scale being evaluated.

$$\mathrm{RII} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5N}$$

$$= \frac{5(42) + 4(2) + 3(0) + 2(15) + 1(1)}{5(60)}$$

$$= \frac{249}{300}$$

$$= 0.83$$

Table 1 presents the results related to the safety management system component of BBS:

Table 1. Element of BBS Safety Management System Result

COMPONENT	QUESTION	RII	RANK
B10	"Do safety management team support and follow standard of procedure"	0.83	1
B9	"The safety management team always ensure the capability of contractor "	0.797	2
B7	"There is SPOC system in my department for raising our safety issues."	0.783	3
B5	"The safety audit department are conducted at regular intervals."	0.777	4
B6	The safety committee meetings are conducted effectively."	0.763	5
B8	"Safety issues raised in audits in my work area are liquidated with all seriousness."	0.763	6
B2	"Safety and health procedures do not describe how to perform the task"	0.49	7
B4	"The permit system for work is impractical and less suited to real risks."	0.48	8
B1	"The task in this operational maintenance is difficult to do safely."	0.477	9
B3	Safety and health procedures/instructions/ rules are difficult to follow.	0.470	10
	Average Value RII	**0.585**	

According to Table 1, respondents either agreed (A) or strongly agreed (SA) with the following elements: the safety management team's support for and adherence to standard procedures (B10), the team's consistent commitment to ensure the contractor's capabilities (B9), the presence of a Single Point of Contact (SPOC) system for raising safety issues (B7), and the regular conduct of safety audits (B5). Respondents also agreed that safety committee meetings were conducted effectively (B6), and safety-related issues raised in various audits were addressed seriously (B8).

Conversely, respondents disagreed with statements related to the impracticality of safety and health procedures (B2), the permit system for work being less suited to real risks (B4), the task's difficulty in being performed safely (B1), and the difficulty in following safety and health procedures/instructions/rules (B3). Notably, component B10 had the highest RII value at 0.830, while B3 had the lowest RII value at 0.470.

In summary, the findings suggest that the safety management system component of BBS has a positive impact on compliance with safety during both operational and maintenance phase in the petrol station industry. These results align with the study by Zhou et al. (2008), which associates safety compliance with safety management system factors, indicating a high level of safety system compliance in the industry.

Table 2. Element of BBS Management Commitment Result

COMPONENT	QUESTION	RII	RANK
B20	"The company need established a PERT according to MITI's"	0.860	1
B19	The management responsible to do enforcement of C19 control on staff and contractor	0.853	2
B18	All employees know about emergency response plan procedures	0.800	3
B16	All the required Personal Protective Equipment (PPEs)	0.787	4
B14	Our management visibly demonstrates an interest in the safety and health of their employee	0.783	5
B15	"I am satisfied with the facilities at our Occupational safety and health"	0.770	6
B17	Management always supports financially related to additional item during performing work in construction or maintenance	0.767	7
B11	Productivity is often prioritized by management over safety and health factors	0.673	8
B12	Suggestions given to improve safety and health are rarely taken seriously	0.593	9
B13	Accident investigations are often used to find out who is to blame	0.557	10
	Average Value RII	**0.744**	

Based on the results presented in Table 2, respondents disagreed with the statement of component B13, which suggests that accident investigations are often used to find out who is to blame. Additionally, they disagreed with component B12, which indicates that suggestions given to improve safety and health are rarely taken seriously.

In contrast, most of the other statements or questions were agreed or strongly agreed upon by the respondents. These statements included:

The need for the company to establish a Preparedness and Emergency Response Team (PERT) in accordance with MITI's Manufacturing and its related services SOP for staff and contractors (B20).

The management's responsibility for enforcing Covid-19 control measures for staff and contractors (B19).

The assertion that all employees are knowledgeable about emergency response plan procedures, and the management conducts training and fire drills (B18).

The availability of all required Personal Protective Equipment (PPE), such as safety shoes, helmets, goggles, and gloves for their job (B16).

The visible interest of management in the safety and health of their employees (B14).

Satisfaction with the facilities related to Occupational Safety and Health (B15).

The financial support provided by management for additional items during construction or maintenance work (B17).

However, respondents also agreed that productivity is often prioritized by management over safety and health factors (B11).

In summary, the findings suggest that elements related to management commitment within the framework of BBS have a positive impact on compliance with safety regulations during both operational and maintenance phase in the petrol station industry. This aligns with the notion that management commitment is a crucial factor influencing the effectiveness of safety programs, as proposed by Zohar's (1980), and it contributes to employees' improvement in safety compliance during work.

Table 3. Elements of BBS Safe Behaviours Result

COMPONENT	QUESTION	RII	RANK
B30	Rewards for safe behaviours are a good way to increase safety awareness levels.	0.880	1
B27	"Safety and Health is a high priority when I am performing my job responsibilities."	0.850	2
B29	"If I saw another employee committing an unsafe practice, I would say something directly to him or her."	0.853	3
B28	Penalties for safety violations would cause employees to work more safely.	0.820	4
B26	"In my department, safety and health issues / hazards identified are corrected in a timely manner."	0.690	5
B22	The safety posters on display have little influence on the awareness and behaviours of employees here.	0.640	6
B31	Usage of face mask for all employee in the work area all time was difficult to do in work area.	0.553	7
B21	The permit system for work is impractical and less suited to real risks.	0.500	8
B25	"I am comfortable with the work environment (noise, dust, heat and vibration) in my workplace."	0.497	9
B32	Some employees were not complying the standard procedure to control Covid -19 in work area, we just ignored	0.403	10
B23	"Health and safety issues are not my problem."	0.397	11
B24	"Accidents happen to unlucky employees."	0.390	12
	Average Value RII	**0.623**	

Table 3 illustrates that respondents agreed with several component statements or questions related to safe behaviors. Specifically, they agreed or strongly agreed with the following statements:

Rewards for safe behaviors are a good way to increase safety awareness levels (B30).

"Safety and Health is a high priority when I am performing my job responsibilities" (B27).

"If I saw another employee committing an unsafe practice, I would say something directly to him or her" (B29).

"Penalties for safety violations would cause employees to work more safely" (B28).

"In my department, safety and health issues/hazards identified are corrected in a timely manner" (B26).

"The safety posters on display have little influence on the awareness and behaviors of employees here" (B22).

"Usage of face masks for all employees in the work area at all times was difficult to do in the work area" (B31).

Conversely, respondents disagreed with the following statements or questions:

The permit system for work is impractical and less suited to real risks (B21).

"I am comfortable with the work environment (noise, dust, heat, and vibration) in my workplace" (B25).

"Some employees were not complying with the standard procedure to control Covid-19 in the work area, and we just ignored it and continued to work without reporting to the management" (B32).

"Health and safety issues are not my problem" (B23).

"Accidents happen to unlucky employees" (B24).

The top-ranked component in Table 3 is B30, with an RII value of 0.880, and the lowest-ranked component is B24, with an RII value of 0.390.

In conclusion, the findings suggest that respondents agree that safe behaviors have a positive effect on compliance with safety regulations during both operational and maintenance phase in the petrol station industry.

Table 4. Element of Co-Worker Influence Result

COMPONENT	QUESTION	RII	RANK
B36	My superior often observes my work practices for the purpose of protecting my safety and health.	0.793	1
B35	My immediate superior shows interest in the safety and health of the employees in my department / work area.	0.783	2
B33	Colleagues do not reprimand if someone violates safety and health procedures/instructions/rules.	0.523	3
B34	"It is not important for me to work safely if I want other employees to respect me."	0.437	4
	Average Value RII	**0.634**	

Table 4 displays the results of the Likert scale questionnaire for the Co-worker Influence section. Respondents agreed or strongly agreed with the statements from components B36 and B35, which indicate positive co-worker influence:

"My superior often observes my work practices for the purpose of protecting my safety and health" (B36).

"My immediate superior shows interest in the safety and health of the employees in my department/work area" (B35).

Conversely, respondents disagreed with the following statements or questions:

"Colleagues do not reprimand if someone violates safety and health procedures/instructions/rules" (B33).

"It is not important for me to work safely if I want other employees to respect me" (B34).

The top-ranked component in Table 4 is B36, with an RII value of 0.793, while the lowest-ranked component is B34, with an RII value of 0.437.

In summary, the findings suggest that respondents agree that the influence of colleagues or co-workers has a positive impact on compliance with safety regulations during both operational and maintenance phase in the petrol station industry.

Table 5. Element of Employee Engagement Result

COMPONENT	QUESTION	RII	RANK
B40	"If I have a concern about safety and health, I know whom to contact."	0.820	1
B39	The safety and health policy of my organization is clearly understood by me.	0.813	2
B43	All employees in my work area are provided information on type, cause and recommendations of all accidents in our company.	0.807	3
B44	I have opportunities to provide input into the health and safety program in my organization.	0.807	3
B38	"I feel that observing both the safe / unsafe behaviours of individuals and giving them feedback will improve the safety levels."	0.803	4
B42	"I use the safety committee team to get action on a safety complaint which concerned me."	0.793	5
B41	The Supervisors / Front line officers of my department / section discuss accidents with employees concerned.	0.790	6
B45	All the agreement especially regarding safety and health that had been reached in the meeting of the safety committee members was not communicated to me.	0.547	7
B37	"I feel like I am not involved in the formation and review of safety and health procedures/instructions/regulations."	0.520	8
	Average Value R11	**0.838**	

Table 5 illustrates the Likert scale questionnaire results for the Employee Engagement section. Respondents agreed or strongly agreed with the following statements:

"If I have a concern about safety and health, I know whom to contact" (B40).

"The safety and health policy of my organization is clearly understood by me" (B39).

"All employees in my work area are provided information on the type, cause, and recommendations of all accidents in our company" (B43).

"I have opportunities to provide input into the health and safety program in my organization" (B44).

"I feel that observing both the safe/unsafe behaviors of individuals and giving them feedback will improve the safety levels" (B38).

"I use the safety committee team to get action on a safety complaint that concerned me" (B42).

"The Supervisors/Front line officers of my department/section discuss accidents with employees concerned" (B41).

On the other hand, respondents disagreed with the statements:

"All the agreements, especially regarding safety and health, that had been reached in the meeting of the safety committee members were not communicated to me" (B45).

"I feel like I am not involved in the formation and review of safety and health procedures/instructions/regulations" (B37).

The top-ranked component in Table 5 is B40, with an RII value of 0.820, while the lowest-ranked component is B37, with an RII value of 0.520.

In conclusion, the findings suggest that respondents agree with employee engagement having a positive impact on compliance with safety regulations during both operational and maintenance phase in the petrol station industry. This aligns with Hofmann and Stetzer (1996) hypothesis that greater employee involvement in safety activities leads to enhanced employee commitment to safety performance and reduces the tendency to commit unsafe behaviors.

Table 6. Effective Element of Base Behaviour Safety (BBS) in The Workplace

ELEMENT BASE BEHAVIOR SAFETY	RII	RANK
Safe management system	0.585	5
Management commitment	0.744	2
Safe behaviour	0.623	4
Co-worker influence	0.634	3
Employee engagement	0.838	1

Based on Table 6, the majority of respondents agree that the elements of Base Behavior Safety (BBS) are influential and effective when implemented in the operational maintenance phase of the petrol station industry. The top-ranking elements, considered the most effective, is employee engagement, each with an average RII of 0.838. The second-ranking element is management commitment, with an average RII of 0.744. Followed by co-worker influence element, and then safe behaviour is the second last ranking. The last-ranking element of BBS is safe management system, with an average RII of 0.585.

This result indicates a strong consensus among respondents that these BBS elements play a significant role in enhancing safety compliance in the workplace. This aligns with the findings of previous studies, such as Ismail et al. (2013) which highlight the importance of influencing front-line safety behavior to foster a culture of safety within an organization. Kabil and Sundararaju (2019), have also noted that safety management is only to support employees' morale and positively impact safety attitudes and behaviors. Additionally, project management commitment has consistently been found to be a significant factor in improving safety performance at construction industry (Zerguine et al., 2016). Enhancing employee engagement and understanding of workplace health and safety has been associated with a reduction in accidents, occupational illnesses, and injuries, as well as improvements in the working environment through process refinement and facility changes (Jasiulewicz-Kaczmarek, Szwedzka and Szczuka, 2015). Overall, these findings shed light for the safety practitioners for implementing BBS on the highly influential element affecting safety performance.

CONCLUSION

The data collected in this research, as summarized in the literature review, aimed to achieve the primary objectives of comparing the impact of five Base Behavior Safety (BBS) elements on the safe working environment within the petrol station industry during operational, and maintenance phase. These BBS elements encompassed a safety management system, management commitment, safe behavior, co-worker influence, and employee engagement.

The findings from the survey data gathered in sections A, B, and C were derived from employees within the operational and maintenance phase of the petrol station industry. Section A provided a comprehensive demographic profile of the respondents, including their age, gender, educational background, work experience, organizational category, involvement of clients in the petrol station industry, and positions within their respective organizations. The results showed that the majority of respondents fell within the age range of 25 to 34 years (65%), were predominantly male (58%), held advanced degrees (76.7%), had work experience ranging from 1 to 5 years (46.7%), and occupied roles such as executives, engineers, safety health officers, and others (63.3%). The majority of respondents also worked as contractors (61.7%).

Section B aimed to fulfil the second objective of the research, which was to assess the awareness of employees regarding workplace safety compliance, including awareness of work environment factors, standard procedures, and other aspects. The overarching goal of this section was to determine the effective approaches to implementing each BBS element within the petrol station industry during operational and maintenance phase. The results, presented in Table 1 to Table 6, showed that the Relative Importance Index (RII) values were high (greater than 0.600) when the statements were related to positive safety compliance and low (less than 0.500) when associated with negative statements. These results suggest that employees in the operational and maintenance phase of the petrol station industry have a high level of safety compliance and work safely.

The results also identified the most effective approaches within the BBS elements, as shown in Table 1 to Table 6. Employee engagement ranked highest with an RII of 0.838, followed by management commitment with an RII of 0.744. These two elements are interconnected and significantly influence the base safety behaviors of employees, thereby fostering a safer work environment. Aryee and Hsiung (2016), emphasized the importance of management commitment in enforcing safety regulations, ensuring compliance with safety laws, and engaging employees in safety initiatives to prevent accidents and injuries. This study suggests that employee engagement is the most influential factor when compared to other BBS elements.

Section C aimed to fulfil the final objective of recommending the most effective BBS elements to be implemented in the petrol station industry during operational and maintenance phase. The results from the section C questionnaire indicated that the most recommended and effective BBS elements, which are likely to diffuse and positively influence safety performance within the workplace, are the safe management system, management commitment, and employee engagement, each with an average RII of 0.857. (Neal and Griffin, 2002), employee engagement was shown to be the most important element when compared to another element BBS.

Kabil and Sundararaju (2019) mentioned that safety management practices not only improve employee morale but also have a positive impact on employees' safety attitudes and behaviors, reducing occupational injuries. Other than that, the level of project management commitment frequently has a considerable influence on safety performance, where involvement and encouragement, management style, and expertise are the three primary variables influencing construction industry safety (Zerguine et al., 2016). According to Jasiulewicz-Kaczmarek et al. (2015), the most frequently mentioned are increasing employee engagement and understanding of workplace health and hygiene, reducing the number of accidents, industrial illnesses, and potentially dangerous injuries, and improving the working environment by refining processes and changing facilities.

The outcomes of this study show the differences between each element of BBS, including which element of BSS was the most efficient approach and effective factor affecting base behavior safety or safety performance in the workplace. The improvement of commitment and awareness of the management employer and safety management system was, throughout the area of workplace safety and health, the decrease in the number of injuries and potentially dangerous incidents, as well as the enhancement working atmosphere, will influence the employee to engage more positively in compliance with safety during operational and maintenance phase in the petrol station industry.

RECOMMENDATION AND LIMITATION

In light of the findings from this study, it is recommended that future research endeavors prioritize direct engagement with employees in the operational and maintenance phase of petrol stations. This can involve interviews or face-to-face interactions using the questionnaire to ensure a more comprehensive understanding of the employees' perspectives on safety and compliance. While this study focused on five key BBS elements, future investigations could explore additional factors such as the physical work environment and personal experiences, broadening the scope of research in this domain. Moreover, these questionnaires can be adapted for use in various industries beyond petrol stations, offering valuable insights into safety compliance. Lastly, it is essential to consider language and literacy barriers that might affect responses, especially for those in non-executive roles. Clear instructions and multilingual questionnaires may improve response rates and accuracy, enhancing the quality of future research.

Several limitations must be acknowledged in this study. The limited engagement with operational and maintenance employees was due to time constraints and the ongoing disruptions caused by the Covid-19 pandemic. Movement restrictions imposed by the government hindered site visits and interviews, potentially affecting the diversity of respondents. Additionally, the distribution of questionnaires to employees posed challenges, as they may have limited access to email or smartphones at worksites. This may have contributed to lower response rates and potential selection bias in favor of executive roles. Furthermore, language barriers could have deterred some employees from participating in the survey, impacting the overall generalizability of the findings. These limitations should be considered when interpreting the results, and future research should aim to address these challenges for a more comprehensive understanding of safety compliance in diverse work settings.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of this study under the Special Incentive for Supervision in Geran Penyelidikkan Khas (GPK) by Universiti Teknologi MARA, Malaysia [Ref. No: 600-RMC/GPK 5/3 (261/2020)].

REFERENCES

Abdullah, M.S. *et al.* (2016) 'Safety Culture Behaviour in Electronics Manufacturing Sector (EMS) in Malaysia: The Case of Flextronics', *Procedia Economics and Finance*, 35(October 2015), pp. 454–461. Available at: https://doi.org/10.1016/s2212-5671(16)00056-3.

Aryee, S. and Hsiung, H.H. (2016) 'Regulatory focus and safety outcomes: An examination of the mediating influence of safety behavior', *Safety Science*, 86, pp. 27–35. Available at: https://doi.org/10.1016/j.ssci.2016.02.011.

DOSH (1994) *Act 514 Occupational Safety and Health Act 1994, Percetakan Nasional Malaysia Berhad*.

Geller, E.S. (2005) 'Behavior-based safety and occupational risk management', *Behavior Modification*, 29(3), pp. 539–561. Available at: https://doi.org/10.1177/0145445504273287.

George, D., & Mallery, P. (2019) *Step by Step: A Simple Guide and Reference, IBM SPSS Statistics*. Available at: https://doi.org/https://doi.org/10.4324/9780429056765.

Hofmann, D.A. and Stetzer, A. (1996) 'A cross-level investigation of factors influencing unsafe behaviors and accidents', *Personnel Psychology*, 49(2), pp. 307–339. Available at: https://doi.org/10.1111/j.1744-6570.1996.tb01802.x.

Ismail, F. *et al.* (2012) 'Behaviour Based Approach for Quality and Safety Environment Improvement: Malaysian Experience in the Oil and Gas Industry', *Procedia - Social and Behavioral Sciences*, 35(December 2011), pp. 586–594. Available at: https://doi.org/10.1016/j.sbspro.2012.02.125.

Ismail, F. *et al.* (2013) 'The behavioural based safety (BBS) and culture change approach for managing workplace safety', *Pertanika Journal of Social Science and Humanities*, 21(4), pp. 1327–1339.

Jasiulewicz-Kaczmarek, M., Szwedzka, K. and Szczuka, M. (2015) 'Behaviour Based Intervention for Occupational Safety – Case Study', *Procedia Manufacturing*, 3(Ahfe), pp. 4876–4883. Available at: https://doi.org/10.1016/j.promfg.2015.07.615.

Kabil, G.V.A. and Sundararaju, V. (2019) 'Behaviour Based Safety in Workplace', *International Journal of Research in Engineering, Science and Management*, 2(12), pp. 327–333. Available at: www.ijresm.com.

Koonce, G.L. and Kelly, M.D. (2014) 'Analysis of the Reliability and Validity of a Mentor ' s Assessment for Principal Internships', 15(2), pp. 33–48.

Nasyrah Ibrahim, S. *et al.* (2015) 'The Awareness Level of Behaviour Based Safety (BBS) In Construction Industry', *International Journal of Engineering Research and Reviews ISSN*, 3(1), pp. 2348–697.

Neal, A. and Griffin, M.A. (2002) 'Safety Climate and Safety Behaviour', *Australian Journal of Management*, 27(1_suppl), pp. 67–75. Available at: https://doi.org/10.1177/031289620202701s08.

Osman, R., Awang, N. and Yusof, S.A.H.S.H.N.M. (2015) 'Level of awareness BBS in manufacturing industry towards reducing workplace incidents', *International Journal of Education and Research*, 3(1), pp. 77–88.

Pathak, A. (2018) 'Need of Behaviour Based Safety in Industries', *International Journal of Institution of Safety Engineers (India)*, 2(2), pp. 1–5. Available at: www.iseindia.in%0ANeed.

Salem, O. *et al.* (2007) 'A behaviour-based safety approach for construction projects', *Lean Construction: A New Paradigm for Managing Capital Projects - 15th IGLC Conference*, (July), pp. 261–270.

Samsudin, N.S. *et al.* (2022) 'A thematic review on Prevention through design (PtD) concept application in the construction industry of developing countries', *Safety Science*, 148(December 2021), p. 105640. Available at: https://doi.org/10.1016/j.ssci.2021.105640.

Samsudin, N.S. *et al.* (2023) 'An Ontology to Represent the Prevention through Design (PtD) Concept in Integrated Project Delivery (IPD) in the Construction Industry from an Architectural Perspective', *Buildings*, 13(5). Available at: https://doi.org/10.3390/buildings13051128.

Samsudin, N.S., Khalil, N. and Zainonabidin, A. (2022) 'The Sustainable Aspect of Safety in Architectural Early Design : An Introduction to Prevention through Design (PtD) Concept', *International Journal of Sustainable Construction Engineering and Technology*, 13(2), pp. 34–50.

Zerguine, H. *et al.* (2016) 'Behaviour Based Safety Approach And Factors Affecting Unsafe Behaviour in Construction Sector: A Review', *Asia Pacific Environmental and Occupational Health Journal*, 2(2), pp. 1–12. Available at: http://apeohjournal.org/index.php/v/article/view/21.

Zhou, Q., Fang, D. and Wang, X. (2008) 'A method to identify strategies for the improvement of human safety behavior by considering safety climate and personal experience', *Safety Science*, 46(10), pp. 1406–1419. Available at: https://doi.org/10.1016/j.ssci.2007.10.005.

Zin, S.M. and Ismail, F. (2012) 'Employers' Behavioural Safety Compliance Factors toward Occupational, Safety and Health Improvement in the Construction Industry', *Procedia - Social and Behavioral Sciences*, 36(June 2011), pp. 742–751. Available at: https://doi.org/10.1016/j.sbspro.2012.03.081.

Zohar, D. (1980) 'Safety climate in industrial organizations: theoretical and applied implications. Journal of applied psychology', *Journal of Applied Psychology*, 65(1), pp. 96–102.

BUILDING A SUSTAINABLE FUTURE: DESIGNING AN ENERGY-EFFICIENT PUBLIC HOSPITAL IN MALAYSIA

Jamaludin Muhammad[1], Amirul Amin Ismail[1*], Muhammad Faris Arman[1], Mohammad Syathir Amini Shahbudin[1] and Zaniman Sulong[2]
[1]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610, Seri Iskandar, Perak, Malaysia
[2]VERITAS Architect Sdn. Bhd. 200301009748 (612168-X) Level 16, Tower 2, Wangsa 118, No 8, Jalan Wangsa Delima, Wangsa Maju, 53300 Kuala Lumpur, Malaysia

**Corresponding Email:* amiru683@uitm.edu.my

Abstract
As Malaysia strives to enhance its healthcare infrastructure, designing energy-efficient public hospitals becomes crucial. This paper aims to explore the concept of energy efficiency in the context of public hospital design in Malaysia. Based on a comparison of the findings of several previous scholars and their relation to public issues, the researcher has discovered studies pertaining to passive design for the energy efficiency of public hospitals in Malaysia. Therefore, the primary purpose of this study is to identify the success criteria for passive design commonly used by designers, especially architects, for local public hospital design projects. By incorporating sustainable practices and utilizing innovative technologies, the proposed design aims to minimize energy consumption, reduce carbon footprint, and promote environmental sustainability. Expert sampling was employed and data were derived from semi-structured interviews. Research objectives were established to minimize the potential for overrepresentation of dominant perspectives and limit potential bias. Moreover, this study considers various aspects such as building orientation, efficient layout, natural and artificial lighting, efficient Heating, Ventilation, and Air Conditioning (HVAC), and other mechanical systems. The findings highlight the potential benefits of an energy-efficient design, including reduced operational costs, improved patient comfort, and a positive environmental impact. The research also addresses potential challenges and provides recommendations for effective implementation.

Keywords: *Public hospital; Energy Efficient; Sustainable; Healthcare Facilities; and Hospital Design*

INTRODUCTION

Buildings consume half of the energy used daily which itself increases significantly due to the homogeneous environment created by the designer and the solution from standard engineering. Today, most buildings tend to waste much energy by not responding to the inhabitants' climatic conditions and comfort requirements. Therefore, energy consumption in a building needs to be handled efficiently and optimally. It is in line with the reports issued by the Environmental and Energy Branch under the Malaysian Public Works Department through the Building Sector Energy Efficiency Project (BSEEP), which stated that 50% of energy consumption wastage is in a building. The agenda of building design, particularly in hospitals, in reducing the use of mechanical energy by establishing green buildings is a good step forward in Malaysia (Rina et al., 2014). The introduction of green initiatives and environmentally user-friendly practices in the hospital's design will be able to provide much comfort to the hospital occupants and create a healthy environment. Hospitals may be considered as icons of pain, sickness, and distress, but they are also icons of healing, life, family, and hope (Yimin et al., 2014). They are essential buildings for any community, and how they were designed, constructed, and operated profoundly impacts health environment and the society.

LITERATURE REVIEW

Physical Environment in Public Healthcare

In 2023, the healthcare sector in Malaysia received a significant budget allocation of RM36.3 billion, surpassing the previous year's allocation of RM32.4 billion, RM31.9 billion, and RM30.6 billion. This positions the healthcare sector as the second-largest recipient of the Budget 2023, with the education sector receiving RM55.2 billion. The majority of the allocation will be utilized for procuring essential items such as medicines, reagents, vaccines, and disposables (MoF, 2022). Public hospitals, being a significant part of the building sector, contribute to a substantial portion of energy consumption in Malaysia. Between 2005 and 2010, there was a noticeable upward trend in energy consumption in buildings across the country, with a 34% increase observed (Ab. Azis et al., 2019). Addressing energy efficiency in public hospitals becomes crucial given their substantial energy needs. By optimizing energy usage, reducing costs, and promoting sustainability, public hospitals can contribute to a greener future in Malaysia.

The World Health Organization (WHO) describes health as a condition of complete physical, emotional, and social well-being and not simply the absence of sickness. It safeguards the atmosphere from unsafe circumstances, fulfills the basic needs of healthy living, and promotes equal social contact with an attractive environment with quality physical characteristics and practical architectural design that brings satisfaction to life and happiness levels. The physical environment of public healthcare plays a critical role in ensuring the well-being of patients, staff, and visitors (Makram et al., 2022). Sustainable design is not merely about the external aspects of a building or a particular model; it is an integrated idea with philosophical dimensions (Alsawaf et al., 2022). Sustainable principles and practices are vital in minimizing environmental impact and conserving resources. Key aspects of the physical environment in public hospitals include building layout and design, safety and security measures, lighting and ventilation systems, noise, and infection control strategies, as well as amenities and auxiliary spaces. By creating an attractive and functional environment that promotes communication, physical, and mental well-being, public hospitals can enhance the overall healthcare experience (Bulakh et al., 2021). While access to and awareness of green spaces and other common areas are frequently low, these areas are vital due to their natural properties and can benefit staff, patients, and families by lowering stress and errors (Bernhardt et al., 2022). The physical environment can be evaluated in terms of emotional or physical impact on users and it can be classified into three categories of architectural elements namely ambient environment, architectural features, and interior design features.

Passive Design Strategies in Healthcare Setting

Hospital sustainability is a paramount concept in the modern world, with the goal of providing a patient-oriented hospital while safeguarding the ability of future generations (Aydin et al., 2017; Alhmoud et al., 2020). Passive design plays a significant role in attaining sustainable objectives by optimizing indoor air quality, thermal comfort, acoustics, and lighting while minimizing energy consumption. Sustainability in public hospitals is a critical concern in Malaysia, as its implementation aims at meeting the current healthcare needs while minimizing environmental impact and ensuring resource efficiency. Passive design strategies have emerged as an effective approach to optimize energy consumption and enhance the environmental performance of hospital buildings. In the Malaysian context, the integration of passive design principles in public hospitals holds great potential for achieving energy efficiency, reducing operating costs, and providing a healthy indoor environment for patients and staff. On a larger scale, it is essential for social, economic, and ecological purposes (Weisz et al., 2011). In the future, passive design also needs to consider the technology of construction methods to minimize the environmental impact and emphasize the efficient building by using the BIM to also give benefits in green buildings. BIM-based sustainable approaches enhance design and execution processes, minimizing resource use and promoting savings in electricity and waste (Khahro et al., 2021; Vavili Faniand Kyrkou, 2020). For lasting sustainability, location, use, adaptability, available technological resources, orientation, volume, form, and engineering must be considered for a building (Bulakh et al., 2020).

Proper building orientation is key for implementing cost-effective passive design strategies that harness the natural environment. Prioritizing user comfort and energy efficiency in hospitals fosters a conducive indoor environment for both patients and staff. Maximizing wind-flow as natural ventilation is essential, and this requires the building's extended facades to face the windward direction. Atriums, courtyards, and rooflights further contribute to natural lighting and ventilation (Mahmoud, 2020). To prevent disease transmission and optimize service benefits, well-designed ventilation and lighting systems are paramount. These ensure a comfortable indoor environment, since such design promotes thermal comfort (Sapian, 2019). Hospitals, as unique environments, demand a distinct approach in which it has to emphasize on user comfort, energy efficiency, and a serene atmosphere to prevent disease spread and facilitate optimal service utilization (Uslu, 2015). Efficient management of energy use is crucial for hospitals and it can be attainable with ventilation and lighting playing their vital roles. Natural ventilation has gained prominence, especially in the context of green architecture and pandemics like COVID-19 (Park et al., 2021). Given the challenge of high energy consumption in hospitals, implementing energy-efficient measures, such as passive design elements, becomes imperative. Proactive incorporation of passive design principles in the initial stages of hospital design not only achieves notable energy and cost savings but also enhances resource management and minimizes energy losses.

Energy Consumption in Public Hospitals

In buildings, there are two types of energy systems namely the passive and active systems. The active system utilizes electricity which is inclusive of Heating, Ventilation, Air Conditioning (HVAC), artificial lighting, and energy management systems (Health Research, 2014). On the other hand, the passive system involves designing buildings that leverage natural resources for ventilation and lighting while remaining in a static state. Incorporating both passive and active systems in public hospitals is crucial to achieving optimal performance, energy efficiency, and user comfort. The most effective way to cut down on the consumption of energy in public and medical settings is to use passive building design strategies (Balali et al., 2021). Energy consumption in healthcare facilities is notably higher compared to commercial and residential buildings. Energy audits conducted in Malaysian public hospitals reveal inefficiencies in their energy usage, with consumption ranging from 250 kWh/m² to 400 kWh/m² per year (Ji & Qu, 2019). Unfortunately, this falls short of the Green Building Index target of at least 200 kWh/m² per year. In foreign countries, hospital buildings have an energy consumption rate of around 700 kWh/m² per year due to different climates and increased (HVAC) requirements (Reddy, Sandbhor & Dabir, 2019).

Public hospital buildings in Malaysia have experienced an increase in energy consumption over time, especially during the COVID-19 pandemic. Lighting accounts for approximately 36% of the energy use, while medical and office equipment contribute to about 60%. (HVAC) usage constitutes of 4% due to the predominant use of ceiling fans for ventilation in these buildings (Reddy et al., 2019). Architects and designers must address this growing reliance on active energy systems early in the design process to curb further increases. Incorporating passive design strategies can optimize and improve energy efficiency. Previous studies have explored various approaches such as reducing energy modes for medical equipment, enhancing energy efficiency in waiting rooms and pharmacies, implementing LED lighting in ward areas, and utilizing variable water volume (Azizi et al., 2018; Wang et al., 2016). Despite the implementation of various technical measures to reduce energy consumption in public hospital buildings, there is limited emphasis on passive design as an energy-saving approach. Achieving optimal energy efficiency performance remains challenging, with occupants responsible for only 20% of energy consumption, while the remaining 80% is attributed to the building operations (Ahmed et al., 2014).

Energy Benchmarking Initiatives for Public Hospitals

Energy benchmarking is vital to promote energy efficiency in public hospitals, which involves the establishment of usage benchmarks for comparison with similar facilities (Ahmed et al., 2014). Despite a global lack of strategic evaluation of hospital performance in asset management activities, initiatives like the UK's Energy Usage Guide for Hospital Buildings (ECG-72) provide valuable metrics and guidelines for measuring energy utilization and costs (Wang et al., 2016). This guide sets standards for different hospital categories that enable the identification of potential savings and distinguishing between excellent and standard practices. Another benchmarking guide, "Energy Efficiency in Healthcare Buildings," utilizes a Standardized Efficiency Indicator (SEI) based on annual energy usage data from a diverse sample of hospitals (Saidur et al., 2010). It assesses performance in terms of excellent, fair, and harmful practices, considering factors such as building size, Degree Days, and occupancy rates specific to each hospital type (Kamaluddin, Imran & Yang, 2016; Wang et al., 2016). While the Chartered Institution of Building Services Engineers provides comprehensive guidance on energy efficiency, such as Energy Use Guide 19 (EUG, 19), designed for office buildings, its applicability to hospitals may be limited (Christiansen et al., 2016).

Overall, energy benchmarking in hospitals is crucial in identifying energy-saving opportunities. The ECG-72 guide, SEI-based benchmarking, and other standards and guidance documents provide valuable tools and metrics to assess energy performance and promote energy efficiency in hospital buildings. The success criteria for energy consumption in the operating building focus on ensuring efficient energy use and meeting the needs and satisfaction of clients and users. These criteria are derived from previous researchers and tailored to the specific requirements and goals of the project. The success criteria include:

1. Implementation of specifications and client and user satisfaction in accordance with the project brief.
2. Customization of design performance data to align with the preferences and requirements of users and clients.
3. Providing reasonable returns in terms of cost, time, and material quality through energy-efficient design performance.
4. Efficient utilization of energy by identifying and reducing dependence on mechanical systems.
5. Designing for energy efficiency to effectively meet the needs and desires of users and clients.

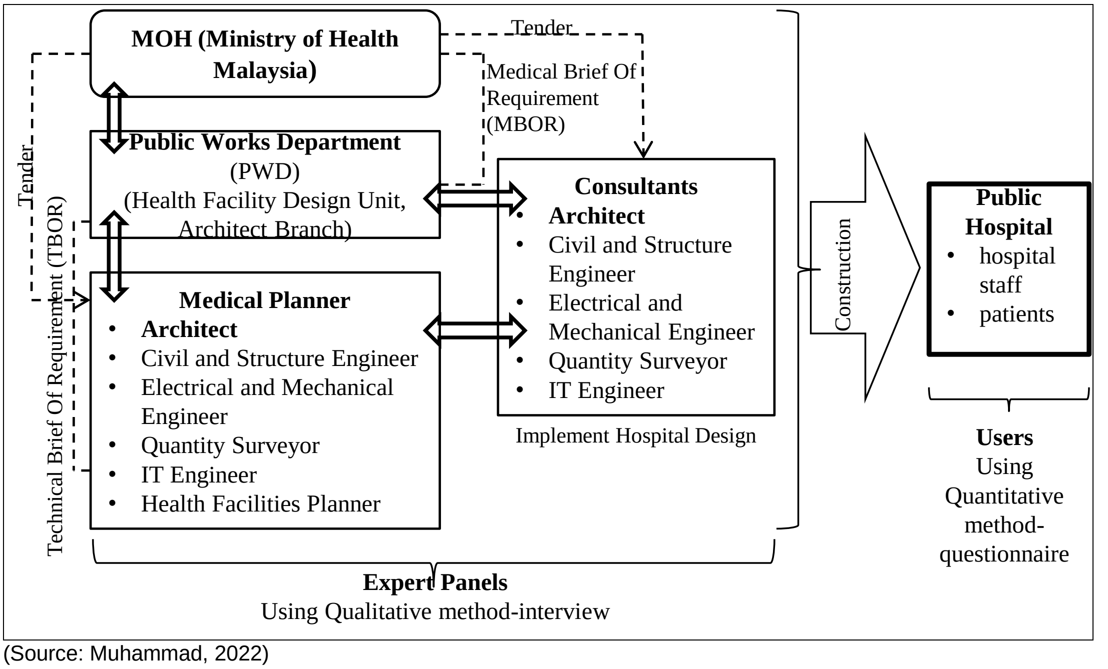
METHODOLOGY

This study aims to bridge the gap between theoretical knowledge and practical implementation, as well as provide valuable insights into the design of energy-efficient public hospitals in Malaysia. A survey-based approach was adopted from which the researcher utilized semi-structured interviews as the primary data collection tool. The interview design was derived from a comprehensive review of relevant literature and established qualitative research frameworks (Miles & Huberman, 1994; Miller & Crabtree, 1999; DeWalt & DeWalt, 2002; Mason, 2002; Maynard & Schaeffer, 2006). Questions were carefully developed on energy efficiency, design principles, best practices, challenges, and recommendations in implementing sustainable design strategies in public hospitals to ensure data validity and reliability and minimize potential bias. The semi-structured interviews allowed for a combination of predetermined questions and flexibility in exploring additional areas of interest, as recommended by Robson (2002). Participants were selected through purposive sampling which involved personnel from the Public Works Department, medical planners, and consultants with over 10 to 20 years of experience in healthcare design who were suitable for the study's objectives (Zainudin et al., 2023; Patton, 2002). Face-to-face interviews were chosen for their ability to elicit in-depth information and insights, creating a neutral environment for participants to share ideas and goals (Mack et al., 2005; Leaman et al., 2010). Transparency and clarity were maintained throughout the research process by addressing potential limitations or partialities. The output of semi-structured interviews will be cross-referenced with guidelines, project documentation, and industry reports to enhance credibility. Thematic analysis will be employed to identify patterns and key findings; they are aligned with interview data to gain insights into energy-efficient design approaches for public hospitals in Malaysia. Care is needed to avoid overlooking patterns when focusing on individual accounts within the thematic analysis. While manual procedures offer a more comprehensive understanding of the healthcare environment's energy efficiency, software specifically NVivo12 enhances data compilation and parameter management efficiency. Manual data classification of key parameters serves as a guide for the NVivo12 coding process. Given that the respondents converse both in Malay and English, mixed-method data analysis is crucial, necessitating manual identification and attachment of parameters to the passive design criteria for each developed questionnaire. The analysis of the interview data will yield valuable insights into energy-efficient design approaches for public hospitals in Malaysia and contribute to the body of knowledge in this field.

Table 1. Respondents Expert Panel Data Information

Respondents (Expert Panels)		Professional Architect (Ar.)	Academic Qualifications		Experience in The Industry			Experience in Hospital Projects		
			Master	Degree	10-14 year	15-20 year	21 years and above	10-14 year	15-20 year	21 years and above
Architect Officer (PWD)	Respondent 1 (Panel A)		√	√	√			√		
	Respondent 5 (Panel E)	Ar.		√	√			√		
	Respondent 6 (Panel F)		√	√	√			√		
Medical Planner (Architect)	Respondent 2 (Panel B)	Ar.	√	√		√		√		
	Respondent 7 (Panel G)	Ar.		√			√		√	
	Respondent 8 (Panel H)			√			√			√
Architect (Consultant)	Respondent 3 (Panel C)			√		√			√	
	Respondent 4 (Panel D)			√	√			√		

(Source: Muhammad, 2022)



(Source: Muhammad, 2022)

Figure 1. The Progress of Project for Design and Construction Public Hospital in Malaysia

RESULTS AND DISCUSSION

Feedback on Accuracy Testing

The feedback on accuracy testing is done by utilizing a two-step validation process, beginning with consultations with medical expert panels to validate findings from the literature review. The researchers ensured robust validation by conducting significant semi-structured interviews with an expert panel, and refining keywords in user questionnaires based on insights from the literature review. To facilitate user feedback, questionnaires were distributed to patients and staff. Other measures such as streamlining contacts through the Ministry of Health Malaysia for expert panel respondents were also taken. By integrating insights from the literature review, thematic analysis, and expert panels, the researcher achieved the objective of identifying two main criteria for energy-efficient passive design strategies in public hospitals; effective positioning of building orientation, natural and artificial lighting, and utilization of passive and active cooling systems for energy-saving measures.

Effective Positioning of Building Orientation, Natural and Artificial Lighting

Table 2. Measures of Energy Saving for Lighting

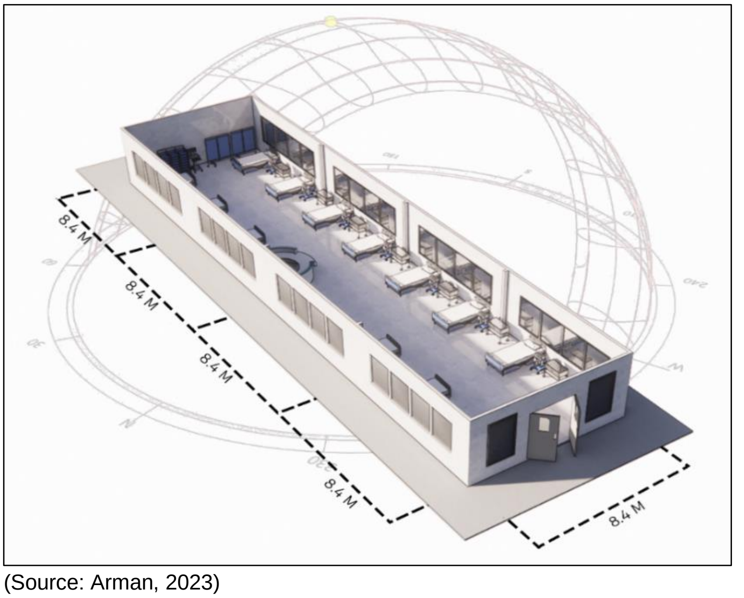
No	Unit of Analysis of An Entire Interview	Expert Panel	Description (Condensed Meaning Units)	Attributed & Parameter (Subcategory)	Code (Related to A Measure of The Key Question)	Criterion (or Parameter)
1	Energy Consumption in Ward Space Lighting	A, B, C, G & H	Incorporation of passive design strategies from site planning to design stages	Passive Design Strategies	Function	Measures of Energy Saving for Lighting
2		B, D & G	Variable of lux requirements (lighting intensity) based on the space function	Artificial Lighting Design Guidelines for Healthcare Facilities	Specification/ Standard	
3		B & D	Grid design enhances space efficiency in healthcare setting	Architectural Design	Design Process	
4		A, B, C, D & H	Incorporation of 2-way system and sensors in lighting fixtures improving efficiency and resources	Energy Saving Technology	Technology	

(Source: Ismail, 2023)

Panel A underscores the importance of effective positioning of the building's orientation for optimal natural lighting and ventilation in the public hospital. The proposal suggests using wall-mounted louvers to block excessive light. Additionally, curtain tracks are recommended to prevent glare and ensure patient privacy as this approach is aligned with standard specifications. Panel B emphasizes the need to prioritize ward design which has, often overlooked considerations for office areas. Window design varies based on the room's function, with operation theatres typically lacking windows for lighting purposes. Careful attention is needed to ensure that window placement in the ward does not compromise visibility and it meets the prescribed standards. The positioning of ceiling lamps should also adhere to the required standards. Panel C suggests an innovative lighting approach by proposing the layering of ceiling lamps aligned with the ward bed layout. Placing these lights horizontally at the foot of the patient's bed helps prevent glare and discomfort during rest. Panel G highlights the limitation of relying solely on natural lighting, emphasizing the need for electrical lighting equipment to ensure consistent illumination in the ward space. The inconsistency of natural lighting in meeting the needs of ward users underscores the reliance on active lighting solutions. Panel H stresses the importance of proper site planning in the following excerpt;

> *The first thing is site planning and then building orientation, which is sunrise and sunset, and each one needs regulation. Then, it will start with the shape of the building and through the shape of the building will look to the planning zoning more than the arrangement of spaces. From here will be included the organization in the space, including ward rooms, rooms between the wardroom and Operation Theatre [O.T.]*

Respondent 8 (Panel H)



(Source: Arman, 2023)

Figure 2. Building's Orientation in Passive Design and Basic Grid Study

Panel B and Panel D urge the importance of consultants to understand the end user's requirements and follow the relevant guidelines. Panel G emphasizes the need for careful spatial planning in designing public hospitals, including proper coordination of power points, electric sockets, and electrical equipment. The selection of grids for designing public hospitals is crucial, as highlighted by Panel B and Panel D. The commonly used basic grids are 7.2 meters, 7.8 meters, and 8.1 meters, and their selection is significant for determining corridor and ward sizes. Panel B concluded, "The grid will usually do 8.1 meters by 8.1 meters for four grids and this ward will be more practical". In pursuit of energy savings and efficiency, Panel B suggests a strategic two-way wiring system, with switches placed near the nurse station for easy supervision by staff as highlighted by Panel D. Panel H emphasizes the use of individual lamps for patient beds, allowing for personalized control. Panels A and C advocate for the use of sensors to optimize energy usage. Areas with constant occupancy may not require sensors, as artificial lighting can be controlled by the staff. LED lamps are recommended for their energy efficiency, with specific Lux requirements for clinical areas and wards as mentioned by Panel B: "For the clinical area you can use artificial lighting with certain Lux you need, so there is no need for windows. However, for the patient room, your ward cannot compromise". While sensors can be used in auxiliary areas, they are not suitable for wards where individual activities require different lighting needs.

In summary, the synthesis reveals a holistic view of effective lighting solutions for public hospitals. The key aspects include the strategic orientation of buildings for optimal natural lighting and ventilation, innovative lighting solutions like wall-mounted louvers and layered ceiling lamps, and the importance of understanding end-user requirements. Spatial planning considerations, such as grid selection and a two-way wiring system, the integration of sensors, LED lamps, and individual control options underline the commitment to energy-efficient measures. Overall, the panels emphasize a comprehensive and user-centric approach to hospital design that aligns with sustainability and energy efficiency goals.

(Source: Arman, 2023)

Figure 3. Mounted Louvers are Proposed to Effectively Block Excessive Glare

(Source: Arman, 2023)

Figure 4. Lighting Layout Corresponding with Bed Arrangement, Understanding the End User's Requirements, and Relevant Guidelines

Utilization of Passive and Active Cooling Systems for Energy-Saving Measures

Panel G highlights that natural ventilation can help prevent and control infections among ward patients while Panel A emphasizes that architects design large openings or windows to maximize natural light and ventilation in the ward. Cross ventilation is created through the design of openings to provide comfort to ward users. The choice of louvers and window types is carefully considered during the design process. Panel D points out that passive design methods can result in a 40% annual reduction in energy consumption. Effective furniture layout in ward spaces as highlighted by Panel C is crucial for energy-saving measures. Room data, including material properties of walls, ceilings, and floors, helps to determine how much energy the layout can save. Proper space arrangement can reduce heat and decrease the need for mechanical systems, making energy use more efficient as discussed by Panel A who stated: “We will arrange based on the patient's position, treatment position and doctor's position”. Panel E stresses a significant annual increase in energy consumption in public hospitals up to 50% to 60%. Panel A notes that not all wards can have air conditioning systems due to energy consumption limits set by the JKR-approved architecture benchmark (around 140 kilowatts). Decisions are made strategically on where air conditioning can be used. Active energy use in the ward, like air conditioners and fans, is crucial for user comfort. The average room temperature during the day ranges from 30 to 32 degrees Celsius, and a mix of ceiling fans and planned natural ventilation is used to keep conditions optimal. Standard room temperatures in the ward usually range between 18 to 24 degrees Celsius. In spaces such as the operating theatre (OT) room and isolation ward, temperature control is essential to prevent the spread of disease and bacteria.

Table 3. Measures of Energy Saving for Mechanical Equipment

No	Unit of Analysis of An Entire Interview	Expert Panel	Description (Condensed Meaning Units)	Attributed & Parameter (Subcategory)	Code (related to a measure of the key question)	Criterion (or Parameter)
1	Energy Consumption in Ward Space (Active and Passive Cooling System)	A, B, D & G	Incorporation of natural ventilation and openings	Passive Design Strategies	Function	Measures of Energy Saving for Working Space
2		A, C & E	Effective furniture layout and room data help to determine optimum material selection and energy consumption	Selection of Material	Specification/ Standard	
3		A, B & C	Efficient HVAC placement for critical ward and staff comfort	Mechanical Equipment	Mechanical System	
4		D	Integration of Courtyard Design to reduce heat and use of active cooling system	Passive Design Strategies	Design Process	
5		B, D & G	Adjustable windows and ceiling fans as alternatives to air conditioning to reduce energy consumption	Mechanical Equipment	Mechanical System	
6		A & C	Coordination between consultants. Effective mechanical layout plan and 2-way wiring system for user's comfort	Layout Plan /	Function	

(Source: Ismail, 2023)

Panels A and B note the provision of air conditioning systems in doctor's and nurses' rooms, while the general workspace for nurses in public hospital wards may not have air conditioning. Panel C concurs with the above statement by highlighting the importance of air conditioning systems in critical areas like the Intensive Care Unit (ICU), Coronary Care Unit

(CCU), and other wards needing special attention "for the general ward space, we designed the space capitalizing on natural lighting and ventilation. If the ward is for infectious patients, it's entirely air-conditioned". Central air conditioning systems are favored for their economy, providing ventilation over large spaces. Emphasis is placed on the importance of separation between clinical and non-clinical space affecting the openings for natural lighting and ventilation in the following excerpt;

> *The Architect will take into account the orientation of this public hospital building. Therefore, the rooms located to the west for the afternoon sun are clinical, and non-clinical spaces are placed on the east-facing the morning sun because this space requires natural lighting and ventilation such as rehab.*
>
> Respondent R3 (Panel C)

(Source: Arman, 2023)

Figure 5. Proper Arrangement of Spaces and Natural Cross Ventilation for User Comfort

Courtyard design is pivotal for facilitating natural lighting and ventilation, creating an optimal environment. Wards facing the courtyard benefit from comfortable natural ventilation, contributing to a pleasant and well-ventilated space. Panel D explains how the courtyard aids in cooling surrounding areas through natural ventilation, providing comfort to users and offering pleasant views. The inclusion of green plants in the courtyard further cools the environment and reduces reliance on mechanical cooling systems. Combining passive design with minimal assistance from active systems results in 50% to 60% in energy efficiency. Panel B underlines the importance of alternative cooling systems such as adjustable windows and ceiling fans. While natural ventilation captures outside breezes, ceiling fans are necessary for optimal comfort, as highlighted by Panel B and G. The 3rd class wards use ceiling fans and cross ventilation for cost-effectiveness. The more luxurious 1st class ward relies on air conditioning, and the 2nd class ward offers flexibility with options like ceiling fans, air conditioning, or a mix of both, catering to specific needs. This approach tailors cooling solutions to the distinct requirements of each ward class. Next, the coordination between consultants is crucial in hospital design, with each playing a distinct role. Panel A and Panel C also suggest a two-way wiring system for the ceiling fans which must be strategically located based on the patient bed layout and circulation flow in the ward.

In conclusion, the panels highlight the critical role of natural ventilation and cooling systems in public hospitals, as well as emphasize various design considerations to optimize energy efficiency and user comfort. Passive design methods, such as effective furniture layout, room data utilization, and proper space arrangement, are highlighted to reduce energy consumption. Active intervention strategy such as temperature control showcases a balance between energy efficiency and prioritizing user needs. Courtyard design, green plants, and the combination of passive and active systems emerge as effective strategies for achieving substantial energy savings. The coordination between consultants and builders is emphasized for a holistic and efficient hospital design. The placement and control of ceiling fans, careful selection of grids, and the use of energy-efficient technologies contribute to creating sustainable and comfortable healthcare environments. Overall, the panels advocate for an inclusive approach to hospital design, integrating both passive and active design elements.

(Source: Arman, 2023)

Figure 6. Alternative Cooling Systems Such as Adjustable Windows, Ceiling Fans, and 2-Way Wiring Systems for User Comfort

CONCLUSION

Public hospitals operate 24 hours a day, resulting in substantial energy consumption. Achieving a balance between energy efficiency and patient comfort is crucial in addressing this challenge. The study uncovered a notable electricity consumption pattern in public hospitals, particularly in lighting and medical equipment usage. Across all panels, there was a strong consensus regarding the imperative need for adopting energy-efficient strategies. These strategies ranged from technical approaches to simpler measures like efficient maintenance and operational procedures. Passive design strategies in the initial planning to design stage such as building orientation, positioning and proper space arrangement help to reduce the dependency on active design intervention. The recommendation from the panels was the emphasis on utilizing natural lighting to minimize the reliance on artificial lighting and align with established building code guidelines. From the analysis, it is evident that integrating energy efficiency considerations from the inception of hospital design is crucial. There was a shared recognition of the significance of user involvement in the planning process, emphasizing both mental and physical comfort. Smart utilization of both passive and active cooling systems in public hospitals can effectively reduce energy waste without compromising patient well-being. To successfully implement passive design in Malaysian public hospitals, careful consideration of the local climate and building context is essential. Factors like temperature, humidity, solar radiation, and outdoor air quality should be taken into account to ensure the appropriateness of passive design strategies. Computational simulations and performance evaluations can further optimize the design for specific hospital settings, maximizing the potential benefits. Beyond the immediate environmental impact, the incorporation of passive design from the early stages of hospital planning also can lead to long-term operational cost savings, improved patient outcomes, and the creation of a healthier and more sustainable healthcare environment for patients, healthcare providers, and the community at large. Beyond the conclusions drawn from the study, further recommendations include continuous building performance monitoring, regular energy audits, and keeping updates on the latest smart building technologies. Furthermore, improved efficiency in human capital can be achieved by hosting community engagement, collaborating with experts for research initiatives, and staff training. Implementing these recommendations can contribute not only to reduced environmental impact but also to long-term operational cost savings, improved patient outcomes, and the overall well-being of stakeholders. In essence, aligning public hospitals with sustainable practices is not only a necessity for environmental stewardship but it is also a crucial step towards creating resilient, community-centric healthcare institutions.

ACKNOWLEDGEMENT

We would like to express our sincere appreciation to the research participants who generously dedicated their time and shared their expertise. Their contributions and willingness to participate in interviews were invaluable in gathering the necessary data for this study. We deeply value the immense support and assistance provided by everyone involved in any capacity, as their contributions played a crucial role in the success of our research. Lastly, we extend our heartfelt gratitude to our family and friends for their unwavering support and compassion throughout the research process.

REFERENCES

Ab. Azis, S. S., Sipan, I., Sapri, M., Mohd Yusoff, N. S., & Abdullah Hashim, H. (2019). Comparison on energy saving: green roof and green wall. *Planning Malaysia Journal of the Malaysian Institute of Planners*, 17(1), 48–57.

Abd Rani, N. A., Baharum, M. R., Nizam Akbar, A. R., & Nawawi, A. H. (2015). Perception of Maintenance Management Strategy on Healthcare Facilities. *Procedia - Social and Behavioral Sciences*, *170*, 272–281.

Ahmed, S., Hanan, S., Rasha, A. &, & Ayman, W. (2014). Energy Efficient Hospital Patient Room Design: Effect of Room Shape on Window- to-Wall Ratio in a Desert Climate. *30th International Plea Conference 16-18 December 2014, CEPT University, Ahmedabad, December 2014*.

Alhmoud, S. H., Çağnan, Ç., & Arcan, E. F. (2020). Improving interior environmental quality using sustainable design in jordanian hospital bedrooms. *European Journal of Sustainable Development*, *9*(3), 443–456. doi: 10.14207/ejsd.2020.v9n3p443

Alsawaf, E. S., & Albadry, A. M. (2022). Principles for the Sustainable Design of Hospital Buildings. *International Journal of Sustainable Development and Planning*, *17*(6), 1797–1808. doi: 10.18280/ijsdp.170614

Aydin, D., Yaldiz, E., & Buyuksahin, S. (2017). Sustainable Hospital Design for Sustainable Development. *8th International Conference on Urban Planning, Architecture, Civil and Environment Engineering (UPACEE-17)*, *UPACEE-17*(March 2019), 40–43.

Azizi, N. S. M., Din, M. A. M., Phan, Y. T., & Tai, J. Y. (2018). Review of energy saving behaviour strategies in hospital buildings. *International Journal of Civil Engineering and Technology, 9*(11), 2782–2790.

Balali, A., & Valipour, A. (2021). Prioritization of passive measures for energy optimization designing of sustainable hospitals and health centres. *Journal of Building Engineering, 35*, 101992. doi: https://doi.org/10.1016/j.jobe.2020.101992

Bernhardt, J., Lipson-Smith, R., Davis, A., White, M., Zeeman, H., Pitt, N., Shannon, M., Crotty, M., Churilov, L., & Elf, M. (2022). Why hospital design matters: A narrative review of built environments research relevant to stroke care. In International Journal of Stroke (Vol. 17, Issue 4, pp. 370–377). SAGE Publications Inc. doi: 10.1177/17474930211042485

Building Sector Energy Efficiency Project (BSEEP). (2013). *Building Energy Efficiency Technical Guideline for Passive Design*.

Bulakh, I., Didichenko, M., Kozakova, O., & Chala, O. (2020). Sustainable futures in the context of architectural design of hospitals. *E3S Web of Conferences, 166*. doi: 10.1051/e3sconf/202016608001

Bulakh, I., Didichenko, M., Kozakova, O., Chala, O., & Kovalska, G. (2021). Is the hospital-park future of the sustainable hospital architecture? *E3S Web of Conferences, 280*. doi: 10.1051/e3sconf/202128004014

Christiansen, N., Kaltschmitt, M. &, & Dzukowski, F. (2016). Electrical Energy Consumption And Utilization Time Analysis Of Hospital Departments And Large

Kamaluddin, K. A., Imran, M. S. &, & Yang, S. S. (2016). Development Of Energy Benchmarking Of Malaysian Government Hospitals And Analysis Of Energy Savings Opportunities. *Journal of Building Performance, 7*(1), 72–87.

Khahro, S. H., Kumar, D., Siddiqui, F. H., Ali, T. H., Raza, M. S., & Khoso, A. R. (2021). Optimizing energy use, cost and carbon emission through building information modelling and a sustainability approach: A case-study of a hospital building. *Sustainability (Switzerland), 13*(7). doi: 10.3390/su13073675

Mahmoud, E. S. (2020). The Role of Atriums and Courtyards in Improving Natural Light and Ventilation in Hospitals. *MEJ-Mansoura Engineering Journal*, 44(4), 1-15.

Makram, A., & El-Ashmawy, R. A. (2022). Future Hospital Building Design Strategies Post COVID-19 Pandemic. *International Journal of Sustainable Development and Planning, 17*(4), 1169–1179. doi: 10.18280/ijsdp.170415

Ministry of Finance (MoF). (2022, October 7). *Budget 2023: Public health services capacity strengthened, RM36.1 bln allocated to MOH* [Press release]. https://www.mof.gov.my/portal/en/news/press-citations/budget-2023-public-health-services-capacity-strengthened-rm36-1-bln-allocated-to-moh

Park, S., Choi, Y., Song, D., & Kim, E. K. (2021). Natural ventilation strategy and related issues to prevent coronavirus disease 2019 (COVID-19) airborne transmission in a school building. *Science of The Total Environment, 789*, 147764. doi: https://doi.org/10.1016/j.scitotenv.2021.147764

Reddy, S., Sandbhor, S. &, & Dabir, V. (2019). Bringing Energy Efficiency for Hospital Building through the Conservative and Preventive Measures. *International Journal of Innovative Technology and Exploring Engineering (IJITEE), 8*(12), 3056–3060.

Rina, S., & Zakaria, R. (2014). Green Assessment Criteria for Public Hospital Building Development in Malaysia. *Procedia Environmental Sciences, 20*, 106–115.

Sahamir, S. R., Zakaria, R., Alqaifi, G., Abidin, N. I. &, & Raja Muhd Rooshdi, R. R. (2017). Investigation of Green Assessment Criteria and Sub-criteria for Public Hospital Building Develop

Saidur, R., Hasanuzzaman, M., Yogeswaran, S., Mohammed, H. A., & Hossain, M. S. (2010). An end-use energy analysis in a Malaysian public hospital. *Energy*, *35*(12), 4780–4785.

Sapian, A. R. (2019). Architectural & Passive Design Strategy. *Malaysia Standard (MS 1525: 2019)*, 1–66.

Uslu, P. G. (2015). Benchmarking in Health Services. *Emerald Insight: An International Journal*, *12*(No.4), 293–309.

Vavili Fani and Kyrkou, A. (2020). Sustainability and Energy Efficiency Design in Hospital Buildings. In A.-M. Dabija (Ed.), Energy Efficient Building Design (pp. 157–169). Cham: Springer International Publishing. doi: 10.1007/978-3-030-40671-4_10

Wang, T., Li, X., Liao, P. C., & Fang, D. (2016). Building energy efficiency for public hospitals and healthcare facilities in China: Barriers and drivers. *Energy*, *103*, 588–597.

Yimin, S., Wenyu, Z., & Chunyang, Z. (2014). Preliminary Study on Natural Ventilation for Hospital Building in Hot and Humid Regions. *PLEA 2014 - 30th INTERNATIONAL PLEA CONFERENCE*, *December 2014*, 1–8.

Zainudin, M. M., Asif, N., Nur, A., & Mohd, S. (2023). *Effect of hospital interior environment and decoration on healthcare providers-patient communication: A case study of Sultan Ahmad Shah Medical Center and Kuantan Medical Center*. *April*. https://doi.org/10.46529/darch.2023apr08

UNVEILING THE DRIVERS OF FLASH FLOODS IN CONSTRUCTION SITES: INSIGHTS FROM FACTORS FOR RESILIENT URBAN DEVELOPMENT

Siti Nur Aishah Mohd Noor[1*], Mohd Khairul Amri Ramly[1], Puteri Sidrotul Nabihah Saarani[1], Zailawati Khalid[2] and Mohamad Badruzhisham Mohd Mazlan[1]
[1]Department of Built Environment Studies & Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, Seri Iskandar Campus, Perak, Malaysia
[2]Department of Construction Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn, Parit Raja, Batu Pahat, Johor, Malaysia

**Corresponding Email: sitinuraishahmn@uitm.edu.my*

Abstract
As cities confront escalating challenges posed by climate change, the occurrence of flash floods emerges as a formidable threat to urban development and infrastructure, with construction sites particularly susceptible. Characterized by their sudden onset and intense nature, flash floods can wreak havoc on construction projects, imperilling worker safety, causing equipment and materials damage, and leading to project delays and budget overruns. In the quest to foster resilient cities, a critical examination of the role of flood risk management in addressing flash floods, especially within construction sites, becomes imperative. This paper meticulously goes into the realm of flood risk management and its pivotal role in curtailing the detrimental impacts of flash floods within construction sites. By uncovering the root causes of flash floods in construction sites, this research seeks to contribute to the formulation of strategies and best practices that bolster the resilience of construction sites and curtail the adverse consequences of flash flood events. In summary, this study offers invaluable insights into the factors driving flash floods, particularly among contractors operating in the central region of Malaysia. Ultimately, the vision of constructing resilient cities hinges upon the seamless integration of flood risk management practices into the fabric of urban planning and construction processes.

Keywords: *Flash flood; Risk Management; Resilient Cities; Construction Sites*

INTRODUCTION

In an era marked by rapid urbanization and the increasing impacts of climate change, the concept of building resilient cities has gained significant attention. Resilient cities are those that can effectively adapt and respond to various shocks and stresses, including natural disasters and climate-related hazards (Samsuri, Bakar and Unjah, 2018). Among these hazards, flooding stands out as a major threat to urban areas worldwide, necessitating the integration of robust flood risk management strategies into urban planning and development (Zakaria, Zin, Mohamad, Balubaid and Mydin, 2017). The research explores the relationship between building resilient cities and the roles of flood risk management. Within this context, the study meticulously investigates the underlying causes of flash floods, recognizing their dual potential to both escalate flood risks and fortify the resilience of cities. The consequences of flooding events, both immediate and long-lasting, encompass substantial infrastructure damages, loss of lives, economic upheaval, community displacement, and disruption of essential services.

According to Wang, Cui, Li, Huang, Manandhar, Nitivattananon, and Fang (2022), with climate change intensifying rainfall patterns and sea-level rise, the frequency and intensity of flooding events are anticipated to surge, casting an even more risk to urban areas. Effectively countering these escalating risks hinges upon the construction of cities fortified against flood-related perils. This objective inherently encompasses the imperative of addressing flash flood occurrences within construction sites, necessitating a comprehensive approach that seamlessly integrates a diverse array of strategies and measures. A pivotal facet of this holistic approach is the meticulous identification of the root causes that underline flash floods, particularly in the context of construction sites. Recognizing that construction activities and contractors play pivotal roles in this multifaceted landscape, this research strives to unearth the key factors that contribute to flash floods. By doing so, it serves as a critical strategy within the collective endeavour to ameliorate flash flood issues within the construction industry and advance the broader goal of constructing resilient cities.

LITERATURE REVIEW

Flood Risk Management

Flood risk management related to addressing flash floods in construction areas refers to the systematic approach of identifying, assessing, and implementing measures to minimize the risks and impacts of flash floods on construction sites (Zhen, Liu, Zhong, Zhou, Liang, and Zheng, 2022; Chia, Fui, Siau, Joo, and Tien, 2023). It involves a range of strategies and actions aimed at preventing or mitigating flood-related damages ensuring workers' safety and minimizing disruptions to construction activities. Ideally, based on NADMA Risk Assessment (2021), the first step in flood risk management is to conduct a comprehensive risk assessment specific to the construction site. This involves identifying the potential sources of flooding, evaluating the likelihood and magnitude of flash floods, and assessing the vulnerability of the site and its infrastructures to flood hazards (Mourato, Fernandez, Pereira, and Moreira, 2023). By understanding the risks, construction stakeholders can develop effective mitigation measures. Besides, proper drainage design and management play a crucial role in flood management in construction areas. This includes the design and installation of effective drainage systems, such as drains, culverts, and retention ponds, to effectively collect and redirect surface water away from the construction site (Chang, Sung Lai, Pan, Liu, and Tung, 2013; NADMA Risk Assessment, 2021). In addition, regular maintenance of drains and removal of debris is also important to ensure their optimal functioning.

Other than that, construction activities can contribute to soil erosion, which can exacerbate the risk of flash floods. Implementing erosion control measures such as building sediment barriers, silt fences, and erosion control blankets, helps to prevent soil erosion and the sedimentation of drainage systems. These measures help maintain the integrity of the site and reduce the potential for flash flood occurrence. Besides, Pham (2018) also stated that adhering to construction best practices is essential in flood risk management which includes using flood-resistant building materials and techniques, elevating critical components and electrical systems above flood level, and ensuring proper waterproofing measures are in place. Moreover, incorporating sustainable construction practices, such as green roofs and permeable pavements, can also help reduce surface runoff and manage stormwater effectively. Emergency preparedness and response are also considered important steps in flood risk management, whereby developing and implementing emergency preparedness and response plans is crucial in addressing flash floods in construction areas (Muzamil, Zainun, Ajman, Sulaiman, Khahro, Rohani, Mohd and Ahmad, 2022). It involves establishing clear protocols for evacuating workers, securing equipment, and safeguarding construction materials in the event of a flash flood. Training construction personnel on emergency procedures and conducting regular drills can improve their readiness to respond to flood events. In relation to that, flood risk management and flash flood in Malaysia is intertwined and focused on reducing the adverse impacts of flash floods through proactive measures and strategic interventions.

Flash Flood in Malaysia

Flash floods in Malaysia are a recurring natural disaster that poses significant risks to both urban and rural areas. As mentioned previously, the country's tropical climate, with heavy rainfall and monsoonal patterns, contributes to the frequent occurrence of flash floods. Flash floods are characterized by their rapid onset and short duration, often resulting from intense rainfall in a short period of time. Malaysia's geographical features, including its hilly terrain and extensive river systems, play a role in exacerbating the risk of flash floods. Ideally, when intense rainfall transpires, water runoff from slopes and highlands can swiftly accumulate, overwhelming drainage systems and causing flash floods downstream. Low-lying areas and regions with poor drainage systems are particularly vulnerable to flash floods.

Malaysia experiences a tropical climate with heavy rainfall, especially during monsoon seasons. Short but intense downpours are common, leading to rapid water accumulation and flash floods. Climate change is intensifying rainfall patterns and sea-level rise, which is expected to increase the frequency and intensity of flooding events, further exacerbating flash flood risks (Wang, Cui, Li, Huang, Manadhar, Nitivattananin, and Fang, 2022). Additionally, rapid urban development in Malaysia often involves land clearing, changing natural drainage patterns, and increasing surface runoff. The construction of impervious surfaces, such as concrete roads and buildings, reduces the land's ability to absorb rainfall, increasing the risk of flash floods in urban areas. The conversion of open spaces into built-up areas further exacerbates the problems. Besides, deforestation in Malaysia also contributes to increased surface runoff and reduced natural water absorption. This leads to higher flash flood risks, as forests play a crucial role in maintaining ecological balance and regulating water flow.

In rural areas, flash floods can affect agricultural lands, livestock, and rural communities' livelihoods. Efforts to address flash floods in Malaysia involve a combination of structural and non-structural measures. Malaysia employs structural measures to mitigate flash floods, including the construction of flood mitigation infrastructure. This involves the development of retention ponds, flood barriers, and improvements to river channel water flow (Abdullah, 2004). These structures are designed to prevent flash floods from occurring or to reduce their impact. On the other hand, non-structural measures focus on enhancing flood forecasting and warning systems, improving land-use planning, promoting community preparedness, and implementing sustainable water resources management practices (Ghani, Abdullah, Sidek, Kassim, and Ainan, 2004). These measures aim to improve the overall preparedness and resilience of communities and reduce the impact of flash floods.

In addition to that, the Malaysia government, through agencies like the Department of Irrigation and Drainage (DID) and the National Disaster Management Agency (NADMA), plays a crucial role in coordinating and implementing flood mitigation and management efforts (Kandari, Saudi, Chyang, Kamaruddin, Saad, Azid, Saudi and Mahmud, 2018). These agencies work to develop policies, regulations, and strategies to address flash floods and protect communities. In terms of emergency preparedness, establishing clear protocols for evacuating workers, securing equipment, and safeguarding construction materials in the event of flash floods is an essential part of flood risk management (Muzamil, Zainun, Ajman, Sulaiman, Khahro, Rohani, Mohd and Ahmad, 2022). Training construction personnel on emergency procedures and conducting regular drills can improve their readiness to respond to flood events.

On top of that, current methodologies to address flash floods in Malaysia also use erosion control were implementing erosion measures, such as building sediment barriers, silt fences, and erosion control blankets, helps prevent soil erosion and the sedimentation of the drainage system (Pham, 2018). These measures are essential for maintaining the integrity of construction sites and reducing the potential for flash flood occurrence. Besides, adhering to construction best practices is crucial in flood risk management. This includes using flood-resistant building materials and techniques, elevating critical components and electrical systems above flood levels, and ensuring proper waterproofing measures are in place (Pham, 2018). Incorporating sustainable construction practices, such as green roofs and permeable pavements, can also help reduce surface runoff and manage stormwater effectively.

Additionally, regular maintenance of drainage systems, including cleaning and removing debris, is vital to ensure their optimal functioning (Chang, Sung Lai, Pan, Liu, and Tung, 2013). Properly designed and maintained drainage systems are essential in managing water flow and reducing the risk of flash floods. Hence, the measures aim to reduce the vulnerability of construction sites and urban areas to flash floods and enhance overall resilience to flood-related hazards.

Current Scenario of Flash Flood in Construction Sites

In Malaysia, the current scenario of flash floods in construction sites presents significant challenges to the construction industry and urban development. Flash floods, characterized by their rapid onset and high intensity, pose a particular risk to construction sites due to their vulnerability to water accumulation, inadequate drainage systems, and soil erosion (Bhuiyan, Reza, Choy, and Pereira, 2018). One of the key factors contributing to flash floods in construction sites in Malaysia’s tropical climate is characterized by heavy rainfall and monsoon seasons (Muslima, Che Omar, Jamaluddin, and Taha, 2018). These weather patterns can result in sudden and intense downpours, overwhelming the capacity of existing drainage systems and leading to rapid water accumulation in construction sites. Inadequate or poorly designed drainage infrastructure is a significant issue (Hammong, Chen, Djordjevic, Butler, and Mark, 2015). These drainage systems are often ill-equipped to manage the volume of water during heavy rainfall events. The accumulation of debris, sediment, and waste in the drains can obstruct the passage of water, leading to localized flooding during sudden and intense rainfalls.

Moreover, the rapid urbanization and construction activities taking place in Malaysia further amplify the vulnerability of construction sites to flash floods. Urban development often involves extensive land clearing, altering natural drainage patterns, and increasing runoff. Meanwhile, construction activities, including excavation and land grading, can further disrupt the natural topography and exacerbate soil erosion, making construction sites more susceptible to flash floods. This is particularly concerning as Malaysia continues to experience significant urban growth (Buiyan, Reza, Choy and Pereira, 2018). The current scenario also highlights the need for increased awareness and preparedness among contractors and developers regarding the occurrence and impact of flash floods on construction sites. While certain regulations and guidelines exist, there may be gaps in their implementation and enforcement.

Many contractors and developers may lack sufficient knowledge and understanding of flood risk management practices specific to construction sites, leading to inadequate mitigation measures and increased vulnerability to flash floods. In order to address the current scenario of flash floods in construction sites in Malaysia, several measures can be taken and necessitate immediate actions to enhance flood risk management. By implementing the appropriate course of action, Malaysia can mitigate the impacts of flash floods in construction sites and undoubtedly help to protect workers' safety and foster the development of resilient cities that can withstand the challenges posed by climate change and rapid urbanization. Therefore, the methodology employed in this research directly aligns with the identified causes of flash floods, particularly in construction sites.

METHODOLOGY

This study adopted a quantitative approach by distributing questionnaires to the targeted group. The target group of this research is the contractor company that was selected from the list of G1 to G7 contractors who have registered with CIDB and currently have construction projects or construction sites located in the Klang Valley areas. The Klang Valley, located in the state of Selangor and the federal territory of Kuala Lumpur is known to be prone to flash floods. The Klang Valley encompasses major urban areas such as Kuala Lumpur, Petaling Jaya, Shah Alam, and Klang. Flash floods occur in various parts of the Klang Valley due to its geographical features, urbanization, and intense rainfall events. The specific areas in the Klang Valley that are particularly prone to flash floods include lying areas, river basins, and areas with poor drainage systems. Some notable locations prone to flash floods in Klang Valley include the areas as elaborated in Table 1 below.

Table 1. Locations Prone to Flash Flood in Klang Valley

Area	Location Coverages
Kuala Lumpur City Center	Certain areas in the heart of Kuala Lumpur, e.g., Sungai Klang and Sungai Gombak
Petaling Jaya	Parts of Petaling Jaya, e.g., Sungai Damansara, Sungai Kayu Ara and Sungai Penchala
Shah Alam	The capital city of Selangor, prone to flash floods due to its urban development, e.g., Sungai Klang and Sungai Kayangan
Klang	Location at the mouth of Sungai Klang

(Source: Kandari et al., 2018)

The sampling method used in this research is purposive sampling where the respondents of the contractors were purposely selected from the list of G1 to G7 contractors' companies which only involved individuals who have construction projects within the area of location (ongoing projects) and the contractor in question has the necessary experience to handle construction projects within the areas as well (completed projects), as stipulated in Table 1. All respondents' information will then undergo data cleaning to ensure only usable data and relevant data in the mentioned area are used for this research. At the end of the data collection stage, there are only 50 usable questionnaires that can be proceeded further for data analysis for this research. The output of the data will be discussed in the section below.

FINDING AND DISCUSSION

According to Figure 1, the analysis of the factors contributing to flash floods revealed several key findings. Among the surveyed areas, the highest factors contributing to flash floods were clogged or inadequate drainage systems (29%), rapid urban development (28%), failure to construct proper damp and levee structures (27%), and heavy rainfall events (16%). Clogged or inadequate drainage systems emerged as the primary factor contributing to flash floods in the studied areas, accounting for 29% of the cases. This finding underscores the critical role of effective drainage systems in mitigating flash flood risks. The accumulation of debris, sediment, and waste in drains obstructs water passage, leading to localized flooding during heavy rainfall events (Bradley, 2005). This highlights the need for regular maintenance and cleaning of drainage infrastructure. Neglecting this aspect can result in increased vulnerability to flash floods.

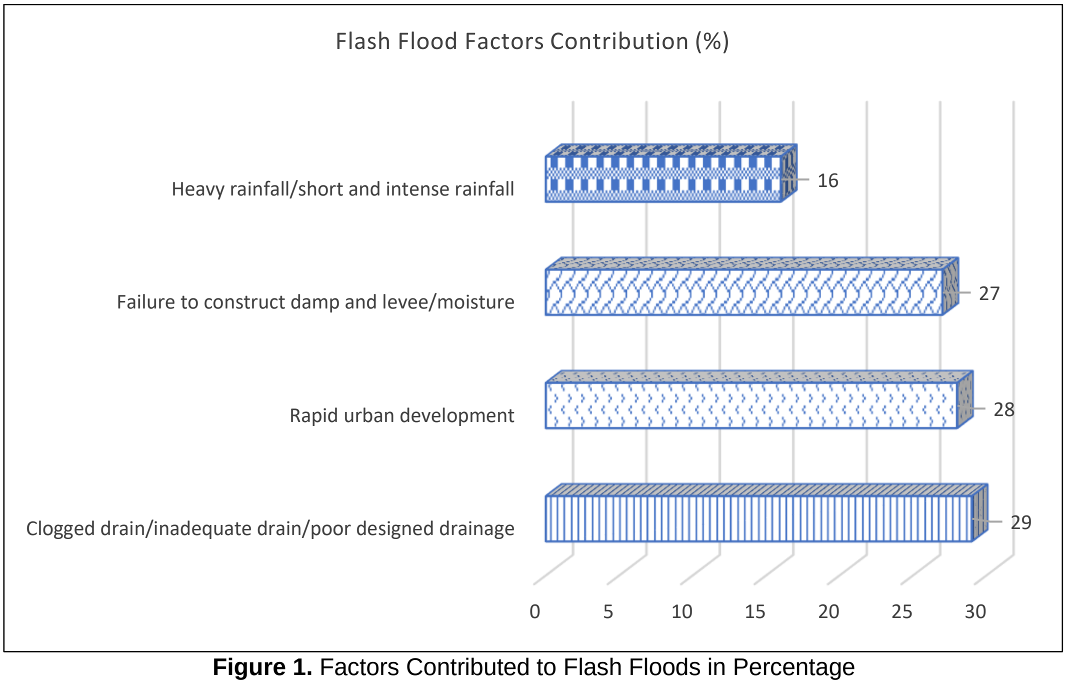


Figure 1. Factors Contributed to Flash Floods in Percentage

Rapid urban development ranked closely behind, accounting for 28% of the cases. The expansion of urban areas often involves the construction of impervious surfaces, such as concrete roads and buildings. This interferes with natural water absorption and increases surface runoff. Consequently, open spaces are converted into built-up areas, reducing the land's capacity to absorb rainfall. These findings emphasized the critical importance of urban planning that incorporates green infrastructure and sustainable construction practices. Such measures can help counteract the negative effects of urban development on flood risk.

Table 2. The Mean and Standard Deviation for Factors Contributing to Flash Floods in Construction Sites

Factors	Means	Standard Deviations
Clogged drain/inadequate drain/poor designed drainage	4.48	0.720
Failure to construct damp or levee/moisture	4.28	1.049
Rapid urban development	4.38	0.884
Heavy rainfall/short and intense rainfall	4.16	0.976

The failure to construct proper damp and levee structures was identified as another significant factor, accounting for 27% of flash flood occurrences. This factor is closely related to construction practices. Inadequate construction techniques, including the absence of proper waterproofing measures and ineffective stormwater management, exacerbate flood risks in construction sites. The key takeaway is the imperative of adhering to construction best practices and ensuring the implementation of appropriate drainage systems and moisture control measures during construction activities. Failing to do so increases the chances of flash flood-prone. On the other hand, heavy rainfall events, characterized by short and intense downpours, accounted for 16% of the observed flash flood cases. Malaysia's climate particularly during the monsoon seasons is characterized by periods of heavy rainfall, which can quickly overwhelm drainage systems and lead to flash flooding (Zakaria et al., 2017). Moreover, climate change projections indicate that extreme rainfall events may become more frequent, underscoring the need for adaptive strategies and improved flood risk management practices. These findings emphasize the necessity of enhancing forecasting and early warning systems to effectively respond to heavy rainfall events.

The findings of this research also demonstrate the multifaceted nature of flash floods and the various factors that contribute to their occurrence. Effective flood risk management strategies should address these key factors through a combination of measures, including regular maintenance of drainage systems, proper urban planning (MSMA 2nd Edition, 2012), and development, adherence to construction best practices, and enhanced forecasting and early warning systems In addition to that, collaboration among stakeholders, including government agencies, local authorities, and the construction industry, is crucial to successfully mitigate the impacts of flash floods and build resilient cities that can withstand such events (Yusmah, Bracken, Sahdan, Norhaslina, Melasutra, Ghaffarianhoseini, Sumiliana and Farisha, 2020). It is important to note that the percentages mentioned above are based on the specific findings of this research and may vary in different geographical locations or over time. Further research and monitoring are necessary to continuously assess and understand the evolving factors contributing to flash floods and to inform targeted flood risk management strategies.

CONCLUSION

In conclusion, this research has successfully identified and emphasized the key causes of flash floods in construction sites in Malaysia. These causes encompass clogged drainage systems, rapid urban development, and the failure to construct proper damp or levee structures. Such a comprehensive understanding of these factors is vital for developing effective flood risk management strategies. The findings expose the pressing need for robust flood risk management strategies, especially in the context of building resilient cities. Flash floods can have severe consequences, and recognizing their underlying causes is the first step in mitigating their impacts effectively. On top of it, the research highlights the detrimental impact of clogged or inadequate drainage systems, which are exacerbated by rapid urban development. Urbanization leads to increased impervious surfaces, altering natural drainage patterns, and elevating the risk of flash flooding. This emphasizes the importance of urban planning that integrates green infrastructures and sustainable construction practices.

In addition, inadequate construction techniques, such as the absence of proper waterproofing measures and ineffective stormwater management, significantly contribute to flash flood occurrences during construction activities. Addressing these issues is paramount to prevent flash floods on construction sites. Building resilient cities capable of withstanding flash floods necessitates a multifaceted approach. This includes the implementation of various measures, such as regular maintenance of drainage systems, integrating green infrastructure, promoting sustainable construction practices, and enhancing early warning systems. These strategies collectively enhance the resilience of cities. On top of this, the findings also emphasize the critical role of collaboration among stakeholders, including government agencies, local authorities, and the construction industry. Strict adherence to regulations is essential to ensure that flood risk management practices are effectively implemented.

By recognizing that flash flood causes and impacts may evolve over time, the research highlights the importance of continuous monitoring and adaptation. This is crucial in responding to changing climatic conditions and urban development patterns. In essence, the conclusion underscores the significance of understanding the root causes of flash floods in construction sites and developing comprehensive strategies to mitigate their impact. By implementing the suggested measure, cities in Malaysia can reduce vulnerability, enhance overall resilience and safeguard the well-being and safety of both construction site workers and the surrounding communities.

ACKNOWLEDGEMENT

The authors extend heartfelt gratitude to the numerous respondents whose active participation and willingness to share their time, invaluable experiences, and profound insights were instrumental in the accomplishment of this research. Their engagement and cooperation in this study not only enriched our understanding but also underscored the significance of their contributions to the success of this research. Additionally, we would like to express our sincere thanks to Universiti Teknologi MARA for their unwavering support and assistance throughout the various stages of this research. Their valuable resources, guidance, and infrastructure significantly facilitated the completion of this study. We deeply appreciate the contribution to our research efforts, which undoubtedly enhanced the quality and scope of this project.

REFERENCES

Abdullah, K. (2004). Kuala Lumpur: Re-engineering a flooded confluence. *14th Professor Chin Fung Kee Memorial Lecture. Kuala Lumpur.* Retrieved from http://www.smarttunnel.com.my/ construction/images/news/special/SR01.pdf

Bhuiyan, T. R., Reza, M.I.H., Choy, E. A. & Pereira, J. J. (2018), Direct impact of flash floods in Kuala Lumpur City: Secondary data-based analysis, *ASM Science Journal*, Volume 11(3)

Bradley, J. (2005) Debris Control Structures- Evaluation and Countermeasures, *Federal Highway Administration.*

Chang H., Tan Y., Lai J., Pan T., Liu T. & Tung, C. (2013) Improvement of a drainage system for flood management assessment of the potential effects of climate change, *Hydrological Science Journal*, Volume 58, Issues 8

Chia, K. L., Fui, C. Y., Siau, C. L., Joo H. Y., and Tien C. T (2023), Critical Risk Factors in Construction Projects: A Dematel-Based Model, *Malaysia Construction Research Journal (MCRJ),* Special Issues, Volume 18, page 168-188.

Ghani, N. A., Abdullah, A., Sidek, R., Kassim, L. M., & Ainan, A. (2004) MSMA – A new urban stormwater management manual for Malaysia. *Advances in Hydro-Science and Engineering*, 6, 1-11.

Hammond, M. J., Chen, A. S., Djordjevic, S., Butler, D. and Mark, O. (2015) Urban flood impact assessment: A state-of-the-art review. *Urban Water Journal,* 12(1), pp. 14-29.doi:10.1080/1573062X.2013.857421

Kandari, P.N.A., Saudi, A.S.M, Chyang, P. J, Kamarudin, M.K.A, Saad M.H.M, Azid, A. Saudi, N.S.M & Mahmud, M. (2018), Flood risk pattern recognition analysis in Klang River basin. *International Journal of Engineering & Technology*, 7, 4.34, 86-90

Maulana, S., Abdul Samad, M. H. and Nordin, J., (2022), The Role of Extensive Green Roof to Reduce Flood Risk In Urban Scale Using Multi-Criteria Decision Analysis, *Malaysia Construction Research Journal (MCRJ)*, Special Issues, Volume 15, page 169-184.

Mourato, S., Fernandez, P., Pereira, L. G. & Moreira, M. (2023) Assessing Vulnerability in Flood Prone Areas Using Analytic Hierarchy Process – Group Decision Making and Geographic Information System: A Case Study in Portugal, *Applied Science*, Volume 13, Issue 8

MSMA 2nd Edition (2012) Urban Stormwater Management Manual for Malaysia - Department of Irrigation and Drainage (DID) Malaysia, Government of Malaysia.

Muslima, F. S., Che Omar, R., Jamaluddin, T. A. & Taha, H (2018) Flood and Flash Flood Geo-Hazards in Malaysia, *International Journal of Engineering & Technology*, 7, 4.35, 760-764

Muzamil, S.A.H.S, Zainun, N. Y, Ajman, N. N., Sulaiman, N., Khahro, S. H., Rohani, M. M., Mohd, S.M.B. & Ahmad, H., (2022), Proposed Framework for the Flood Disaster Management Cycle in Malaysia. *Sustainability*, 14(7), 4088

NADMA Risk Assessment – Guidelines Integrating Climate Change Projection into Flood Risk Assessment and Mapping at the River Basin Level, Jakarta, *ASEAN Secretariat*, 2021

Pham, L. and Ekambaram, P. (2018), Resilient Buildings: Informing Maintenance for Long-term Sustainability, Sustainable Built Environment National Research Centre, *Swinburne University of Technology*

Samsuri, N., Bakar, R. A. & Unjah, T. (2018). Flash flood impact in Kuala Lumpur- approach review and way forward. *International Journal of the Malay World and Civilisation 6 (Special Issue 1),* 2018: 69-76;

Wang, L., Cui, S., Li, Y., Huang, H., Manaddhar, B., Nitivattananon, V., Fang, X. & Huang, W. (2022), A review of the flood management from flood control to flood resilience, *Heliyon 8*, Cellpress, e11763.

Yusmah, S. M. Y., Bracken, L. J., Sahdan, Z., Norhaslina, H., Melasutra, M. D., Ghaffarianhoseini, A., Sumiliana, S. & Farisha, A. S. (2020), Understanding urban flood vulnerability and resilience: A case study of Kuantan, Pahang, Malaysia. *Natural Hazards*, 101, 551-571

Zakaria, S. F., Zin, R. M., Mohamad, I., Balubaid, S., Mydin, S. H. & MDR, E. R. (2017). The development of flood map in Malaysia. *AIP Conference Proceedings*, 1903(1), 1-8

Zhen, Y., Liu, S., Zhong, G., Liang, J., Zheng, W. and Fang, Q. (2022) Risk Assessment of Flash Flood to Buildings Using an Indicator-Based Methodology: A Case Study of Mountainous Rural Settlements in Southwest China, Front. Environ. Sci, Sec. Water and Wastewater Management, Volume 10, 2022

CHALLENGES IN SELECTING THE APPROPRIATE TYPE OF INDUSTRIALISED BUILDING SYSTEMS (IBS) IN HOUSING PROJECTS: THE ROLE OF INTUITION AND HEURISTICS APPROACH

Mohd Rofdzi Abdullah*, Mohd Najib Abd Rashid and Wan Nur Syazwani Wan Mohammad
Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak, Malaysia

**Corresponding Email: rofdzi159@uitm.edu.my*

Abstract
Selecting the type of Industrialised Building System [IBS] for Malaysian housing projects involves the selection of suppliers for the construction industry from the contractor's point of view. The challenges of choosing the best supplier or IBS manufacturer are dealt with from the perspective of project goals and objectives. Nevertheless, for there are limited guidelines in selecting an appropriate type of IBS for housing projects, by contractor available in Malaysian Construction Industry. Thus, the aim of this paper is to identify the significant decision-making approaches and challenges of decision-making in selecting the IBS types. Data collected via survey in the form of a structured questionnaire from 101 respondents are then analysed using IBM SPSS software. A descriptive analysis highlights the pattern of approaches in decision-making to select the type of IBS for housing projects, the extent of individual employment and organizational experiences toward the decision-making for housing projects in Malaysia, and the significant level of knowledge for IBS contractors when selecting the best type of IBS for housing project. The most frequently used approach in decision-making is 'Intuition and Experiences' of which the Middle Manager is found to be the personnel that uses it. Furthermore, the 'Unclear Project Goals and Objectives' is the most challenging of decision-making in selecting the IBS types in this study. Hence, findings from the study provide insight into the IBS players who have considered the types of approaches and challenges in decision-making for the type of IBS selection in housing projects in the Malaysian construction industry.

Keywords: *Industrialised Building System; Decision Making Approaches; Intuition; Housing Project*

INTRODUCTION

In the construction industry, decision-making is a crucial aspect that impacts the success of construction projects. Numerous decisions need to be made at different phases of the construction process, from the initial phase until project completion (Mohd Sofberi & Zainal, 2020). Throughout these phases, decision- makers in construction must consider factors such as cost, time, quality, safety, and regulatory compliance (Zhong et al., 2022). Moreover, effective communication and collaboration among the project stakeholders (i.e., owners, designers, contractors, and subcontractors) are crucial for successful decision making in the construction process. Other than that, the adoption of technology, as exemplified in the use of Building Information Modelling (BIM) and project management software can aid in data driven decision-making and improve overall project outcomes (Bartels & Hahne, 2023; Rashid et al., 2018; Wan Mohammad & Mohd Azmi, 2023).

Hence, the process of selecting the appropriate type of Industrialised Building System (IBS) during pre-construction is categorized as a decision-making exercise. The role for criteria to be established as preferences measures should be considered. An appropriate preference in decision making in IBS is subjected to the level of knowledge possessed by decision makers in an organization. The maturity of knowledge varies among professionals and managers in construction industry and IBS depending on the level of exposure to and creativity of the initiatives which are taken to enhance the knowledge. Nevertheless, for contractors there are limited guidelines to select an appropriate type of IBS for housing projects, available in the Malaysian Construction Industry (Abdullah & Egbu, 2010; Rashid et al., 2019). Accordingly, the objectives of this paper are to identify the significant decision-making approaches and challenges of decision-making in selecting the IBS types. To achieve these objectives, this paper further discusses the IBS and Decision Approaches, methodology, results and discussion.

Industrialised Building System and Decision Approaches

Industrialised Building System (IBS) is a general term which refers to construction approaches in the context of the Malaysian construction industry. A study by Dzulkalnine, (2019) and Hamid et al. (2008) revealed that IBS has various definitions from different practitioners point of views. There seems to be a continuous debate and ambiguous standards. Junid (1986) provided a definition of IBS as the process by which components of building are conceived, planned, and fabricated, transported, and erected at site. However, Rahman and Omar (2006) agreed with Esa and Nurudin (1998) who claimed that the IBS is defined as a system which uses industrial production techniques either in the production of components or assembly of the building or both.

Relatively, definition by Salam and Chai (1986) seem to be the basis for CIDB (2003) to standardize the definition and meaning of IBS. Hence the term use of IBS in Malaysian construction industry is a technique of construction whereby components are manufactured in a controlled environment, either at site or off site, and transported, positioned, and assembled into construction work (Abdullah and Egbu, 2009). Badir et al. (2002) quantified that the type of IBS systems in Malaysia are basically based on four already identified, namely conventional building system, cast in-situ formwork, prefabricated system, and composite system. However, CIDB (2003) distinguished the IBS systems into five categories or types. These are precast concrete framed building; precast concrete wall system, reinforced building with precast concrete slabs, steel formworks' systems and steel frame building (Abdullah & Egbu, 2010; CIDB, 2016; 2020).

Due to the nature of the construction industry, which is fragmented, homogenous, it requires involvement of various parties in a project organization: this may result in a situation where consensus or agreement among project stakeholders to allow IBS to be adopted would not be achieved (Nawi et al., 2018; Rashid et al., 2021). Kamar & Hamid (2011) and Rashid et al. (2018) concurred with Thanoon et al. (2003) on the issues of lack of knowledge and scientific information among project stakeholders as one the barriers to the use of IBS. Therefore, the initiatives of knowledge management approach to externalise the tacit knowledge possessed by the experts to explicit knowledge for sharing should be a vital solution (1995). Without appropriate knowledge and information in IBS, the decision to consider the IBS in construction projects at design or feasibility study stage is argumentative. Therefore, the implementation of IBS was ignored even though the project's characteristics were extremely appropriate to implement the IBS. It was believed that project stakeholders' decision to choose IBS resulted from the lack of knowledge and information on their part (Hamid et al., 2017; Hung et al., 2015).

Decision Making Approaches

Management of decision making is considered as an art because it is dependent on the experience, intuition, and creativity of the decision maker. The successful solution of a single problem can be achieved by a variety of approaches (Karamoozian & Hong, 2023; Khosrowshahi & Howes, 2005). The author also stated that the complex nature of today's managerial decisions, at the executive level, especially in complex construction projects demands high quality information and the use of scientific decision-making tools (Karamoozian & Hong, 2023; Khosrowshahi & Howes, 2005). The information is supplied hand in hand with the knowledge possessed by the decision makers. There are two main categories of knowledge which deal with the managerial level. Knowledge stored in people as tacit knowledge which should be shared helps the decision organizational making process by making it better (Kucharska & Erickson, 2023). The sharing from manager to executive or operatives level needs tools for explicit knowledge to go through by groupware, intranet, company portal and others could be materialized by decision support systems as logical and rational approaches of decision making (Akmam Syed Zakaria et al., 2018).

The Role of Heuristics and Intuition for Integrated Approaches

Slovic and Tversky (1982) infer that the approach which involves defining to intuition from the perspective of heuristics and biases as judgment based on representatives, availability, and anchoring and adjustment can be useful: but they may also lead to severe and systemic errors. Tversky and Kahneman (1979) hypothesized that people use the heuristics approach in decision-making to reduce time and effort undertaken in reasonable judgments or systematic logic approaches. Smith and Sparrow (2008) suggest the definition of intuition made by Barnard (1938) that human mind works with two main processes which are known as logical and non-logical processes. Therefore, intuition expresses the approaches to judgment, decision and action through good sense, inspiration, and brilliance which in a sense are not equivalent to illogical or irrational judgement. Due to the error that is commonly caused by intuition approaches, Smith and Sparrow (2008) suggested the significant roles of implicit knowledge as organic to impress the unconscious element.

In the heuristics approach, the common errors in decision-making are created by elements of bias. Volker (2010) claimed that mood and emotions often have a significant effect on decision-makers. She also asserts that a heuristics approach such as a set of values and beliefs, specific goals and operational plans are the premises for individuals when making decisions in organisations. Due to this, the decision-making base for heuristics tends to be related to human factors. Generally, the role of intuition judgment shall be part of the rational and logical analysis approaches complementary. Design practitioners use their experience to assess the impact on their specialist area while a decision is being made or when a decision is made (Hindmarch et al., 2010).

Smith and Sparrow (2008) also discusses Khairbut negatively work on the finding of intuitive approaches often used in decision making by senior managers where they are positively associated with the organizational performance in an unstable environment but negatively in a stable environment. Smith and Sparrow (2008) also concluded that the situation in which intuition is an inappropriate approach to be used is when the problems' situation are tightly structured, involves intellective tasks in data that are rich, objectively quantifiable and have computationally complex domains. Hence, statistical models or rational logical approaches would perform better than human judgment. It seems to support the previous work by Laughlin (1980) and Klien (2003). Their findings on the favoured situations for analytical approaches are characterized by computational complexity, a need for justification, requirement for optimization and situations in which the objective criteria for success exist. In addition to that, intuition is not an appropriate approach when the situation allows the explicit criteria to be identified, reliable and valid procedures are available (Walsh et al., 2022).

Challenge of Decision Making in Selecting Type of IBS

In any decision-making approach, there are difficulties and challenges faced by decision makers to achieve the best solutions. However, the knowledge and information supplied as well as the experience possessed by decision makers seem to be the main challenges. The challenges of decision-making in selecting the type of Industrialized Building System (IBS) underscore the need for a holistic and informed approach. Decision makers must carefully weigh the diverse options, consider project-specific requirements, analyse costs, assess the availability of skilled labor, and navigate regulatory complexities. Overcoming these challenges is essential to unlock the full potential of IBS in enhancing efficiency, sustainability, and innovation in the construction industry. This paper studied the challenges faced by managers in construction organisation during the exercises of selecting the IBS.

METHODOLOGY

A quantitative approach in the form of structured questionnaires was used in this study to achieve its objectives. The main objective of this study is to identify the significant decision-making approaches and challenges of decision-making in selecting the IBS types. The closed-ended survey questions were prepared using Google forms and sent to the respondents via social media platforms (i.e., email) and phone call to meet the research objectives. The study's population comprised of 1500 Malaysian IBS contractors who had registered with construction industry Development Board (CIDB) and these individuals represented various designations (i.e., The Managing Director (MD), Chief Executive Officer (CEO), middle, operational and low manager level). Later, the questionnaires were distributed by stratified random sampling to the 300 contractors in Klang Valley. According to Roscoe (1975), in deciding the sample size of a study, researchers are recommended to use the sample size larger than 30 or less than 500. As a result, 101 respondents were received, yielding a 33.7% response rate. Fellows and Liu (2003) revealed that when considering a statistical analysis, response rate with a 25% to 35% is considered acceptable.

A structured questionnaire with three components was developed to achieve the research objective. The first section of the questionnaire describes the respondents' background information, and the second section collects the decision-making approaches by using a 4-point Likert scale, with 1 indicating 'always' and 4 indicating 'never'. The final section of the questionnaire is prepared to gauge the challenges of decision-making in selecting the IBS types by using a 4-point Likert scale (i.e., 1 – Most Challenging; 2 – Challenging; 3 - Fairly Challenging and 4 – Not Challenging). Then, the data from the questionnaires were analysed using the IBM SPSS software and the descriptive analysis was employed as explained in the next section.

RESULTS AND DISCUSSION

Result 1: Demographic Profile

The distributions of the respondent's designation are presented in Figure 1: it shows the respondents' job positions namely, 10% represents the top highest hierarchy in the organisation either the Managing Director (MD) or Chief Executive Officer (CEO) and they are directly involved in final and ultimate strategic decision making. The other 70% represents middle managers and the remaining 20% represents the operational and low manager levels. These informants held key positions within an organisation, and this suggests the high-profile participation in the survey that adds weight to the data quality (Alashwal et al., 2017).

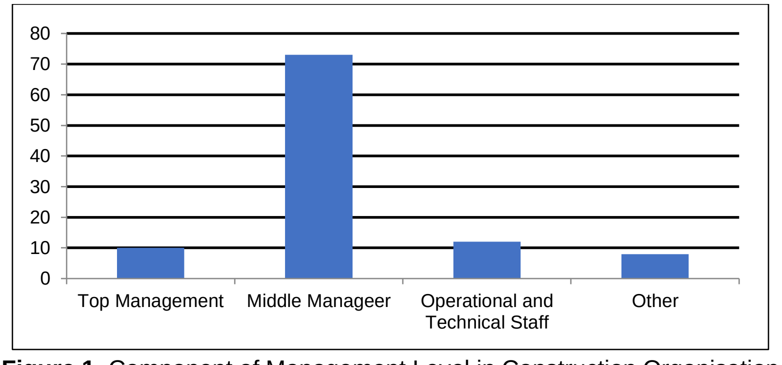


Figure 1. Component of Management Level in Construction Organisation

Result 2: Decision Making Approaches

In this study the respondents were asked to rate their extent of use or application of the decision-making approaches. From the survey conducted, the intuition and experiences scored the mean of 1.78 which is from 1 to 2 on the means of always to frequently, while 3 and 4 for sometimes and never scale. On the other hand, the decision support tools had a mean score of 3.03 which is more toward sometimes and never from the Likert scale. In addition to the correlation perspective, the intuition and support tools show a negative correlation. Table 1 below shows the score from 101 respondents on the approaches to the criteria for decision making.

Table 1. Ranking of Approaches

	Approaches to The Criteria	Mean	Std. Deviation	Ranking
1.	Intuition and Experiences	1.7800	.77303	1
2.	Organization Past Experiences	1.7900	.71485	2
3.	Client Instruction	1.8900	.88643	3
4	Superior Instruction	2.2600	.76038	4
5.	Management Brainstorming Meeting	2.3100	.76138	5
6.	Decision Support Tools	3.0300	.90403	6

In the realm of decision-making, professionals often navigate a complex landscape where intuition, experiences, and various external factors come into play. A recent study delves into the frequency and consistency of different decision-making approaches, shedding light on the preferences and tendencies of respondents in the given context. At the forefront of decision-making approaches, intuition and experience emerge as the favoured tools among respondents. The study assigns a mean score of 1.7800 to this approach, indicating a preference for relying on gut feelings and past knowledge. The strikingly low standard deviation (0.77303) implies a remarkable consistency among respondents, showcasing a unanimous inclination towards drawing upon intuition and personal experiences in decision-making processes. Furthermore, aligning with individual intuition, organizational past experiences also hold significant weight in the decision-making arena. The mean score of 1.7900 suggests a shared tendency among respondents to consider the historical context of their organization when making decisions. This parallels with the consistency observed in the first approach, indicating a collective reliance on both personal and organizational experiences. While intuition and organizational experiences set the foundation, the study reveals a nuanced role for external guidance in decision-making. The mean score for client instruction, slightly higher at 1.8900, underscores the impact of external directives in shaping decisions.

However, the comparatively higher standard deviation (0.88643) signals a greater diversity in responses, which highlights that the influence of client instructions is more variable among respondents (Kozioł-Nadolna & Beyer, 2021). Elevating the hierarchy of decision-making influences, superior instruction emerges as a notable factor. The higher mean score of 2.2600 suggests that decisions which are influenced by the superior's instructions occur more frequently on average. Most importantly, the lower standard deviation (0.76038) indicates a consistent response pattern among participants, and this shows that there is a shared proclivity for considering guidance from higher-ups in the decision-making process. Collaborative decision-making surfaces as a notable theme, as evidenced by the mean score of 2.3100 for decisions influenced by management brainstorming meetings. This suggests a slight increase in frequency compared to the superior's instruction. Similar to the superior's instruction approach, the standard deviation (0.76138) indicates a consistent response pattern, underlining the reliability of this collaborative decision-making avenue. In a modern context where technology plays a pivotal role, decision support tools emerge with the highest mean score of 3.0300. However, the higher standard deviation (0.90403) signals a more diverse range of responses, indicating that opinions on the use of decision support tools vary significantly among respondents (Stanitsa et al., 2022). This suggests a more polarized stance on the integration of technological aids in decision-making processes.

Table 2. Crosstab Between Level of Management and DM Approaches of Intuition and Experienced

Management Level	Always	Frequently	Sometimes	Never	Total
Top Management	6	1	3	0	10
Middle Manager	31	32	10	0	73
Operational and Tech Staff	2	5	2	2	11
Others	2	5	0	0	7
Total	41	43	15	2	101

Table 2 shows the crosstab between the management level and decision-making approaches. It clearly shows that large organisation chose 'always' as the frequency of intuition and experiences. In conclusion, to choose the appropriate type of IBS for housing projects, large companies are more likely (always and frequently) to use the intuition and experiences approaches in making their decision. It also can be summarised that Top and

Middle managers are in line with the pattern of which the size of organisation determines the decisions which are made when it comes to intuition and experience.

In any organizational setting, the behaviors and actions of individuals at different management levels play a crucial role in shaping the overall work environment and influencing decision-making processes (Kozioł-Nadolna & Beyer, 2021). A recent survey captured the frequency of certain behaviors across various management levels, shedding light on notable patterns and differences. Top Management demonstrates a consistent approach, with a majority of responses falling within the "Always" to "Sometimes" categories. The relatively lower frequencies, especially in the "Always" category (6), suggest a measured and deliberate approach to specific behaviors. This consistency aligns with the strategic and visionary roles typically associated with top-level executives. In stark contrast to Top Management, Middle Managers exhibit a more diverse range of behaviors, with a significant number indicating frequent actions ("Frequently" - 32). The high frequency in the "Always" category (31) indicates a proactive and hands-on approach. This variability in responses suggests that Middle Managers engage in a wide spectrum of activities, reflecting the multifaceted nature of their roles. Operational and Tech Staff display a mix of responses across the categories, indicating a varied pattern of behaviors. While the frequencies are generally lower compared to Middle Managers: the responses suggest a balance between consistent and occasional engagement in the specified actions. This variability may reflect the diverse responsibilities and specialized roles within this group. The "Others" category also demonstrates consistency, with the majority of responses falling within the "Always" and "Frequently" categories. This group appears to be characterized by a proactive and engaged approach to the specified behaviors, which are aligned with the observed patterns in Top Management.

Understanding these behavioral patterns is crucial for organizational leaders. The consistent approaches of Top Management and Others may contribute to a stable and visionary organizational direction. The variability in Middle Managers' behaviors suggests adaptability and versatility, which can be harnessed for effective team management. Recognizing the diversity in Operational and Tech Staff behaviors is essential in tailoring support and resources to meet the specific needs of this group (Mendling et al., 2017). In conclusion, the survey data provides a nuanced perspective on the behaviors exhibited across different management levels. This insight is invaluable for organizational leaders who seek to optimize their teams, enhance collaboration, and align individual behaviors with broader strategic objectives.

Result 3: Challenge of Decision Making in Selecting Type of IBS

This paper studied the challenges faced by managers in construction organisation during the exercises of selecting the IBS. The respondents were asked to indicate the extent of the challenged issues. The Likert scale of 1 to 4 was set up. The “very challenging” issues were assigned as 1, 2 – Challenging, 3 - Fairly Challenging and 4 – Not Challenging. The result was tested on the Reliability Test with Cronbach's Alpha 0.788 and it is reliable. Table 3 summarised the findings of the challenges of selecting tasks. The unclear project goals and objectives, uncertainty of criteria used, lack of information about IBS product and inability to share the critical important information was the high rankings of the challenges issues with the means score below 2.1.

Table 3. Statistics of Mean Challenges to Select Type of IBS

Challenges	Mean	Std. Deviation	Ranking
Unclear Project Goals and Objectives	1.7228	.72276	1
Uncertainty Criteria Used	1.7228	.69453	2
Lack of Product Information	2.0495	.68376	3
Inability to Share Critical Important Information	2.0495	.73995	4
Prioritizing Two Criteria	2.1584	.57849	5
Limitation Choice and Alternative	2.2178	.81980	6
Lack of Skills to Operate DST	2.2574	.83251	7
Working towards needed time and cost	2.2574	.73012	8
Shortcoming Decision Support System	2.2673	.82330	9
Contradiction Intuitive and DST	2.3267	.66496	10

In the intricate world of decision-making, professionals often find themselves confronted with an array of challenges that can significantly impact the quality and effectiveness of their choices. A recent study, as depicted in the table below, sheds light on the mean scores, standard deviations, and rankings associated with key challenges faced by decision-makers. The researcher delves into the nuanced landscape of these challenges and explored their implications for decision-making processes. The foremost challenge faced by decision-makers is the ambiguity surrounding project goals and objectives. The mean score of 1.7228 indicates a significant struggle, while the moderate standard deviation suggests a shared experience among respondents. This challenge underscores the critical importance of establishing clear project foundations for effective decision-making (Ahmed & Jawad, 2022). Closely following is the challenge of uncertainty regarding the criteria used in decision-making, with a matching mean score of 1.7228. The moderate standard deviation implies a collective effort is required to define and communicate decision criteria consistently (Zhong et al., 2022). Clarity in criteria is fundamental to informed decision-making. Decision-makers grapple with insufficient product information, ranking third with a mean score of 2.0495. The relatively low standard deviation suggests a shared difficulty in obtaining comprehensive product details. This challenge highlights the importance of robust information sources for effective decision-making.

The challenge of inadequate information sharing occupies the fourth position, with a mean score of 2.0495 and a higher standard deviation. This indicates a varied experience among decision-makers, and it emphasizes the need for streamlined communication channels to facilitate effective decision processes. Decision-makers face challenges in prioritizing two criteria, ranking fifth with a mean score of 2.1584. The lower standard deviation suggests a consistent struggle in navigating the complexities of assigning priority when faced with competing criteria. This challenge points to the need for robust decision frameworks. The sixth challenge involves limitations in choice and alternative, with a mean score of 2.2178 and a higher standard deviation. This reflects a diverse range of experiences among decision-makers, highlighting the importance of broadening available options to enhance decision flexibility. Operational challenges in utilizing Decision Support Tools (DST) rank seventh, with a mean score of 2.2574 and a higher standard deviation. This indicates varying proficiency levels, which gives more emphasis on the need for comprehensive training programs to equip decision-makers with the skills required to leverage advanced tools effectively (Yu et al., 2022) The challenge of aligning decisions with required time and cost constraints occupies the eighth position, with a mean score of 2.2574. The moderate standard deviation suggests a shared struggle among decision-makers, and this highlights the importance of balancing efficiency with resource considerations. Ranked ninth is the challenge associated with the shortcomings of Decision Support Systems (DSS), with a mean score of 2.2673. The higher standard deviation implies varied experiences with the effectiveness of existing DSS, signaling a need for enhancements to better support decision-making processes. The challenge of managing the contradiction between intuitive decision-making and the use of Decision Support Tools (DST) is ranked tenth, with a mean score of 2.3267. The relatively lower standard deviation suggests a more consistent experience among decision-makers, highlighting the delicate balance required between traditional and technological approaches (Yu et al., 2022).

CONCLUSION

From the survey findings, the top and middle managers from a large-scale contractor organisation always and frequently use the intuition and past experience owned by their organisation in business or their personal working experience to choose the appropriate type of IBS. The process of selecting an appropriate type of IBS involves a complex interplay of various decision-making factors, and among them, intuition and experiences play a crucial role. The results suggest there is a utilization of intuition, often described as the ability to make decisions based on gut feelings or implicit knowledge, and experiences, which encompass past knowledge and lessons learned. This can significantly impact the decision-making process in the context of IBS. Furthermore, intuition in decision making suggests a reliance on hunches, instincts, or tacit knowledge when faced with choices related to IBS methods. This intuitive approach may be influenced by a professional's familiarity with certain building systems, gained through years of exposure and hands-on experience. On the other hand, when deciding that type of IBS, the main challenges faced by decision makers are lack of and unclear strategic project direction and shortfall of important information related to the product and process of construction using IBS. Decision-makers must navigate uncertainties in project goals, criteria, and information sharing while addressing the intricate balance between intuition and advanced tools. The varying standard deviations indicate the nuanced nature of these challenges across respondents. Organizations can leverage these insights to tailor interventions, training programs, and decision support systems that address specific pain points, fostering a more resilient and effective decision-making culture. As the industry players move forward, acknowledging and proactively addressing these challenges will be instrumental in enhancing the strategic capabilities of decision-makers and driving organizational success.

Therefore, this paper recommended that significant knowledge and information should be explicitly documented and shared for improved decision-making process and results. The benefits of these knowledge management exercises will ensure the retention of tacit knowledge owned by expert and experienced managers to be shared or transferred to the juniors and inexperienced managers.

REFERENCES

Abdullah, M. R., & Egbu, C. (2010). The Role of Knowledge Management in Improving the Adoption and Implementation Practices of Industrialised Building System (IBS) in Malaysia. *CIB World Congress*, 1–12.

Ahmed, R., & Jawad, M. (2022). Avoiding or disregarding: Exploring the relationship between scope creep, project complexity, and the success of construction projects. *Project Leadership and Society*, *3*.

Akmam Syed Zakaria, S., Gajendran, T., Rose, T., & Brewer, G. (2018). Contextual, structural and behavioural factors influencing the adoption of industrialised building systems: a review. *Architectural Engineering and Design Management*, *14*(1–2), 3–26.

Alashwal, A. M., Fareed, N. F., & Al-obaidi, K. M. (2017). Determining Success Criteria and Success Factors for International Construction Projects for Malaysian Contractors. *Construction Economics and Building*, *17*(2), 62.

Badir, Y. F., Kadir, M. R. A. and Hashim, A. H. (2002) 'Industrialized Building Systems Construction in Malaysia', *Journal of Architectural Engineering,* 8(1), 19.

Bartels, N., & Hahne, K. (2023). Teaching Building Information Modeling in the Metaverse—An Approach Based on Quantitative and Qualitative Evaluation of the Students Perspective. *Buildings*, *13*(9).

CIDB (2003) *Industrialised Building System (IBS) Roadmap 2003 -2010*, Kuala Lumpur: CIDB.

CIDB. (2016). *Construction Industry Tranformation Program 2016 - 2020*.

CIDB. (2020). Construction 4.0 Strategic Plan (2021-2025). In *Construction Industry Development Board (CIDB)*.

Dzulkalnine, N. (2019). IBS Adoption in Malaysian Construction Industry. *Proceedings of the International Conference on Industrial Engineering and Operations Management*.

Esa, H. and Nuruddin, M. M. (1998) *Policy on Industrialised Building System,* Kuala Lumpur.

Hamid, Z. A., Hung, F. C., & Rahim, A. H. A. (2017). Retrospective View and Future Initiatives in Industrialised Building Systems (IBS) and Modernisation, Mechanisation and Industrialisation (MMI). *Modernisation, Mechanisation and Industrialisation of Concrete Structures*, 424–452.

Hamid, Z. A., Kamar, K. A., Zain, M. Z. M., Ghani, M. K., & Rahim, A. H. (2008). Industrialised building system (IBS) in Malaysia: The current state and R&D initiatives. *Malaysian Construction Research Journal*, *2*(1), 1–11.

Hindmarch, H., WGale, A. and Harrison, R. (2010) *A Proposed Construction Design Change Management Tool to Aid in Making Informed Design Decisions* translated by Chan, P., Manchester.

Hung, F. C., Hamid, Z. A., Din, M. I., & Norman, M. R. (2015). Study on industrialised building system (IBS) adoption level and contractors' readiness in Malaysia 2013. *Malaysian Construction Research Journal*, *17*(1), 1–19.

Junid, S. M. S. (1986) 'Industrialised building system', in *UNESCO/ FEISEAP Regional Workshop*, UPM Serdang, Selangor,

Karamoozian, M., & Hong, Z. (2023). Using a decision-making tool to select the optimal industrial housing construction system in Tehran. *Journal of Asian Architecture and Building Engineering*, *22*(4), 2189–2208.

Kamar, K. A. M., Hamid, Z. A., Ghani, M. K. and Rahim, A. H. A. (2007) 'Industrialised Building System : Current Shortcomings and The Vital Role of R&D', *Master Builders,* 62-65

Khairi, N. and Ng, H. A. (2000) 'The Role of Intuition in STrategic Decision Making', *Human Relations,* 53, 57-86

Khosrowshahi, F., & Howes, R. (2005). A Framework for Strategic Decision-Making Based on A Hybrid Decision Support Tools. *Journal of Information Technology in Construction*, *10*, 111–124.

Kozioł-Nadolna, K., & Beyer, K. (2021). Determinants of the decision-making process in organizations. *Procedia Computer Science*, *192*, 2375–2384.

Kucharska, W., & Erickson, G. S. (2023). Tacit knowledge acquisition & sharing, and its influence on innovations: A Polish/US cross-country study. *International Journal of Information Manage*

Klien, G. (2003) *Intuition at Work,* New York: Bantam Dell.

Laughlin, P. (1980) 'Social Ombination Procesess of Cooperative Problem Solving Groups on Verbal Intellective Tasks' in *Progress of Social Psychology*, Hillsdale, NJ: Lawrence Erlbaum Associates, 127-155.

Mendling, J., Baesens, B., Bernstein, A., & Fellmann, M. (2017). Challenges of smart business process management: An introduction to the special issue. *Decision Support Systems*, *100*, 1–5.

Mohd Sofberi, N. A., & Zainal, R. (2020). Decision Making Process Practised At Planning Phase In Malaysia. *Malaysian Journal of Sustainable Environment*, *7*(2), 107.

Nawi, M. N. M., Lee, A., Mydin, M. A. O., Osman, W. N., & Rofie, M. K. (2018). Supply chain management (SCM): Disintegration team factors in Malaysian Industrialised Building System (IBS) construction projects. *International Journal of Supply Chain Management*, *7*(1), 140–143.

Nonaka, I. and Takeuchi, H. (1995) *The knowledge-creating company. ,* New York, Oxford: Oxford University Press.

Rahman, A. B. A. and Omar, W. (2006) 'Issues and Challenges in the Implementation of Industrialised Building Systems in Malaysia', in *Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006),*, Kuala Lumpur, Malaysia, 5 - 6 September 2006.

Rashid, M. N. A., Abdullah, M. R., Ismail, D., & Saberi, M. H. (2019). Automation and Robotics in Industrialized Building System (IBS): The Potential Criteria for Measurement. *International Journal of Academic Research in Business & Social Sciences, July*.

Rashid, M. N. A., Abdullah, M. R., Ismail, D., & Saberi, M. H. (2021). Success Criteria for Automation and Robotics in Industrialised Building System (IBS). *International Journal of Academic Research in Business & Social Science*, *11*(2), 1259–1273.

Rashid, M. N. A., Abdullah, M. R., & Ismail, D. (2018). Critical Success Factors CSFs to Automation and Robotics in Industrialized Building System IBS. *International Journal of Academic Research in Business and Social Sciences*, *8*(12), 2207–2221.

Salam, S. A. and Chai, K. M. (1986) in *Workshop on Towards Industrialisation in the Building Industry*, Univerity Pertanian Malaysia, 29-31 July 1986,

Simon, H. A. (1987) 'Making Management Decisions: The Role of Intuition and Emotion', *Academy of Management Executive,* 1, 57-64.

Slovic, P. and Iversky, A. (1982) *Judgement Under Uncertainty: Heuristics and Biases*, New York: Cambridge University Press.

Smith, E. S.-. and Sparrow, P. R. (2008) 'Intuition in Organizational Decision Making' in Hodgkinsion, G. P. and Starbuck, W. H., eds., *The Oxford Handbook of Organizational Decision Making*, New York: Oxford University Press Inc. New York, 305-324.

Stanitsa, A., Hallett, S. H., & Jude, S. (2022). Investigating key factors influencing decision-making in the design of buildings and places: A survey of stakeholders' perception. *Architecture, Structures and Construction*, *2*(3), 381–401.

Thanoon, W. A. M., Peng, L. W., Kadir, M. R. A., Jaafar, M. S. and Salit, M. S. (2003) *The Essential characteristics of Industrialised Building System,* translated by Jaafar, M. S., Thanoon, W. A. M., Noorzaei, J., Kadir, M. R. A. and Hassim, S., Kuala Lumpur: CIDB, 283 of 330 pages.

Walsh, C., Collins, J., & Knott, P. (2022). The four types of intuition managers need to know. *Business Horizons*, *65*(5), 697–708.

Wan Mohammad, W. N. S., & Mohd Azmi, N. N. (2023). Building Information Modeling (BIM)-Based Information Management Platform in the Construction Industry. *International Journal of Academic Research in Business and Social Sciences*, *13*(4).

Yu, Y., Yazan, D. M., Junjan, V., & Iacob, M. E. (2022). Circular economy in the construction industry: A review of decision support tools based on Information & Communication Technologies. In *Journal of Cleaner Production* (Vol. 349). Elsevier Ltd.

Zhong, S., Elhegazy, H., & Elzarka, H. (2022). Key factors affecting the decision-making process for buildings projects in Egypt. *Ain Shams Engineering Journal*, *13*(3).

DEBRIS FLOOD DISCHARGE ANALYSIS AS A BASIS FOR SABO DAM PLANNING ON THE LEPRAK RIVER AT SEMERU MOUNTAIN, EAST JAVA

Andrea Sumarah Asih[1*], Wahyu Kurniawan[1] and Jati Iswardoyo[2]
[1]Civil Engineering Study Program, Faculty of Civil Engineering and Planning, Institut Teknologi Nasional Yogyakarta, Sleman, Yogyakarta
[2]Sabo Technical Center, Director General of Natural Resources, Ministry of Public Works and Public Housing, Yogyakarta

**Corresponding Email: andrea.sa@itny.ac.id*

Abstract
The Leprak River, disgorging on Semeru Volcano, is greatly potentially affected by Semeru Volcano activity, such as lava flows, hot clouds, and cold lava floods (debris flows) during the rainy season. Debris flows have considerable destructive power to human life, construction infrastructure and the preservation of the surrounding environment. Mitigation and management of debris flood disaster are structurally applied including building a sabo dam to control the cold lava floods. Sabo dam planning requires data input in the form of planned flood discharge, debris flood discharge based on sediment concentration and stability analysis of the sabo dam structure. This study intends to analyse the sediment concentration and debris flood discharge using Standar Nasional Indonesia (SNI) 2851 in 2021. Based on the analysis results, the sediment concentration is 0.31, while the debris flood discharge is 262.041 m^3/s. Furthermore, magnitude of the debris flood discharge and sediment concentration can be used as a reference in planning the design of the sabo dam structure.

Keywords: *Debris flow; Cold lava flood; Sediment; Volcano; Mitigation*

INTRODUCTION

Mount Semeru, which is located between Lumajang and Malang Regencies East Java Province, is one of the active volcanoes in Indonesia. The research location can be seen in Figure 1 below. In a major eruption, it emits lava flows and hot clouds that threaten high elevations on the slopes of the mountain (Suparman et al., 2011). The volcanic activity of Mount Semeru poses a potential hazard, both directly and indirectly, to the surrounding community. The direct danger is eruptive material ejection, while the indirect danger is cold lava floods (debris floods). This flood occurs due to the mixing of loose eruptive sedimentary material with rainwater on the top of the mountain (upstream area) where the damage caused is large and the flow velocity is high. This debris flood disaster occurs in rivers that disgorge on Mount Semeru, one of which is the Leprak River.

High cold lava flood disasters on the Leprak River once happened in the past. According on Wirayudha (2022), cold lava floods have been recorded since 1909 until the latest news on April 19, 2022. Only a few floods that occurred caused floods with large discharge intensities. The major floods occurred from 28th to 29th August 1909, from 12th to 13th November 1976, 14th May 1981, and December 2021. The cold lava disaster in May 1981 hit 16 villages, damaged 626 hectares of rice fields, and killed 252 people. Meanwhile, the disaster in December 2021 caused the Gladak Perak Bridge to be cut off and caused 9,417 victims to be evacuated to 402 shelters.

Disaster management should, therefore, be implemented to minimize the impact. Effective techniques for dealing with sediment and debris flow disasters structurally include applying the technology of sabo dam construction or check dam (Rahayu et al., 2017). The sabo dam planning process consists of several stages, such as analysing the planned flood discharge, determining the location of the sabo dam, analysing debris flood discharge based on sediment concentration and analysing the stability of the sabo dam structure. This study aims to analyse sediment concentration and debris flood discharge using SNI 2851 in 2021. This research is a follow-up to the planned flood discharge analysis research by Kurniawan (2022).

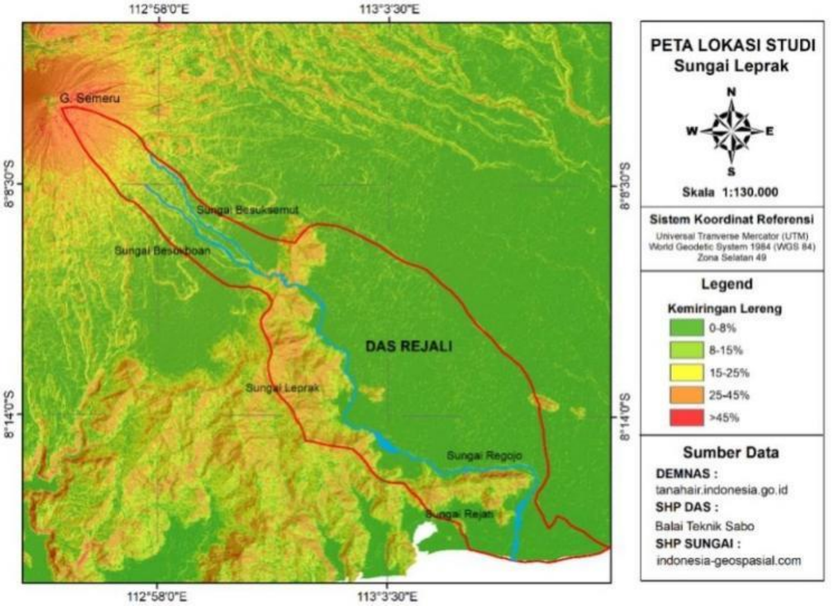


Figure 1. Research Location Map

METHODOLOGY

Determining Sabo Dam Location

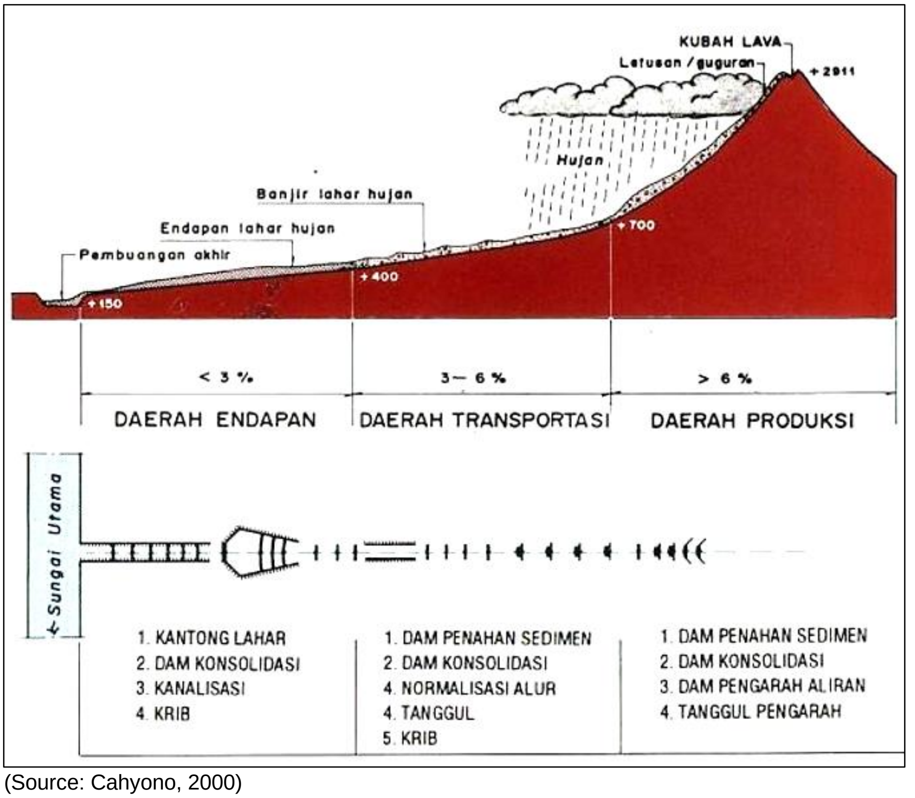
Sabo dam is a transverse water structure in the river that serves to control sediment carried during debris floods. Sabo dam structures must be properly planned in order that they can control debris flows effectively. In the sabo dam planning, the location must be considered according to technical and socio-economic aspects and the dimensions of the sabo dam are safe from the working forces. According to Aritonang (2021) site selection is chosen based on the best location from several potential locations on topographic maps as well as field surveys, so that later it can be accounted for from a technical and socio-economic perspective. SNI 2851 (2021) explains that the layout of the sabo dam must comply with provisions. For example, the location of the sabo dam must pay attention to the main function of the building that has been determined in the sabo plan. The location of the sabo dam is determined in an area with a large capacity where the inundation area does not endanger settlements and agricultural land and other infrastructure. The location of the sabo dam in the sabo plan of a watershed must be integrated with each other and protect against possible dangers of river degradation.

Sediment Control

Sediment is a solid material in the form of sand and rock with certain gradations or clay which undergoes a process of being transported by water from one place to another. The transport of sedimentary material in volcanic areas is known as debris flow. This debris flow is generally caused by rainfall even though it is of low intensity but of long duration or rainfall with high intensity but of short duration. This flow occurs in torrents and has a mass density ranging from 1200-1300 kg/ m^3 (BPSDM, 2018).

Turnbull et al. (2015) and Takahashi (2007) stated that debris flow is influenced by natural conditions, such as slope, rock/soil type, geological structural conditions, slope hydrology, and land use. According to Hardiyatmo (2012) debris flows can move with flow velocities ranging from low to very high, so that the carried material can be eroded during movement down the slope.

Cahyono (2000) and BPSDM (2018) stated that based on the location of the sediment/debris flow and the impact caused by the movement phenomenon, the flow movement area is divided into three areas, namely the sediment production area, the sediment transport area and the sediment deposition area. The form of debris flow control can be pursued in two ways, namely structural debris flow control and non-structural debris flow control. Structurally controlling debris flows is by building sabo buildings whose location and types are adjusted to the purpose of the building. The type of building and its location schematically can be seen in the following figure.



(Source: Cahyono, 2000)

Figure 2. Types of Sabo Structures by Zone

Sediment Concentration

SNI 2851 (2021) explains that sediment concentration is determined based on the sediment flow types and sediment transport zone. Debris flow occurs when the river bed slope is greater than or equal to the critical bed slope (tan θ ≥ tan θd). Cd value, 0.9C* > Cd > 0.3. Sediment concentration is determined using the Takahashi Formula (2007).

$$Cd = \frac{\rho.\tan\theta}{(\sigma-\rho).(\tan\phi - \tan\theta)} \tag{1}$$

where:

Cd : debris flow sediment concentration
θ : riverbed slope (°)
Φ : shear angle in sedimentary material

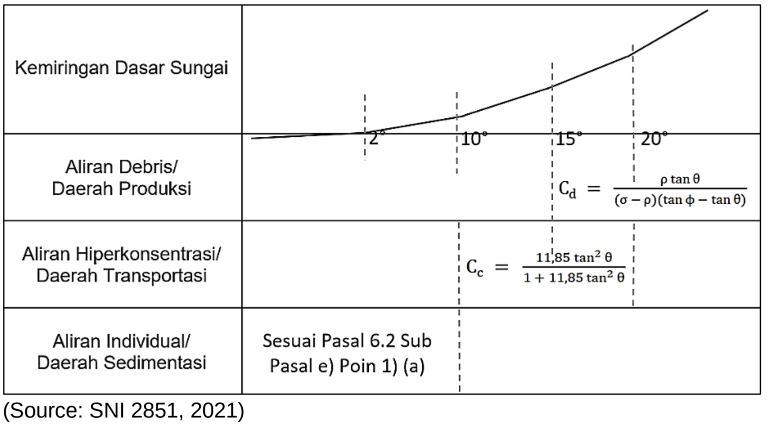
$$\tan\theta_d = \frac{C^*(\sigma-\rho)}{C^*(\sigma-\rho)+\rho\left(1+\frac{1}{k}\right)}\tan\phi \tag{2}$$

$$\tan\theta_h = \frac{C^*(\sigma-\rho)}{C^*(\sigma-\rho)+\rho\left(1+\frac{h_0}{d_{50}}\right)}\tan\phi \tag{3}$$

where:

$\tan\theta_d$: critical riverbed slope for debris flow
$\tan\theta_h$: critical riverbed slope for hyper concentrated flow
C* : sediment concentration in the riverbed before moving (0.6)
σ : specific gravity of sediment (kN/m^3)
ρ : specific gravity of water (kN/m^3)
ϕ : shear angle in bottom grain (°)
k : empirical coefficient in planning (0.85 to 1)
h_0 : flow depth
d_{50} : retained cumulative bottom grain diameter 50 %.

Determination of sediment concentration based on sediment transport zoning according to the following figure.



(Source: SNI 2851, 2021)

Figure 3. Sediment Transport Zoning

Design Discharge and Peak Flow Debris Discharge

Pratiwi (2016), stated that the potential for sediment due to volcanic eruptions is generally calculated based on the amount of deposited material on the slopes of the mountain or in the river bed after the eruption. The ability of water to transport sediment from the amount of discharge can be calculated based on the flood discharge obtained from the analysis of rainfall multiplied by the concentration of sediment in the stream. Thus, the amount of flood discharge with sediment can be calculated later (design discharge).

According to SNI 2851 (2021) for areas with debris flood characteristics, the peak discharge of the debris flow, the height of the debris flow, and the average speed of the debris flow are determined based on the following formula:

$$Q_{sp} = \frac{C_*}{C_* - C_d} Q_p \tag{4}$$

where:

Q_{sp} : debris flow peak discharge (m^3/s)
C_* : sediment concentration (0.6)
C_d : debris flow sediment concentration (0.9 C_*)
Q_p : design flood discharge (m^3/s)

The width of the debris flow (B_d) is determined as 80% of the width of the river (B) and the height of the debris flow is determined using the following formula:

$$h_d = \frac{Q_{sp}}{B_d\ v_{df}} \tag{5}$$

where:

h_d : debris flow depth (m)
Q_{sp} : debris flow peak discharge (m^3/s)
B_d : debris flow width (m)
V_{df} : debris flow average velocity (m/s)

The average velocity of debris flow (V_{df}) is calculated using the following formula (SNI 2851, 2021):

$$V_{df} = \frac{1}{n} R^{2/3} (\sin\theta)^{1/2} \tag{6}$$

$$R = \frac{h_d\ B_d}{2h_d + B_d} \tag{7}$$

where :

R : debris flow radius (m)
θ : riverbed slope (^{o})
h_d : debris flow depth (m)
B_d : debris flow width (m)

$$Q_{sp} = \frac{C_*}{C_* - C_d} Q_p \tag{4}$$

where:

Q_{sp} : debris flow peak discharge (m^3/s)
C_* : sediment concentration (0.6)
C_d : debris flow sediment concentration (0.9 C_*)
Q_p : design flood discharge (m^3/s)

The width of the debris flow (B_d) is determined as 80% of the width of the river (B) and the height of the debris flow is determined using the following formula:

$$h_d = \frac{Q_{sp}}{B_d\, v_{df}} \tag{5}$$

where:

h_d : debris flow depth (m)
Q_{sp} : debris flow peak discharge (m^3/s)
B_d : debris flow width (m)
V_{df} : debris flow average velocity (m/s)

The average velocity of debris flow (V_{df}) is calculated using the following formula (SNI 2851, 2021):

$$V_{df} = \frac{1}{n} R^{2/3} (\sin\theta)^{1/2} \tag{6}$$

$$R = \frac{h_d\, B_d}{2h_d + B_d} \tag{7}$$

where:

R : debris flow radius (m)
θ : riverbed slope (°)
h_d : debris flow depth (m)
B_d : debris flow width (m)

The research was conducted by collecting secondary data consisting of rainfall data, topographical maps, river geometry, sediment concentrations and land cover. These data were obtained from the Lumajang Water Resources Management Technical Implementation Unit (UPT PSDA), East Java and the Sabo Engineering Center, Directorate General of Water Resources, Ministry of Public and Public Housing.

RESULT AND DISCUSSION

Sabo Dam Site Selection

The sabo dam location was selected based on topographic map visualization with the help of Google Earth Pro satellite imagery to determine the condition of the morphology of the Leprak River. Based on satellite imagery, the sabo dam design, named Sabo Dam LE-CD 01, is planned to be located between two damaged sabo dams so that the morphology of the river bed is maintained. The LE-CD 01 Sabo Dam Planning location can be seen in Figure 4 below. The results of the satellite imagery show that the planned location of the sabo dam has a widened upstream area and a narrower sabo area with the width of the river. This makes the sabo dam has a large capacity to control sediment material.

Figure 4. LE-CD 01 Sabo Dam Planning Location

After the sabo dam was located, a cross section was made at the location of the planned sabo dam to determine the condition of the cross section of the river using Google Earth Pro software to obtain a cross section of 16 crosses with an interval of 20 m. Based on the results of the cross section, it is estimated that the location of the sabo dam was between cross sections 5 to 9. To ensure the exact location of the sabo dam, a more detailed cross section is made at an interval of 5 m at CS 5 to 9 locations. From the results, 17 crosses were obtained and the location that has the shortest river width and the largest sabo dam capacity was chosen. Thus, the most appropriate location of the sabo dam is in the cross section 7.2 as in the following image.

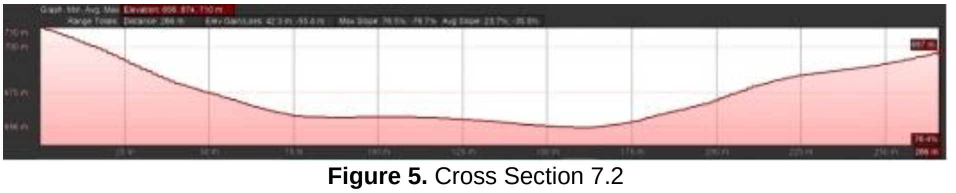


Figure 5. Cross Section 7.2

From Google Earth Pro readings, the location of Sabo Dam LE-CD 01 is determined to be in Supiturang Village, Pronojiwo District, Lumajang Regency with coordinates 113°0'32.9"E, 8°10'39.6"S. Meanwhile, the slope of the river bed (θ) from the analysis results at that location is 13^0. The location of the sabo dam with this slope has met the slope requirements for the construction of a sabo dam.

In order to get a clearer picture of the location of the sabo dam with a river bed slope of13^0, a map of the distribution of sediment transport zones was made based on the slope of the Leprak River bed using Google Earth Pro. Sediment transport production zones in the figure are represented in red, transport zones are represented in yellow, and sedimentation areas are represented in green.

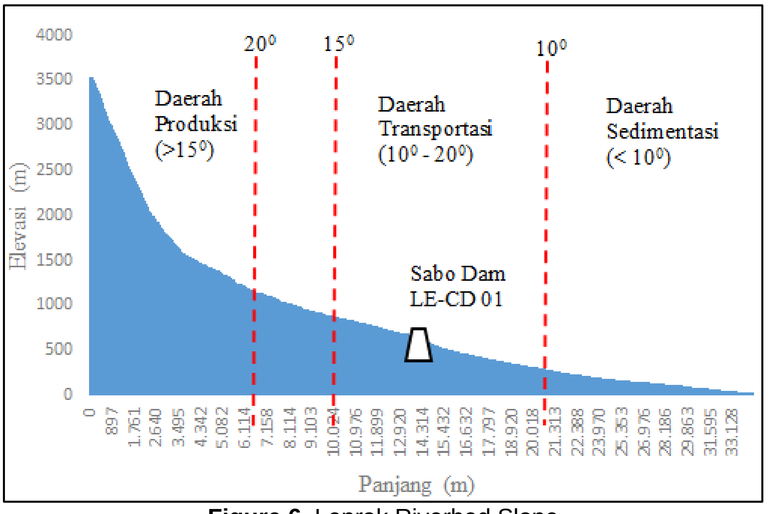


Figure 6. Leprak Riverbed Slope

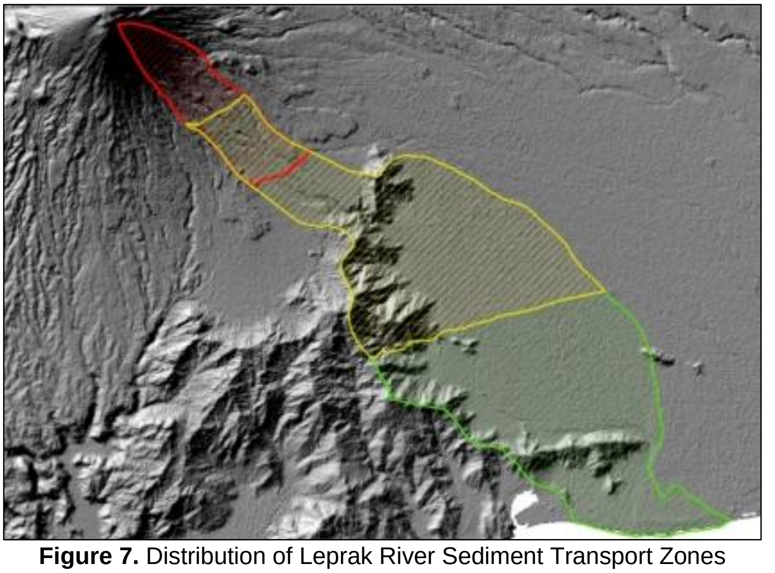


Figure 7. Distribution of Leprak River Sediment Transport Zones

Sediment Effect Analysis

The sediment effect was analysed to obtain the design flood discharge (planned flood discharge with sediment) and the peak debris flow discharge. The planned flood discharge with a return period of 100 years was obtained from previous research (Kurniawan, 2022) which is 200.03 m^3/s. According to SNI 2851 (2021), sabo dam planning in active volcanic areas uses a planned flood discharge with a return period of 100 years (Q_{100}). The flood discharge was obtained from an analysis of the frequency of maximum daily rainfall data in the Rejali watershed on the Leprak River. The rain data used comes from two rain stations, namely Supiturang Station and Koboan Rainfall Station with a data length of 12 years from 2010 to 2021.The methods used in determining the planned flood discharge were the Nakayasu Synthetic Unit Hydrograph method and the hourly Mononobe rain distribution.

Sediment Concentration

Before calculating the debris flood discharge, it is necessary to ascertain the type of flow at the sabo dam planning location and determine the amount of sediment concentration. Determination of the type of flow at the sabo dam planning site was based on the guideline of SNI 2851 of 2021. The guideline explains that debris flow occurs when the slope of the river bed is greater than or equal to the critical base slope for debris flow ($\tan \theta \geq \tan \theta d$).

Based on the slope of the riverbed, $\theta = 13^o$ from the results of the Google Earth Pro analysis above, then the shear angle in the sediment, $\emptyset = 37.1^o$, the mixed mass density, $\rho = 1$ t/m^3, and the sediment mass density, $\sigma = 2{,}538$ t/m^3 taken from previous research on Mount Semeru by Pratiwi (2016). Furthermore, the volumetric sediment concentration value, $C^*= 0.6$ and the empirical coefficient in planning, $k = 0.85$ is determined based on SNI 2851 (2021). Thus, it can be calculated that $\tan \theta = \tan 13^o = 0.231$, while $\tan \theta_d = 0.225$. To sum up, the flow in the planning location of the Leprak River includes the debris one ($0.231 \geq 0.225$).

The results of calculating the amount of sediment concentration, design discharge and peak discharge of the debris flow using the formulas 1 to 7 above (SNI 2851, 2021) are then summarized in the following table.

Table 1. Results of Analysis of Sediment Concentration and Debris Flood Discharge

Calculation Items	Calculation Results
Riverbed slope, tan θ	0.231
Critical basic slope, tan θd	0.225
Sediment concentration, Cd	0.31
Design discharge, Qd	262.041 m^3/s
Debris flow peak discharge, Qsp	413.86 m^3/s
Debris flow width	88 m
Debris flow height, hd	1 m
Debris flow average velocity, Vdf	4.672 m/det

CONCLUSION

1. The planning of Sabo Dam LE-CD 01 on the Leprak River is one of the ways to control debris floods in the future considering the high potential for debris flood events as recorded in previous events.
2. The LE-CD 01 sabo dam is planned to be located on a river bed slope (θ) of 13^0 with coordinates 113°0'32.9"E, 8°10'39.6"S precisely in Supiturang Village, Pronojiwo District, Lumajang Regency, East Java Province.
3. Based on on SNI 2851 in 2021, the sediment concentration is 0.31, while the debris flood discharge is 262.041 m^3/s.

REFERENCES

Aritonang, TD. (2021). *Analisis Stabilitas dan Pengendalian Sedimen Sabo Dam WO-C3 (Oprit Kendalsari) Kali Woro, Desa Kendalsari, Kecamatan Kemalang, Kabupaten Klaten, Propinsi Jawa Tengah.* Skripsi. Fakultas Teknik Sipil dan Perencanaan ITNY, Yogyakarta.

BPSDM. (2018). Konsep Bangunan Sabo. Kementerian PUPR. Bandung.

Cahyono, J. (2000). Pengantar Teknologi Sabo. Yayasan Sabo Indonesia. Yogyakarta.

Hardiyatmo, H.C. (2012). Penanganan Tanah Longsor & Erosi. Gadjah Mada University Press. Yogyakarta.

Kurniawan W., Asih AS., Iswardoyo, J. (2022). *Perencanaan Sabo Dam Le-Cd 01 Tipe Terbuka Di Sungai Leprak Wilayah Gunungapi Semeru, Jawa Timur*. Skripsi. Fakultas Teknik Sipil dan Perencanaan ITNY, Yogyakarta.

Pratiwi, RDS. (2016). *Perencanaan Sabo Dam Tipe Terbuka (Tipe Lubang) sebagai Bangunan Pengendali Sedimen Gunung Semeru di Sungai Mujur Kabupaten Lumajang*. Skripsi. Fakultas Teknik Sipil Dan Perencanaan ITS, Surabaya.

Rahayu N., Dermawan V., Sisinggih D. (2017). Analisa Potensi Sedimen Debris Di DAS Konto Pasca Erupsi Gunung Kelud 2014. *Jurnal Teknik Pengairan*, Volume 8, Nomor 2, Nopember 2017, hlm 231 -240.

SNI 2851-2021. (2021). Desain Sabodam. Badan Standardisasi Nasional. Jakarta.

Suparman, dkk. 2011. SABO Untuk Penanggulangan Bencana Akibat Aliran Sedimen. Edisi ke-3, Yayasan Air Adhi Eka. Jakarta.

Takahashi, T. (2007). Debris flow Mechanics, Prediction and Countermeasures. Taylor & Francis.

Turnbull, B., Bowman, E. T. & McElwaine, J. N. (2015). Debris flows: Experiments and modelling. Comptes Rendus Physique 16(1): 86.

Wirayudha, R. (2022). *Amuk Semeru di Masa Lalu*. URL: https://historia.id/sains/articles/amuk-semeru-di-masa-lalu-6jknw/page/1. Accessed on 15 April 2022.

Wong, A. H. H. (1993) *Susceptibility to Soft Rot Decay in Copper-Chrome-Arsenic Treated and Untreated Malaysian Hardwoods*. Ph.D. Thesis, University of Oxford. 341 pp.

FACTORS AFFECTING THE EFFICIENCY OF FACILITIES MANAGEMENT (FM) IN AGED CONDOMINIUM: A CASE STUDY OF KUALA LUMPUR

Farhan Md Dahlan[1*], Ashrof Zainuddin[1], Mohd Hasrol Haffiz Aliasak[1], Siti Rosemawar Mohd Sahi[2] and Norbaizura Abdul Wahab[1]
[1]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610 Seri Iskandar, Perak, Malaysia
[2]Institut Penilaian Negara (INSPEN), Jabatan Penilaian dan Perkhidmatan Harta, Kementerian Kewangan Malaysia, Persiaran INSPEN, 43000 Kajang, Selangor, Malaysia

**Corresponding Email: farha221@uitm.edu.my*

Abstract
Poor management practises by condominium management bodies have resulted in disputes between residents and management bodies. The purpose of this research is to determine and identify the factors contributing to the efficiency of facilities management (FM) in aged condominiums. Using the method used by Sajan (2015), a quantitative approach was used to try to get real data. The factors were initially identified through a literature review. Then, 348 questionnaires were sent to respondents, including facility managers, committee members, and residents. 52 percent of the questionnaires were filled out, creating a database that can be used for descriptive and ranking analyses. The research concluded that three of the most critical factors affecting the efficiency of FM in aged condominiums were financial, learning and growth, and pre-conditions during the developer's transition period. Measures to improve the inefficiency of FM in aged condominiums were obtained, such as improvement of the management of financial accounts, enforcement and ensuring the payment is done timely, an intervention of the government to ensure that the developer is responsible for the management and governance decisions, as well as leadership and motivation among the facilities managers, staff, and residents.

Keywords: *Facilities management; Condominium; Efficiency*

INTRODUCTION

Facilities management (FM) is an organisational support function. It is the integration of processes within an organisation to maintain and develop services to enhance the effectiveness of its primary activities. FM ensures that each component of a building functions optimally and meets the changing needs of its users.

FM affects neighbourhood conditions. Neighbourhood conditions constitute one of the most expected qualities of life indicators, such as rights for safety, harmony, good conditions of facilities and physical buildings, and conducive neighbourhoods. From 2002 to 2011, the United Kingdom government initiated the Housing Market Renewal Initiative (HMRI) Pathfinder programme, which is a scheme of demolition, refurbishment, and new building aimed at renewing failing housing markets in particular states across the nation (Kasim, 2011). This case study gives insight into the fact that there is a need and opportunity for FM to realign its business operations with the public interest as the initial strategy for tackling the social and economic deprivations of the identified neighbourhoods across the nation.

In other citations, Article 25 of the Universal Declaration of Human Rights (United Nations Human Rights, 2008) stipulates that anyone has the right to an acceptable standard of living. In addition, the Malaysian National Housing Policy (2018–2025) emphasises the maintenance of existing housing in order to develop cohesive and high-quality neighbourhoods. These two references suggest the need to assess the factors affecting the efficiency of facility management in aged condominiums.

Relative to individual landed housing, residents, particularly the homeowners of condominiums, will have less independence from their neighbours (Guilding et al., 2014). This is because they are part of the same management body that manages the condominium. This impacts the residents due to factors such as house rules or by-law creation, repair and maintenance operations, and the setting of service charges and contributions to the sinking fund. Condominiums feature essential facilities such as a playground for children and building services such as an elevator, electricity supply, and water supply (Tiun, 2006). Additionally included are vertical transportation systems, landscaping and gardening, swimming pools, sports and recreational facilities, social facilities, sheltered parking areas, and high-security accessibility (Au-Yong, Jin, Chua et al., 2019). The more facilities that are provided, the more complex the management becomes.

The management and maintenance of these common properties, services, facilities, and physical buildings are crucial to ensuring their operability and functionality. Eventually, demanding integration of FM discipline and local communities towards the effectiveness of FM organisations aiming for an acceptable standard of living. It is essential to manage common properties, services, facilities, and physical buildings in a systematic and effective way, as it will affect the economic value of the condominiums (Rahmawati, Utomo, Suhailah et al., 2020). As stressed by Abidoye and Chan (2016), property state of repair, availability of neighbourhood security, and neighbourhood characteristics, as well as property age, are most influential on the economic value of condominiums.

Such complexities are more apparent in regions where residents' demographic profiles are diverse. Such a circumstance requires systematic and organised management. Several prior studies have determined that aged condominiums pose a greater risk than modern high-rises. If a structure collapses, ignorance can have disastrous results. Such occurrences render it impossible to extend the lifecycle of a building and hasten its demise (Vergara, Gruis, & van der Flier, 2019). In turn, these will have an effect on real estate revenue (Hui et al., 2013).

The management and maintenance of FM in the residential setting should be seriously attended to following Malaysia's agreement in the Declaration of Habitat Agenda and Agenda 21, which was agreed in Rio de Janeiro in 1992 on sustainable development (Federal Department of Town and Country Planning, 2016). The sustainability aspect should be prioritised by the Malaysian government until the matter becomes a core essence of the Tenth Malaysian Plan (2011–2015). The matters were also recently clarified in the essence of the Malaysian National Housing Policy (2018–2025).

Recent evidence claims that the FM of common properties, services, facilities, and physical buildings has a significant effect on the quality of the residents' buildings. According to Jonsson (2020), the FM strategies applied by housing cooperatives (known as management bodies in Malaysia) would have a significant effect on the residents' perception of the building's quality. Formecitation by Sia, Chin Yew, Lim, et al. (2017) argued that the quality of facilities and services provided by management was also found to determine the extent of residents' satisfaction with the building. Hence, the pieces of evidence indicate that residents need to "feel in control of their environment", thus emphasising the existence of a relationship between human beings and their places of residence, as cited by previous scholars (Dupuis & Thorns, 1998).

Such indicates the relevance between the demands of FM disciplines and local community in providing common properties, services, facilities and physical building at optimum functionality and meet the residents' need in changing conditions. Thus, there is a need to achieve an acceptable standard of living and develop a cohesive and good quality neighbourhood in aged condominium. Further, enhance the life span of the building, ensure the common properties, services, facilities and physical building fit for its purpose, maintain the economic value of the properties and enhance the residents' safety and comfort.

Annually, building maintenance costs typically increase by 0.5% (Lee et al., 2016). Ivor (1987) predicted that the cost of maintaining the building would increase dramatically over the next twenty years, before levelling off dependent on the longevity of the structure. However, postponing maintenance work and neglecting to perform it regularly would cause the cost of repairing a building facility to exceed its actual cost.

Likewise, due to the natural deterioration of the building itself, the relationship between building age and building performance may theoretically be linked to a lack of financial resources to maintain or repair aged buildings (Yau et al., 2008). When the age of a building increases, some major maintenance activities, such as painting work, the replacement of new roof tiles, mechanical and electrical elements, and other works, are required to extend the life of the building. This indicates that the financial resources for maintenance activities are likely to increase as the building ages. Financial resources in condominiums are limited as they come from service charges and sinking fund payments by homeowners. However, the quality of services provided by the management affects the payment behaviour of the residents (Rasip, 2017), which in turn leads to insufficient funds.

In order to ensure the efficiency of FM for aged condominiums is improved, it is important to determine the factors affecting them. By identifying the factors, it provides more information regarding the efficiency of FM in aged condominiums. Then, the result could assist the management bodies in reducing the dispute among the residents and management bodies. Therefore, the main objective of this research was to identify the critical factors affecting the efficiency of FM in aged condominiums that have been described by other researchers.

FACTORS AFFECTING THE EFFICIENCY OF FACILITIES MANAGEMENT IN AGED CONDOMINIUM

This section provides the factors affecting the efficiency of FM organisations managing aged condominiums. In this research, the identification of factors focuses on internal and external factors (Vieira et al., 2019) of FM organisations, with a focus on human-related factors because, according to Aziz et al. (2016) and Muhamad Ariff (2018), the role of stakeholders is a key determinant of management effectiveness in high-rise-type housing. In condominium living, the effectiveness of property and facility maintenance is important in both economic and socio-political aspects (Tiun, 2006). Improving an organisation's performance requires identifying and measuring the impact of management practises (Demirbag et al., 2006; Salaheldin, 2009). Such would facilitate the achievement of the government's aspirations, which include the maintenance of existing housing (Jabatan Perumahan Negara, 2018) under the Malaysian National Housing Policy (2018–2025). This research involves seven (7) factors identified by the literature as the following:

Financial Factor

The services provided by an FM organisation include the management, administration, and maintenance of common properties, services, and physical structures. For the smooth management of these tasks, sufficient financial resources are required. Financial in managing condominiums are used for administration, maintenance spending, exclusive facilities maintenance, and also for major which needs a large amount of money. Residents' payment of service charges and contributions to a sinking fund are the only sources of income for these housing schemes. If the budget is insufficient, then appropriate repairs and maintenance cannot be performed. It led to catastrophic results in the event of building failure (Gifford, 2007), as well as in ageing structures (Vergara et al., 2019). In turn, this impacts the residents' safety and comfort, shortens the building's lifecycle, and causes the common areas, services, and physical structure to malfunction.

Committee Members' Factor

Committee members are unit owners who are elected at the annual general meeting (AGM) by the residents. They include the chairman, secretary, and treasurer, who serve as the pillars of decision making as the top management. In managing condominiums, they are indispensable as the mechanism representing the residents' voice. They are responsible for the upkeep and administration of the common properties, services, facilities, and physical structures. This measure ensures that the aged condominium maintains an acceptable level of quality and functionality.

Pre-Condition During Developer Transition Period

The developer constructs the condominium from the stage of strategic definition to the stage of transfer to subsequent management. According to Blandy, Dixon, and Dupuy (2006), the capacity of a developer to coordinate governance, decision-making, and overall development management has long-term implications. These actions are reflected in the contracts signed, the quality of the building, the design and layout, the service charge forecasting, and the funds raised to maintain common areas (Easthope, Warnkern, Sherry et al., 2014; Sajan, 2015; Waziri, 2016). Upon completion, the developer is responsible for determining, among other things, the service charges settings and service providers. These are indications that the developer's role during the pre-construction phase of a condominium has a direct bearing on the effectiveness of the FM management of aged housing.

Learning and Growth

The learning and growth process calls for the participation of the key stakeholders. The key stakeholders in the management of building maintenance are the maintenance manager and staff, organisations, building users, and maintenance service providers (Au-Yong, Shah

Ali et al., 2017). The same researchers claimed that the involvement of key stakeholders with close communication among them improves the effectiveness of FM. A principal aim of learning and growth is directed at measuring human capital. Ratnasingam (2009) recognised human capital as the skills, knowledge, expertise, business cultural attitudes, and the degree of training given to employees. In the FM industry, human capital is critical for continuous enhancement of the delivered services, which De Toni et al. (2007) argued to be dependent on the service or the outsourcing process. De Toni et al. (2007) reiterated that new services or just little innovations may alter and upgrade the current services and outsourcing processes.

Competence Facilities Manager

A facilities manager is appointed by a management organisation to provide agency services on their behalf. Yong Yung (2015) states that the agent is a trustee appointed by unit proprietors to administer their assets for a third party. In other terms, the agent is maintenance staff involved in the maintenance of the condominium, holding the position of building managers, building executives, facilities manager, or resident's manager, who labour daily for the official housing scheme management body. They are responsible for the creation and implementation of maintenance programmes (Chua et al., 2018). They play a crucial role in FM because they superintend the maintenance process and ensure that related duties are effectively carried out. The facilities manager was a member of the Managing Agent (MA) staff in the current study.

Residents

Typically, the owners of a building are involved in its day-to-day management and daily use. Residents are the primary beneficiaries of effective management and the primary victims of ineffectual management (Gao, 2015). Residents, particularly homeowners, have greater incentives to participate in FM management than other stakeholders (government, management body, individual homeowners, MA if appointed, tenants, and the general public, including pedestrians and visitors). Statutorily, they are required to administer their condominium (Gao, 2015). Their function is essential to effective management practises.

Leadership and Motivation

Motivation and leadership are inextricably linked. Leadership is defined by Oxford University Press as "the state or position of being a manager or the person in charge" (Oxford University Press, 2021). In the meantime, motivation is defined as what employees do, how they do it, and their level of effort. Graves and Sarkis (2018) reference Meyer et al. According to Graves and Sarkis (2018), employees who perceived their managers to be more engaged in environmental transformational leadership reported greater motivation, positive emotions, additional resources, and collaboration. Environmental values were also associated with both internal and external employee motivation. Moreover, the relationship between leadership and motivation was moderated by employees' values; leadership perceptions were most positively associated with internal motivation among employees with strong environmental values. Consequently, environmental transformational leadership may be most effective at boosting the internal motivation of employees who value the environment.

RESEARCH METHODOLOGY

This research was conducted using a quantitative approach, based on the work undertaken by Sajan (2015), to which a face-to-face survey was recognized as the most suitable method if the accessibility to reach the respondents is a significant challenge due to the privacy and security of residents. Purposive sampling was adopted to determine potential and relevant respondents who have been or are currently involved in FM in the aged condominium within Kuala Lumpur, Malaysia. Furthermore, the respondents were required to answer questions based on their experience or involvement in FM for aged condominiums. In this research, a total of 348 questionnaires were distributed to the committee members as the owners' front-line representative, facilities manager with the position of building managers, building executives, facilities manager, strata manager or resident's manager which work in daily basis of official management body; and residents used to be members of the committee members.

Aged housing schemes were chosen in accordance with Section 85A of the Building, Road, and Drainage Act 1974 (Act 133) for buildings that are 5 storeys and above. The Act stipulates that after the 10th year from the first date of Certificate of Completion and Compliance (CCC) or Certificate of Fitness for Occupation (CFO). It is mandatory for the building owner to conduct regular inspections of their building. These criteria of selection are more significant to the research as maintenance activities in condominium are found to be at their greatest cost impact within more than ten (10) years post-construction (Kim et al., 2019). These buildings have shown obvious signs of obsolescence. Out of 181 responses, 152 were found to be useful and valid for the analysis. The remaining questionnaires were incomplete or invalid for some reason. Hence, a response rate of 52 per cent was achieved.

Data Analysis and Discussion

This research involved 152 respondents, of which each aged condominium is represented by three (3) groups of respondents; committee members, residents who used to be committee members, and facilities manager. The findings of the descriptive analysis for the category of respondents are shown in Table 1. The majority of the respondents are supervisors (47.37 percent), followed by residents (38.81 percent). Committee members constituted the lowest category of respondents (13.82 percent). This is not surprising given that they work on a voluntary basis and in a part-time mode. They are also considered busy individuals with their full-time job, hence the difficulty in reaching them. Body Text: Times New Roman, 11 pt. All paragraphs must be differentiated by 0.64 cm tab.

Table 1. Category of Respondents (n=152)

Respondents' Characteristic	Subprofile	Frequency	Percentage
Category of Respondents	Committee members	21	13.82%
	Residents	59	38.81%
	Facilities Manager	72	47.37%
Total		152	100.00%

The committee members' and facilities managers' length of holding their current position was needed to identify their experience and maturity in matters relating to the management of FM in aged condominium. Based on the number of respondents, the results indicate that most of the committee members and facilities managers have less than five (5) years of experience in their current position (46.23 per cent). Among them, thirty-four (34) are facilities managers who have less than five (5) years in their current position, while nine (9) of them are committee members. The residents were not considered in this query.

About 23.66 per cent are 5 to 10 years in their current position, followed by those who are eleven (11) to fifteen (15) years in their current position (11.83 per cent). About 6.45 per cent of the respondents have held their current position for more than 16 years. They consist of five (5) facilities managers and only one (1) committee member (Table 2). Whereas the missing value is 11.83 percent. This finding indicates that the lack of experience among the committee members and facilities managers, who are the key stakeholders in managing condominiums, as most of them have less than 5 years of experience. Such a state implies that they have less knowledge and experience in managing aged condominiums.

Table 2. Length of Holding Current Position

Respondents' Characteristic	Subprofile	Frequency (*n*)			Percentage
		Committee Members	Supervisor	Total	
Length of Holding Current Position among Committee members and Supervisor (*n*= 93)	Less than 5 years	9	34	43	46.23%
	5 to 10 years	2	20	22	23.66%
	11 to 15 years	2	9	11	11.83%
	More than 16 years	1	5	6	6.45%
	Missing value	7	4	11	11.83%
	Total	21	72	93	100.00%

Ranking analysis was used by ranking the key variables shown in Table 3. The mean score (with 1 – not very critical to 5 – very critical) was used to rank the factors affecting the efficiency of FM in aged condominiums. The main purpose of ranking analysis is to indicate the differences in the level of critical on FM efficiency among the variables.

Table 3. Ranking Analysis Based on Type of Respondent

Factors	Overall (n=152)		
	Mean	Std. Deviation	Rank
Financial	4.20	0.84	1
Residents	4.13	0.81	2
Pre-condition during Developer Transition Period	4.12	0.93	3
Leadership & Motivation	4.02	0.91	4
Committee Members	3.97	0.89	5
Competence Facilities Managers	3.89	0.97	6
Learning & Growth	3.83	0.95	7

In Table 3, the financial factor (μ = 4.20) was rated the highest rank as the most critical factors affecting the efficiency of FM in aged condominiums. This means that the financial factor was identified as crucial for controlling the quality and functionality of properties and assets. The result of analysis is proven that budget shortage was found to possibly lead improper repair and maintenance. It is believed that an organization's budget shortage impeding repair and maintenance activities (Chong, Mohammed, Abdullah et al., 2019). This factor may have catastrophic consequences in the event of building failure (Gifford, 2007), not to mention in ageing structures (Vergara et al., 2019). The safety and convenience of the residents are compromised, the building's lifespan is truncated, and the common areas, services, facilities, and physical structure may become inoperable. The service charges are imposed by the developer according to facilities provided, hence timely payment will avoid arrears and may affect the FM in the condominiums as the financial resources come from the residents.

Residents' factor (μ = 4.13) was ranked second for factors affecting the efficiency of FM in aged condominiums. Residents typically utilise a building on a daily basis and participate in its day-to-day management. They are required by law to manage their condominiums. The residents must share the responsibilities in order to live in peace and harmony. Collective actions are necessary among them (Ho et al., 2006; Gao, 2015; Gao & Chen, 2016) in order to attain the same benefits and an acceptable standard of living. Hence, every resident is bound by the laws and regulations enshrined in Section 32 Act 757 and the Third Schedule, Strata Management Regulations 2015, By-Laws. The residents also need to consider building maintenance as stipulated in Act 757; it is essential for the residents to make payment of the service charges and sinking funds. Therefore, it is determined that residents' role is the key to good management practices.

Easthope and Randolph (2016) reported that the developer's action during the initial establishment of the scheme can have a significant impact on effective governance throughout the life of the building. The statement is verified by this finding, whereby the pre-condition during developer transition period (μ = 4.12) are one of the highest ranked factors (third) affecting the efficiency of FM in aged condominiums. This finding confirms Sajan's (2015) assertion that poor design, inadequate building regulation, and potential certification inconsistencies are the primary prospective causes of high operational maintenance costs. Easthope et al. (2014) argued that developers are accountable for selecting their design and construction professional team from the stage of strategic definition to the point of vacant possession. As a result, identifying operation and maintenance concerns during the strategic definition phase is crucial, as the measure will impact a building's sustainability.

Leadership and motivation (μ = 4.02) were the fourth-ranked factor that affecting the efficiency of FM in aged condominiums. It is believed that leadership qualities are essential in facilities managers to enable them to assist the committee members in the delivery of FM operational activities. According to Lee et al. (2016) housing management ascertained that the higher the leadership of the office managers (known as facilities managers), the higher the residents' satisfaction. Residents' satisfaction reflects the quality of facilities and maintenance services appearing in the physical conditions of the building (Sia et al., 2017). In addition, FM work tasks largely require continuous and recurrent maintenance activities. Facilities managers may lose interest and motivation to work. This is proven by this research as most of the facilities managers involved were less than five years working experience in the current condominiums. The differences of residents' backgrounds in terms of socio-economic status, culture, types of residents, attitude or action towards the property, and interests in occupying the strata housing schemes, are bound to cause disagreements and disputes among the staff and residents (Yau, 2018). Therefore, Ling and Wong (2016) suggested promoting a sense of responsibility and renewed interest among staff will result in greater internal work motivation.

It is determined that committee members (μ = 3.97) were ranked the fifth-ranked. This finding is consistent with Tyagi et al.'s (2015) assertion that top management is accountable for all activities within an organisation, particularly the formulation of a vision for the successful implementation of mandated and proposed changes. In the context of this study, "top management" refers to the committee members elected by unit owners to represent them in the management and governing of their condominiums. Their primary responsibility is to make decisions within the framework established by the management of the housing scheme in order to achieve the goals set by the management (Johnston and Too, 2015). The remaining factors competence facilities manager ($\mu = 3.89$) and learning and growth ($\mu = 3.83$) can also conclude as critical because they fall within the range of critical scale. However, learning and growth were perceived as the least critical.

Based on the ranking analysis results, the authors found that the first-ranked factor that affecting the FM in aged condominium is financial factors. However, three of the highest-ranked factors were residents, pre-condition during developer transition period and leadership and motivation. As a result, the important factors to be considered in aged condominiums are financial factor, residents, pre-condition during developer transition period, and leadership and motivation.

CONCLUSION

The literature review identified seven factors affecting the efficiency of FM in aged condominiums. After the analysis of data, it was found that four of the most critical factor affecting the efficiency of FM in aged condominiums were financial factor, residents, pre-condition during developer transition period and leadership and motivation. In summary, various measures to improve the efficiency of the FM in aged condominiums were outline as follows:

1. Improvement of the management of financial accounts, service charges amount, adequacy of finance to manage the overall expenditure as well as the collection from the residents.
2. The enforcement and ensuring the payment done timely to avoid arrears in addition of collective action among the heterogenous residents and staffs.
3. An intervention of government to ensure that the developer is responsible for the management and governance decisions as early as in the strategic definition stage. The decisions might relate to establishing management contracts, initial development budgets, by-laws, the establishment of service utility and facility contracts etc., to facilitate long-term housing scheme development functionality and viability.
4. Leadership and motivation among the facilities managers, staff, and the residents.

ACKNOWLEDGEMENT

The authors would like to express their gratitude towards Universiti Teknologi MARA, Perak Branch, Seri Iskandar Campus for the support in the form of a grant [900-KPK/PJI/GKIPP/01(0013/2018)] which made this research possible.

REFERENCES

Abidoye, R. B., & Chan, A. P. C. (2016) Critical Determinants of Residential Property Value: Professionals' Perspective. *Journal of Facilities Management*, 14(3):283–300. https://doi.org/10.1108/JFM-02-2016-0003.

Au-Yong, C. P., Jin, S., Chua, L., Ali, A. S., Tucker, M. (2019) Optimising Maintenance Cost By Prioritising Maintenance of Facilities Services In Residential Buildings. *Engineering, Construction and Architectural Management*, 26(8):1593–1607. https://doi.org/10.1108/ECAM-07-2018-0265.

Au-Yong, C. P., Shah Ali, A., Ahmad, F., & Chua, S. J. L. (2017) Influences Of Key Stakeholders' Involvement In Maintenance Management. *Property Management*, 35(2):217–231. https://doi.org/10.1108/PM-01-2016-0004.

Aziz, N. D., Nawawi, A. H., & Ariff, N. R. M. (2016) Building Information Modelling (BIM) In Facilities Management: Opportunities To Be Considered By Facility Managers. *Procedia - Social and Behavioral Sciences*, 234:353–362. https://doi.org/10.1016/j.sbspro.2016.10.252.

Blandy, S., Dixon, J., & Dupuis, A. (2006) Theorising Power Relationships In Multi-Owned Residential Developments: Unpacking The Bundle Of Rights. *Urban Studies*, 43(13): 2365–2383.

Building, Road, and Drainage Act 1974 (Act 133). Malaysia: Kuala Lumpur International Law Book Services.

Chong, A. K. W., Mohammed, A. H., Abdullah@ Mohd Asmoni, M. N., & Abdul Rahman, M. S. A. (2019) Maintenance Prioritization – A Review On Factors and Methods. *Facilities*, 17(1): 18–93. https://doi.org/doi.org/10.1108/JFM-11-2017-0058.

Chua, S. J. L., Zubbir, N., Ali, A. S., & Au-Yong, C. P. (2018) Maintenance of High-Rise Residential Buildings. *International Journal of Building Pathology and Adaptation*, 36(2):137–151. https://doi.org/10.1108/IJBPA-09-2017-0038.

Demirbag, M., Tatoglu, E., Tekinkus, M., & Zaim, S. (2006) An Analysis Of The Relationship Between TQM Implementation And Organizational Performance: Evidence from Turkish SMEs. *Journal of Manufacturing Technology Management*, 17(6):829–847. https://doi.org/10.1108/17410380610678828.

De Toni, A. F., Fornasier, A., Montagner, M., & Nonino, F. (2007). A Performance Measurement System For Facility Management: The Case Study of a Medical Service Authority. *International Journal of Productivity and Performance Management*, 56(5–6):417–435. https://doi.org/10.1108/17410400710757123.

Dupuis, A., & Thorns, D. (1998). Home, Home Ownership and The Search for Ontological Security. *The Sociological Review*, 46(24–47):1998.

Easthope, Hazel, Warnken, J., Sherry, C., Coiacetto, E., Dredge, D., Guilding, C., Johnston, N., Lamminmaki, D., & Reid, S. (2014) How Property Title Impacts Urban Consolidation: A Life Cycle Examination Of Multi-Title Developments. *Urban Policy and Research*, 32(3):289–304. https://doi.org/10.1080/08111146.2014.899210.

Easthope, Hazel, & Randolph, B. (2016) Principal–Agent Problems In Multi-Unit Developments: The Impact of Developer Actions on The On-Going Management of Strata Titled Properties. *Environment and Planning*, 48(9):1829–1847. https://doi.org/10.1177/0308518X16650894.

Ho, Yau, Y., Wong, S. K., Cheung, A. K. C., Chau, K. W., & Leung, H. F. (2006) Effects of Building Management Regimes Of Private Apartment Buildings in Hong Kong. *Property Management*, 24(3): 309–321. https://doi.org/10.1108/02637470610660174.

Hui, E. C., Lau, H. T., & Khan, T. H. (2013) Effect of Property Management on Property Price : A Case Study In Hong Kong. *Facilities*, 29(11/12):459–471. https://doi.org/10.1108/02632771111157132.

Ivor H, Seeley. (1987) Building Maintenance. (2nd eds). United States: Macmillan Education, 103.

Gao, W. (2015) Collective Actions for the Management of Multi-Owned Residential Building: A Case of Hong Kong. *Habitat International*, 49(2015):316–324. https://doi.org/10.1016/j.habitatint.2015.06.008.

Gao, W., & Chen, G. Z. (2016) Does Owner Heterogeneity Matter In The Management of Multi-Owned Housing?. *Habitat International*, 53(2016):106–114. https://doi.org/10.1016/j.habitatint.2015.11.015.

Gifford, R. (2007) The Consequences of Living In High-Rise Buildings. *Architectural Science Review*, 50.1: 2–17. https://doi.org/10.3763/asre.2007.5002.

Graves, L. M., & Sarkis, J. (2018) The Role of Employees' Leadership Perceptions, Values, And Motivation In Employees' Provenvironmental Behaviors. *Journal of Cleaner Production*, 196:576–587. https://doi.org/10.1016/j.jclepro.2018.06.013.

Guilding, C., Bradley, G. L., & Guilding, J. (2014) Examining Psychosocial Challenges Arising In Strata Titled Housing. *Property Management*, 32(5):386–399. https://doi.org/10.1108/PM-01-2014-0001.

Jabatan Perumahan Negara. (2018, Mac 11) Dasar Perumahan Negara (2018-2025). Jabatan Perumahan Negara. Malaysia: Kementerian Perumahan dan Kerajaan Tempatan. https://www.kpkt.gov.my/kpkt/resources/user_1/MENGENAI%20KPKT/DASAR/BOOKLET_DRN_2018_2025.pdf.

Johnston, N., & Too, E. (2015) Multi-Owned Properties In Australia: A Governance Typology of Issues and Outcomes. *International Journal of Housing Markets and Analysis*, 8(4): 451–470.

Jonsson, A. Z. (2020) Does Facility Management Affect Perception of Building Quality?: A Study of Cooperative Residential Buildings In Sweden. *Facilities*, 38(37518):559–576. https://doi.org/10.1108/F-02-2019-0026.

Kasim, R. (2011) Community-Based Facilities Management. Malaysia: UTHM.

Kim, S., Lee, S., & Ahn, Y. H. (2019) Evaluating Housing Maintenance Costs With Loss-Distribution Approach In South Korean Apartment Housing. *Journal of Management in Engineering*, 35(2):1–9. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000672.

Lee, J.-Y., Lee, D.-H., & Choi, S.-H. (2016) The Effects Of Apartment Office Managers' Servant Leadership On The Residents' Satisfaction And Housing Management Company Contract Renewal Ratio. *Journal of the Korean Housing Association*, 27(5):45–54. https://doi.org/10.6107/jkha.2016.27.5.045.

Ling, F.Y.Y., & Wong, D. M. G. (2016) Redesigning Facility Management Operatives' Jobs To Increase Work Outcomes. *Journal of Facilities Management*, 14(1):50–68. https://doi.org/10.1108/JFM-11-2014-0036.

Muhamad Ariff, N. R. M. (2018) Improving Governance of High-Rise Multi-Owned Property in Malaysia. In E. Altmann, M. Gabriel (Eds.), *Multi-Owned Property in the Asia-Pacific Region: Rights, Restrictions and Responsibilities*. United Kingdom: Springer, 269-289. https://doi.org/10.1057/978-1-137-56988-2_15.

Oxford University Press. (2021, August 27) Leadership. Oxford University Press. https://www.oxfordlearnersdictionaries.com/definition/english/leadership?q=leadership.

Sajan, J. (2015) Design Implications for Multi-Owned Properties from a Household Survey. International *Journal of Housing Markets and Analysis*, 8(7):502–518. https://doi.org/10.1108/IJHMA-02-2015-0009.

Salaheldin, S. I. (2009) Critical success factors for TQM implementation and their impact on performance of SMEs. *International Journal of Productivity and Performance Management*, 58(3):215–237. https://doi.org/10.1108/17410400910938832.

Sia, M. K., Chin Yew, W., Lim, Z. Y., & Dongqing, Y. (2017) Facilities And Maintenance Services For Sustainable High-Rise Living. *Facilities*, 36(7/8): 330–348. https://doi.org/doi/abs/10.1108/F-03-2017-0037.

Strata Title Act 2015 (Act 757). Malaysia: Kuala Lumpur International Law Book Services.

Rahmawati, Y., Utomo, C., Suhailah, N., Sukri, M., Yasinta, R. B., Mohammed, A. H., Al-Aidrous, H., & My, M. H. A. (2020) Environmental Enhancement Through High-Rise Building Refurbishment. *Sustainability*, 12(9350). https://doi.org/10.3390/su12229350.

Rasip, M. K. (2017). Faktor utama yang mempengaruhi kualiti perkhidmatan dan pembayaran caj penyenggaraan bangunan [Unpublished doctoral's thesis]. Universiti Teknologi Malaysia.

Ratnasingam, P. (2009) Service Quality Management Applying The Balanced Scorecard: An Exploratory Study. *International Journal of Commerce and Management*, 19(2):127–136. https://doi.org/10.1108/10569210910967888.

Tiun, L. T. (2006) Managing High-Rise Residential Building In Malaysia: Where Are We? Second *NAPREC Conference*. Malaysia, 1–25.

Tyagi, A. S., Baag, D., Jailkhani, H., Poulose, J., & Patel, J. (2015) Identification of The Success Factors for The Implementation of Total Productive Maintenance In An Organisation Using Interpretive Structural Modeling (ISM). *International Journal of Quality & Reliability Management*, 32(3):308–331.

United Nations Human Rights. (2008) Universal Declaration Of Human Rights. United Nations Human Rights Office of the High Commissioner. https://www.ohchr.org/EN/NewsEvents/HRDay2007-2008/Pages/60UDHRIntroduction.aspx.

Vergara, L. M., Gruis, V., & van der Flier, K. (2019) Understanding Housing Management By Low-Income Homeowners: Technical, Organisational And Sociocultural Challenges In Chilean Condominium Housing. *Buildings*, 9(3). https://doi.org/10.3390/buildings9030065.

Vieira, E. S., Neves, M. E., & Dias, A. G. (2019) Determinants Of Portuguese Firms' Financial Performance: Panel Data Evidence. *International Journal of Productivity and Performance Management*, 68(7):1323–1342. https://doi.org/10.1108/IJPPM-06-2018-0210.

Waziri, B. S. (2016) Design and Construction Defects Influencing Residential Building Maintenance In Nigeria. *Jordan Journal of Civil Engineering*, 10(3):313–323.

Yau, Y., (2018) Efficacy Beliefs And Homeowner Participation. In Erika Altmann & Michelle Gabriel (Eds.), *Multi-Owned Property In The Asia-Pacific Region*. United Kingdom: Palgrave Macmillan, 231-250.

Yau, Y., Ho, D. C. W., & Chau, K. W. (2008) Determinants Of The Safety Performance Of Private Multi-Storey Residential Buildings In Hong Kong. *Social Indicators Research*, 89(3):501–521. https://doi.org/10.1007/s11205-008-9246-3.

Yong Yung, C. (2015) A Legal Guide To Strata Management

MEASURING MAINTENANCE AND OPERATION IMPACTS OF HIGH-RISE RESIDENTIAL BUILDINGS TOWARDS SUSTAINABILITY

Martina Jasoffa Omar[1], Mazlina Zaira Mohammad[1], Nor Syamimi Samsudin[2*], Natasha Khalil[2], Iryani Abdul Halim Choo[2] and Nur Dalila Nadzri[3]

[1]School of Civil Engineering, College of Engineering, University Teknologi Mara (UiTM) 40450, Shah Alam, Selangor, MALAYSIA

[2]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA,Perak Branch, 32610, Seri Iskandar,Perak, MALAYSIA

[3]Manchester School of Architecture, Manchester Metropolitan University, Chatham Building, Cavendish Street, Manchester M15 6BR, United Kingdom

**Corresponding Email: norsya992@uitm.edu.my*

Abstract

The construction industry often neglects the importance of maintenance and operation processes due to a lack of exposure and awareness regarding their significant impacts. The main goals of this systematic literature review research paper are to review the relationship between the maintenance and operation of high-rise residential buildings and sustainability issues due to the rising demand for high-rise residential buildings in developing countries and to identify maintenance and operation impacts by assessing the indicators used. The next goal of this systematic literature review research paper is to provide the conceptual framework from the previous research data for measuring the maintenance and operation impacts on the sustainability of high-rise residential buildings. The developed conceptual framework can help and guide future researchers to identify and be more aware of maintenance and operation impacts on the sustainability of high-rise residential buildings. By following the PRISMA protocol of conducting the systematic literature review (SLR), three stages of screening are conducted, and two software had been used which is Scimago and Atlas.ti software to evaluate and produce the quantitative analysis of the eighteen (18) selected papers. The development of a network diagram from the Atlas.ti helps the development of the conceptual framework and highlights the key findings of the three pillars of sustainability where economic (on the economic performance and investment), environmental (emission, rules and regulations, energy consumption, material resources, and sewage and wastes), and social (customers, employee and law and regulations).

Keywords: *Maintenance impact; Operation Impact; Sustainability; Sustainable; and High-rise Residential Building*

INTRODUCTION

Construction projects are commonly defined as organised processes of constructing, renovating, and refurbishing buildings, structures, or infrastructure. They encompass five vital phases: initiation, planning, implementation, performance, and monitoring, with the final phase being closure. Initiation, as articulated by Lingard et al., 2017), represents the stage where all necessary steps are taken before project approval. This phase primarily focuses on defining the project at a high level and aligning it with the business cases it aims to address. The planning phase involves the development of a comprehensive plan that guides the project through implementation and closure. The implementation phase entails putting the project plan into action. The performance and monitoring phase, in contrast to other phases, is ongoing, spanning from the project's outset to its completion. This phase involves constant oversight of tasks and the comparison of actual performance with planned performance. The final phase, closure, is where all deliverables are finalised, and all work is completed in accordance with the project plan and scope, as noted by Safa et al., 2015.

In the context of Asian countries like Malaysia, characterised by higher population density, economic development, and urbanisation, there is a growing demand for high-rise residential buildings. Over time, Malaysia's construction industry has matured, with the quality of the environment becoming a key factor in attracting potential buyers and developers. 'Green buildings' and 'sustainability' have become well-known concepts among both potential buyers and developers. To maintain the sustainability of these buildings, regular maintenance is imperative. High-rise buildings, characterised by their multi-story design, often require mechanical vertical transportation, such as elevators.

Within the construction process, two critical criteria that significantly influence the building's lifecycle are design and maintenance, as highlighted by Samsudin et al., 2023. Unfortunately, maintenance is frequently overlooked during building construction, with maintenance teams seldom involved in the design process. This oversight leads to challenges for maintenance teams, making it difficult for them to carry out their responsibilities effectively, as discussed by Silva et al., 2016. The awareness of maintenance-sustainability issues has been growing among researchers, with studies like those Aksah et al., 2016; Chohan et al., 2015; De Silva & Ranasinghe, 2010, shedding light on the topic. However, while sustainability is a popular term in contemporary research, most researchers tend to focus on one sustainability pillar in their studies rather than consider a holistic view with a detailed classification of maintenance impacts on all three dimensions or pillars of sustainability. Furthermore, maintenance practices still rely on conventional measures to evaluate their impact on sustainability, and until 2015, most papers lacked sustainability indicators for assessing maintenance and operation impacts on these three sustainability pillars. However, recent studies that have introduced classifications for measuring maintenance and operation performance have yet to provide a comprehensive framework of sustainability performance indicators affected by maintenance and operation processes.

Maintenance and Operation Impacts of High-Rise Residential Buildings

According to Jasiulewicz-Kaczmarek and Stachowiak (2016), maintenance is a major lever of organisational efficiency in the industrial context. Maintenance is applied to keep its production system in an efficient state and provide products with quality requirements. Maintenance is outlined as the technical, administrative, and management combinations of actions during the life cycle of an item intended to preserve or restore it to a state in which it can perform the required function. The first goal of this systematic literature review paper is to determine the maintenance and operation of high-rise residential buildings and sustainable issues in Malaysia. The second goal aimed to review the maintenance and operation of high-rise residential building's impacts on sustainability. The last goal is to identify the indicators for assessing maintenance and operations impacts. In order to reach such goals, a systematic literature review was conducted to analyse all the content of selected papers and come up with a better holistic framework of maintenance impacts on three pillars of sustainability, which are economic, environmental, and social aspects.

Maintenance is the most critical issue ignored in construction industries worldwide (Chew et al., 2019; Kampamba et al., 2020; Khalid et al., 2019). Most of the country often focuses on construction without seeing the importance of maintenance or impacts, ignoring the maintenance and operation of construction projects. This study significantly helps the new researchers gain data about maintenance and operation impacts on high-rise buildings in Malaysia. A systematic literature review appraises previous research data and selects the most evidence-based practice to create a great summary of maintenance impacts in construction.

METHODOLOGY

During the Malaysia Movement Control Order, which effectively restricted all movement and mass gatherings, including social and cultural activities, Malaysians were prohibited from leaving the country, and non-Malaysians were barred from entry. This measure also led to the closure of most local and federal industries, compelling a significant portion of the workforce to work remotely. Consequently, obtaining primary data through on-site interviews or participant observations became unfeasible during the Movement Control Order, creating a substantial limitation. To address this constraint, we opted for an alternative approach, using existing data as case study materials for this research paper. This decision was prompted by the prevailing circumstances and the impracticality of obtaining primary data through traditional means.

It’s worth noting that the state of maintenance management in Malaysia was atypical and outdated compared to more developed countries like Hong Kong and Singapore (Ta, 2006). Furthermore, the current situation, characterised by delays and challenges in scheduling interviews, rendered the acquisition of data from management departments in Malaysia’s industries a time-consuming process. The need to schedule appointments in advance, combined with the ongoing Movement Control Order, made it practically impossible to collect the necessary data before the imposed deadline.

In light of these constraints, we opted to employ qualitative research methods. Qualitative methods hold particular value in offering rich explanations of complex research topics, tracking unique or unexpected aspects of the research, capturing diverse interpretations and experiences, amplifying voices rarely heard, and conducting preliminary investigations to develop and generate theories.

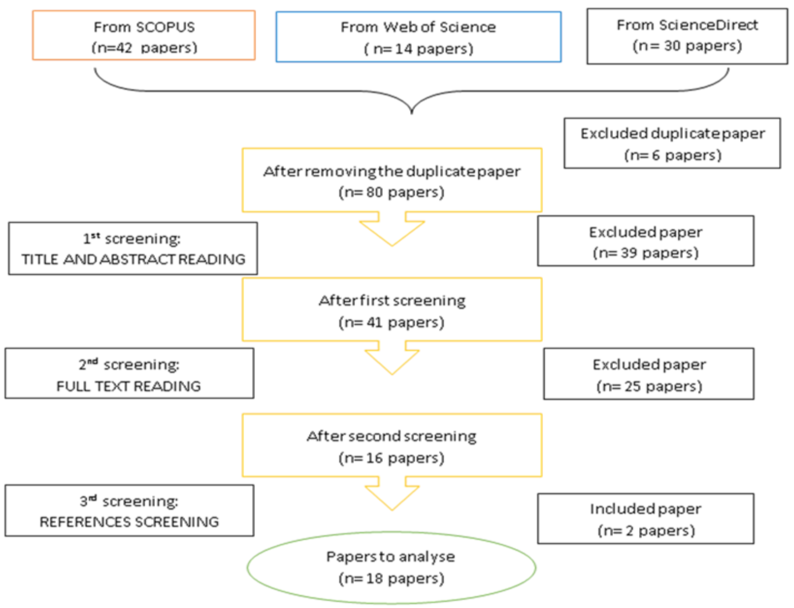
For this systematic literature review, we utilised three different online databases: Scopus, Web of Science (WoS), and ScienceDirect, accessed through UiTM EzAccess website. In the systematic literature review, previous research papers were carefully examined, and content analysis was conducted with the assistance of Scimago and Atlas.ti software. This process entailed the identification and categorisation of keywords and definitions related to maintenance and operation in high-rise residential buildings.

To ensure transparency and rigour in the systematic literature review process, we adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. The review was conducted in three stages, involving the screening of selected research papers, and the data analysis was facilitated by Atlas.ti software, as referenced in Samsudin et al. (2022, 2023). This approach allowed us to generate a graphical network view, providing a comprehensive overview of the results.

Table 1. Research Database and Keywords Structured

Database	Scopus	Web of Science	ScienceDirect
Search String	TITLE-ABS-KEY ((“maintenance” OR “maintenance impact”) AND (“operation” OR “operation impact”) AND (“sustainability” OR “sustainable”) AND (“high rise residential building” OR “residential building”))		TITLE-ABS-KEY ((“maintenance impact”) OR (“operation impact”) AND (“sustainability” OR “sustainable”) AND (“high rise residential building” OR “residential building”))

Source: Author’s Illustration (2023)



Source: Author’s Illustration (2023)

Figure 1. Search Queries Process

Figure 1 above illustrates the flowchart of the research methodology used for this paper. The systematic literature review was conducted following a structured procedure. Three of the largest scientific, multi-disciplinary online databases – Scopus, Web of Science, and ScienceDirect – were utilised for this paper. These databases cover major journal publishers such as Elsevier, Emerald, and Wiley and were accessed through UiTM EzAccess. To ensure comprehensiveness, keywords were structured into four different sets, which were chosen in alignment with the research objectives and three research questions. The first set included “maintenance” OR “maintenance impact,” the second set “operation” OR “operation impact,” the third set “sustainability” OR “sustainable,” and the fourth set involved “high-rise residential building” OR “residential building.” Boolean operators such as OR and AND were used to connect keywords within each set. An example of the search string used for the Scopus database is TITLE-ABS-KEY ((“maintenance” OR “maintenance impact”) AND (“operation” OR “operation impact”) AND (“sustainability” OR “sustainable”) AND (“high-rise residential building” OR “residential building”)).

In terms of inclusion and exclusion criteria for selecting relevant papers, there were no limitations imposed in terms of the year of publication. The literature search encompassed materials available up to October 2021. Only papers in their final stages of publication, open access, and in English were considered.

For the data analysis, four steps were conducted. The first step involved a screening and analysis process in which three steps were undertaken to select papers relevant to maintenance and operation in high-rise residential buildings. The first step involved the reading of the title and abstract of selected papers. Exclusion criteria during this phase included topics that showed no relationship with the aims of this paper and its research questions. The second step involved reading the full text of the papers, and any papers that did not meet the research questions were excluded. Finally, the third step encompassed a screening of the references cited in the selected papers. Any related or relevant references were included for additional review. Results from the three steps of screening were included in the analyses, conclusions, and recommendations for future researchers.

The next procedure involved identifying the elements that would be included in the three dimensions often referred to as 'cubes of knowledge'. This conceptual framework was developed to address the research challenges and answer the research questions of this study.

As per Alhouli (2011) a conceptual framework can be theory-driven or based on common sense, indicating what will and will not be studied by providing dimensions and explaining the possible relationships among elements within those dimensions based on logic. The elements are selected according to the framework's objectives. The first dimension represents the maintenance process, which is related to the first research question aimed at identifying the relationship between maintenance and operation with sustainability. The second dimension represents the type of maintenance impacts, whether direct or indirect and serves as a reference system to address the second research question concerning the impacts of maintenance and operation on sustainability. The third dimension represents sustainability categories, including economic, environmental, and social aspects, to ensure a holistic perspective in line with the sustainability concept (Eslami et al., 2019).

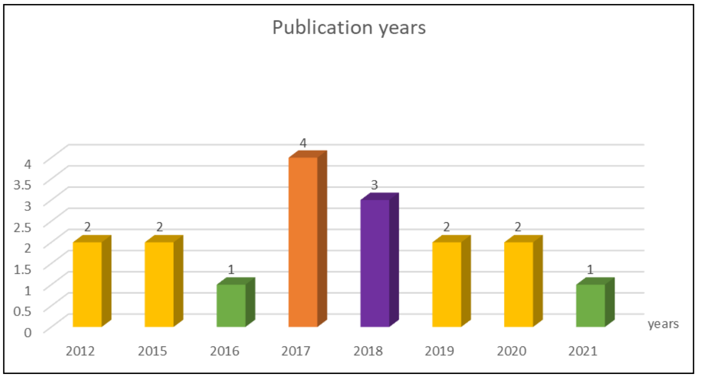
The third step involves identifying the sustainability indicators adopted for measuring maintenance and operation impacts. This entails selecting sustainability indicators affected by maintenance and operation, referring to EN 17007:2017, and classifying these indicators as either directly or indirectly affected.

The final step involves creating and designing the conceptual framework within the cube's dimensions with the elements identified in the second step as outlined in the flowchart. This conceptual framework is prepared to provide future researchers with a general overview, enabling them to understand the selection of indicators and the identification of elements for each dimension.

RESULTS AND DISCUSSION

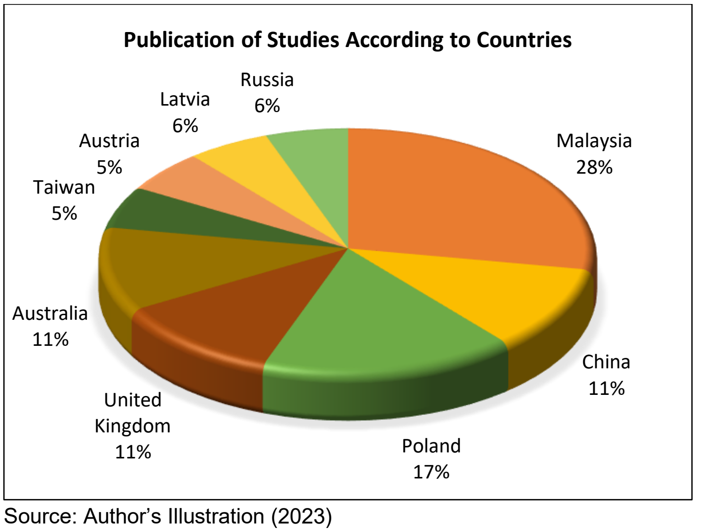
Quantitative Findings

The research string conducted were resulting to analyse 18 articles. Figure 2 displays the quantity of documents published each year and Figure 3 displays the country that published the articles of this study. There are two papers that been published in 2012, 2015, 2019 and 2020. On the year of 2016 and 2021 only, one papers that been published on each year and 2017 resulted in the highest published paper on from eighteen selected paper which four papers had been publish on that year. In 2018, three selected papers had been published.



Source: Author's Illustration (2023)

Figure 2. Publication Years



Source: Author's Illustration (2023)

Figure 3. Publication of Studies According to Countries

According to the countries publication of the selected papers shown in Figure 4, majority of the selected paper is from Malaysia that contribute 28% followed by Poland 17%, United Kingdom, Australia and China 11%, Russia and Latvia 6% and the remaining are from Austria and Taiwan 5%.

Table 2 displays the quantity of publications published from 2012 to 2021. In 2012, the selected paper was published in Int J Life Cycle Assess and the International Journal of Sustainable Development. In 2015, the Proceedings of International Structural Engineering & Construction and the American Society of Civil Engineers (ASCE) were the publishers that published the selected papers. Meanwhile, papers in 2016 are from Facility Maintenance and Management and Matec Web of Conferences 66. Papers in 2017 are from Procedia Engineering, which produced three papers and one from the International Journal of Lean Six Sigma. In 2018, Civil Engineering Journal, IOP Publishing and MDPI Buildings were the publishers of the selected paper, and in 2019 from the International Journal of Recent Technology & Engineering (IJRTE). In 2020, the selected papers are from Engineering Modelling and the International Journal of Building Pathology & Adaptation, while in 2021, the publishers are the Journal of Building Engineering and the Journal of Cleaner Production.

Table 2. Quantity of Publications Published From 2012 To 2021

Publication	2012	2015	2016	2017	2018	2019	2020	2021
Journal of Building Engineering								1
Matec Web of Conferences 66			1					
Journal of Cleaner Production								1
Procedia Engineering				3				
Proceedings of International Structural Engineering & Construction		1						
MDPI Buildings					1			
Facility Maintenance and Management			1					
American Society of Civil Engineers (ASCE)		1						
Civil Engineering Journal					1			
IOP Publishing					1			
International Journal of Lean Six Sigma				1				
Engineering Modelling							1	
International Journal of Building Pathology & Adaptation							1	
International Journal Recent Technology & Engineering (IJRTE)						1		
Int J Life Cycle Assess	1							
International Journal of Sustainable Development	1							
Total	**2**	**2**	**2**	**4**	**3**	**1**	**2**	**2**

(Source: Authors Illustration, 2023)

Figure 4. List of Publications Based on Year

From this figure, Procedia Engineering is the highest publication in 2017, and 2017 is the highest quantity of papers published, followed by 2018.

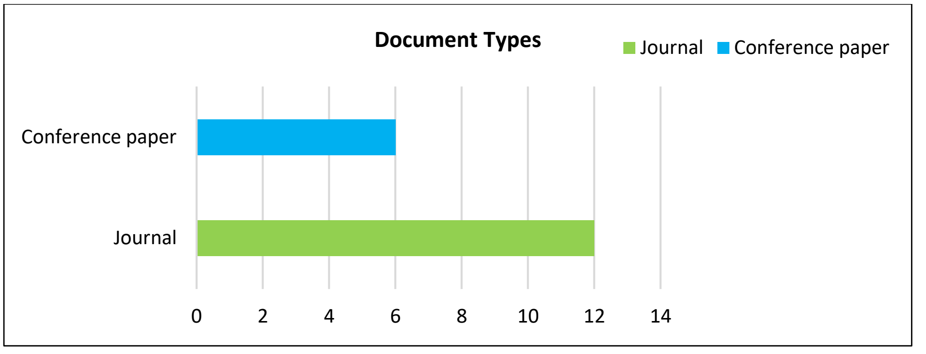


Figure 5. Type of Documents Selected

Figure 5 displays various types of data collection implemented in the reviewed documents. From the selected articles, 6 are from the conference paper, and another 12 are from the journal. While Figure 6 shows the scientific journal ranking (SJR), which is the impact factor of each journal that was calculated through a network analysis of citations using Scimago. SJR has been measured by quartiles where Q1 represents the top 25% of journals while Q4 is the lowest 25%.

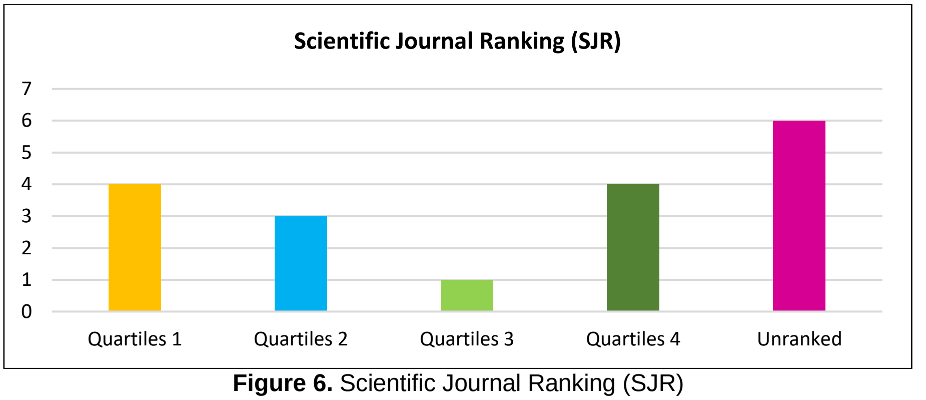


Figure 6. Scientific Journal Ranking (SJR)

Qualitative Analysis

The data from eighteen selected papers that passed all three screenings are being reviewed using Atlas.ti software and has been summarised by the network view diagram in this section. The original authors are being cited as references from the selected papers.

Sustainability Pillars

Accessing the maintenance and operation impacts towards sustainability should be evaluated based on three pillars of sustainability, which are economic, environmental and social (Franciosi et al., 2020) and highlighted the key findings of the three pillars of sustainability where economic (economic performance and investment), environmental (emission, rules and regulations, energy consumption, material resources, and sewage and wastes), and social (customers, employee and law and regulations). Figure 7 shows the network view of the sustainability pillars accessed to measure the maintenance and operation impacts on high-rise residential buildings. In fact, these three pillars of sustainability have many direct and indirect impacts on the sustainability aspects.

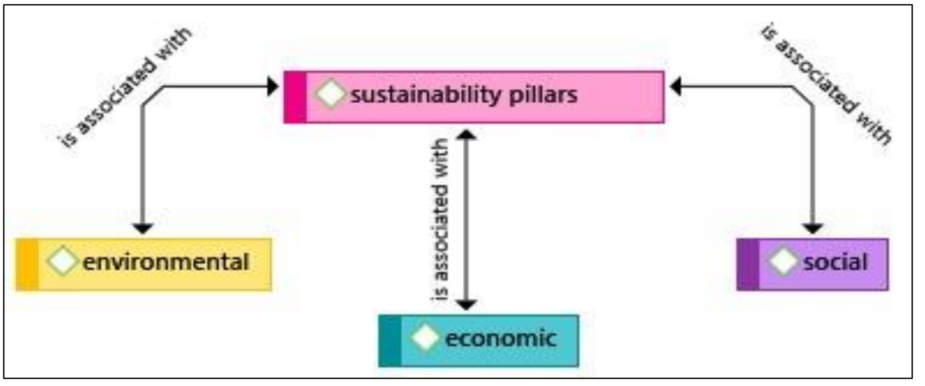


Figure 7. Sustainability Pillars Pattern Network Analysis Using Atlast.Ti 8

Economic Indicator

From eighteen selected papers, only eleven papers describe the economic aspects. The first category of sustainability that will be focused on is the economic indicator shown in the network view in Figure 8. (Bucoń & Czarnigowska, 2021a) stated that the management of multifamily housing stock is an art of reconciling the demand of numerous stakeholders, the technical constraints of the building's fabric, the growing requirements towards the building's environmental performance and restricted budget. This statement has been discussed by Aldairi et al. (2017), who pointed out that the increase in budget is due to unnecessary repairs and inspections and has been supported by Radziejowska (2020) because the quality use of the building and the length of the building life is possibly affected with a proper care and prevention measures without even need to carry out the costly refurbishment. Aldairi et al. (2017) also highlighted that maintenance management faces a critical challenge in validating asset performance and allocating the required funds for maintenance because usually, the cost for maintenance is around 60 and 75 per cent of the life cycle cost of the large system of the building, but it been criticised by Ping and Chen (2016) when it stated that if the building's owner did not adopt the green building criteria they need to foot the bill for another additional 63 per cent sum of monies. These showed that the management can tailor their maintenance budget by implementing the green building criteria with selected key elements on the maintenance work.

Yahya and Ibrahim (2012) identified that the maintenance cost for high-rise buildings is higher due to the complicated maintenance and operation of the high-rise building. They also highlighted that improvement of maintenance effectiveness related to the management approach because the maintenance performance was effectively achieved with the stakeholder's aspects. Liu and Ramadhan (2017) justified that the factor of failed management in maintenance and operation is due to a limited budget, and the budget needed to be allocated manually.

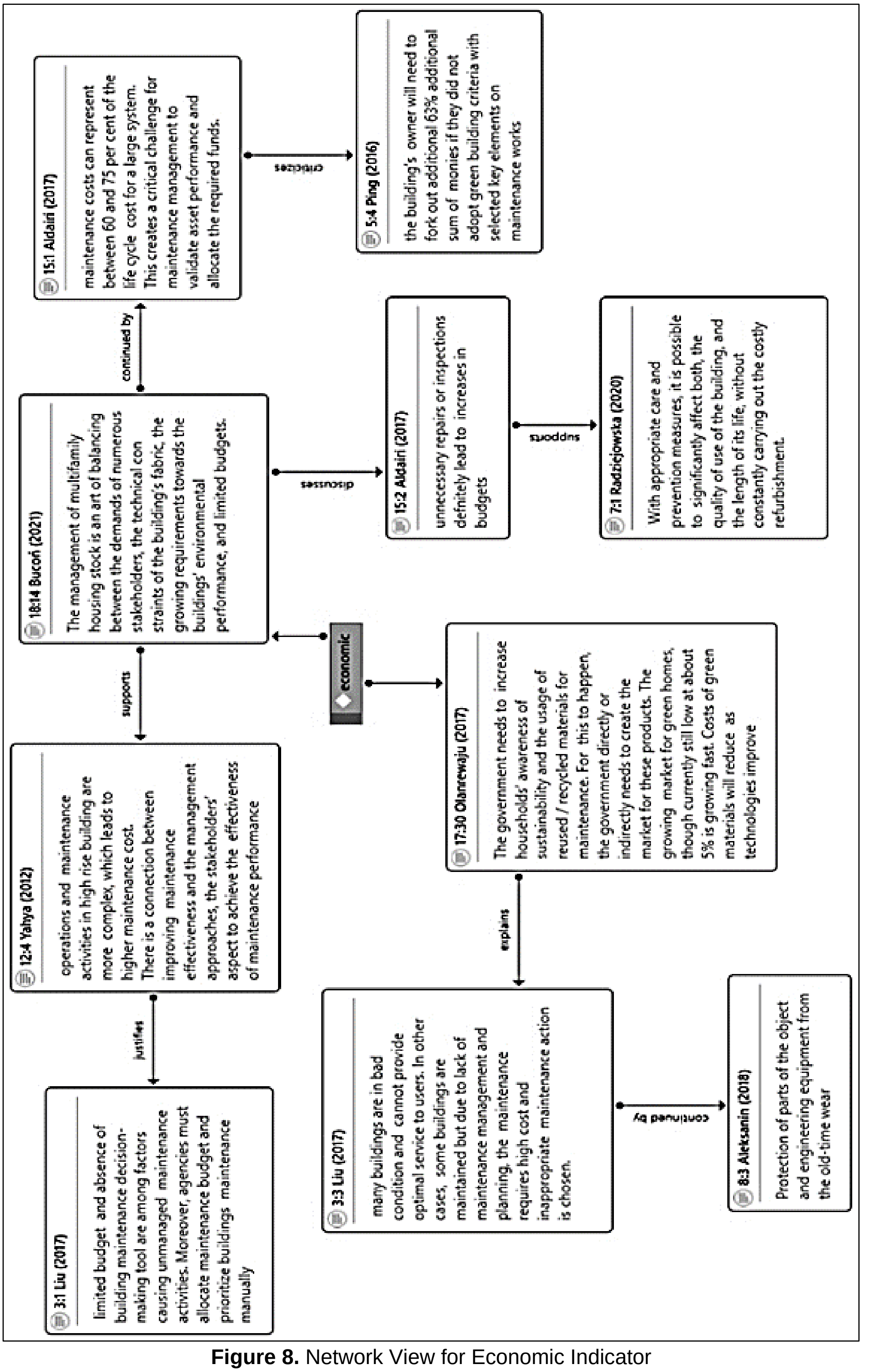


Figure 8. Network View for Economic Indicator

Even the management of the maintenance and operation of high-rise residential buildings is responsible for the effectiveness of the maintenance and operation of the building; however, the household's awareness is slightly important to ensure the sustainability of the buildings taken care (Olanrewaju et al., 2017). They also mentioned the role of government in marketing products that use recycled materials for maintenance, which can reduce the cost of maintenance and increase the market for green homes. Liu and Ramadhan (2017) explained that a lack of household awareness about sustainability and poor maintenance and operation management make inappropriate decisions for maintenance being chosen and that maintenance requires high costs. The poor management of high-rise residential buildings leads to bad conditions and poor services to the user. Aleksanin and Sborshikov (2018) also mentioned maintenance and operation management should be aware of the equipment from the old-time wear.

It can be concluded that the higher demand for green buildings in order to have sustainable buildings will lead to cost reduction on green materials for high-rise residential buildings. From these network views for the economic indicator, economic performance and investment are related to the maintenance and operation impacts because a limited budget for maintenance and operation activities will result in a limited part for the maintenance and operations activities where the management will only be focusing on the necessary part. Unfortunately, these will only result in increasing costs for maintenance and operations of the buildings in the future. Proper investment in maintenance and operation activities, such as the development of proper infrastructure and support in maintenance and operation, and investment in equipment and materials for the building that is energy efficient, are the best initiatives to be considered by the maintenance and operation management.

Environmental Indicator

The second category for sustainability is environmental, and Figure 9 shows the network view of environmental indicators. Twelve out of eighteen selected papers indicated an environmental aspect. The increasing demand from the stakeholders for the building's environmental performance and a limited budget for the maintenance and operation is the skill of balancing in the management of multifamily housing buildings (Bucoń & Czarnigowska, 2021a). One of the skills to reduce the damage to the environment are by lowering the household energy consumption, and this has been justified by (Juan & Cheng, 2018). (Yahya & Ibrahim, 2012) mentioned that from a social and legal point of view, when managing maintenance and operation activities, the significant value is the proper handling of waste and pollutants. This statement has been justified by (Olanrewaju et al., 2017) because maintenance and operation activities generate a lot of waste to the environment. Due to waste generated during the maintenance and operation activities (Aleksanin & Sborshikov, 2018) proposed to establish a separate collection system for household waste and implement local environmental monitoring.

Sustainable buildings are described as buildings that have less impact on the environment, have energy efficiency, and enhance better living for dwellers (Tushar et al., 2021). (Olanrewaju et al., 2017) justified that household comfort and productivity can be enhanced if energy and water consumption, carbon emission, and building performance are reduced. In fact, it can reduce carbon dioxide pollution and waste and lower the cost of maintenance and operation of the buildings. Lateef et al. (2015) explained that buildings can endanger the health and welfare of the communities because most of the buildings are finite and non-renewable, and it place a heavy burden on the earth's resources. Building unable to serve it purposes without a proper maintenance and operations. This can trigger higher cost to own or even operate the building and it did not offer value of money.

Aleksanin and Sborshikov (2018) discussed about using the renewable energy and resource-saving potential on the buildings which beneficial to the environment. Open building is one of the beneficial for environment sustainable building (Juan & Cheng, 2018). However, Tushar et al. (2021) criticises that designer used to ignore the environmental impact during their design stage just to optimise their design. Environmental cost was been neglect because most of the author been narrow down the problem to ensure that they get a quick return on the investment (Bucoń & Czarnigowska, 2021b). Moreover, Chiang et al. (2016) proposed an environmental friendly suggestion where instead of build a new building it is even better to retrofit the existing building.

Based on the network view in Figure 9, the environment indicator that can be listed are the material resources of the maintenance and operation activities, sewage and wastes, emissions emitted during maintenance and operation activities, energy consumptions on the buildings and the laws and regulations implemented by the government where related with maintenance and operations impacts on high-rise residential buildings. Material used for the maintenance and operations activities usually divided into renewable materials and non-renewable material or based on the types of the material used which recyclable materials or reused materials. This based on the realisation of the management on the advantages of the recyclable materials on maintenance and operation impacts on environment. GHG and air emission such as Volatile Organic Compounds (VOC) and Particulate Matter (PM) (usually PM2.5 and PM10) emitted to the environment due to the maintenance and operations activities such as electricity, heating, cooling and steam. Other than that, noise that produces during maintenance and operation activates contribute to noise pollution in the environment.

Social Indicator

Based on the eighteen selected paper, only seven out of eighteen research paper talked about social indicator that contribute to sustainability. Social indicator is most likely related with community life of the buildings. Figure 10 produced a network view that highlighted the social indicator in sustainability. Yim et al. (2018) mentioned that the rise of population in Hong Kong escalate the demand for comfortable living and increase the energy usage and GHG emitted from the residential buildings. These even continued by Bucoń and Czarnigowska (2021b) which buildings are expected to offer a comfortable living by providing sufficient protection to the user such as accessible and hygienic spaces. The continuous behaviors of resident to reduce the energy consumption would definitely increase the building performance and lower the maintenance and operation cost and beneficial to increase the productivity and comfortable living to the user (Olanrewaju et al., 2017). To ensure the safety precaution and quality improvement in population, the design and space-planning decision need to be allocated as main focus to comply sustainability however between designed requirements and actual performance exist a huge gap that associated by the behaviors of the resident and operators of the buildings.

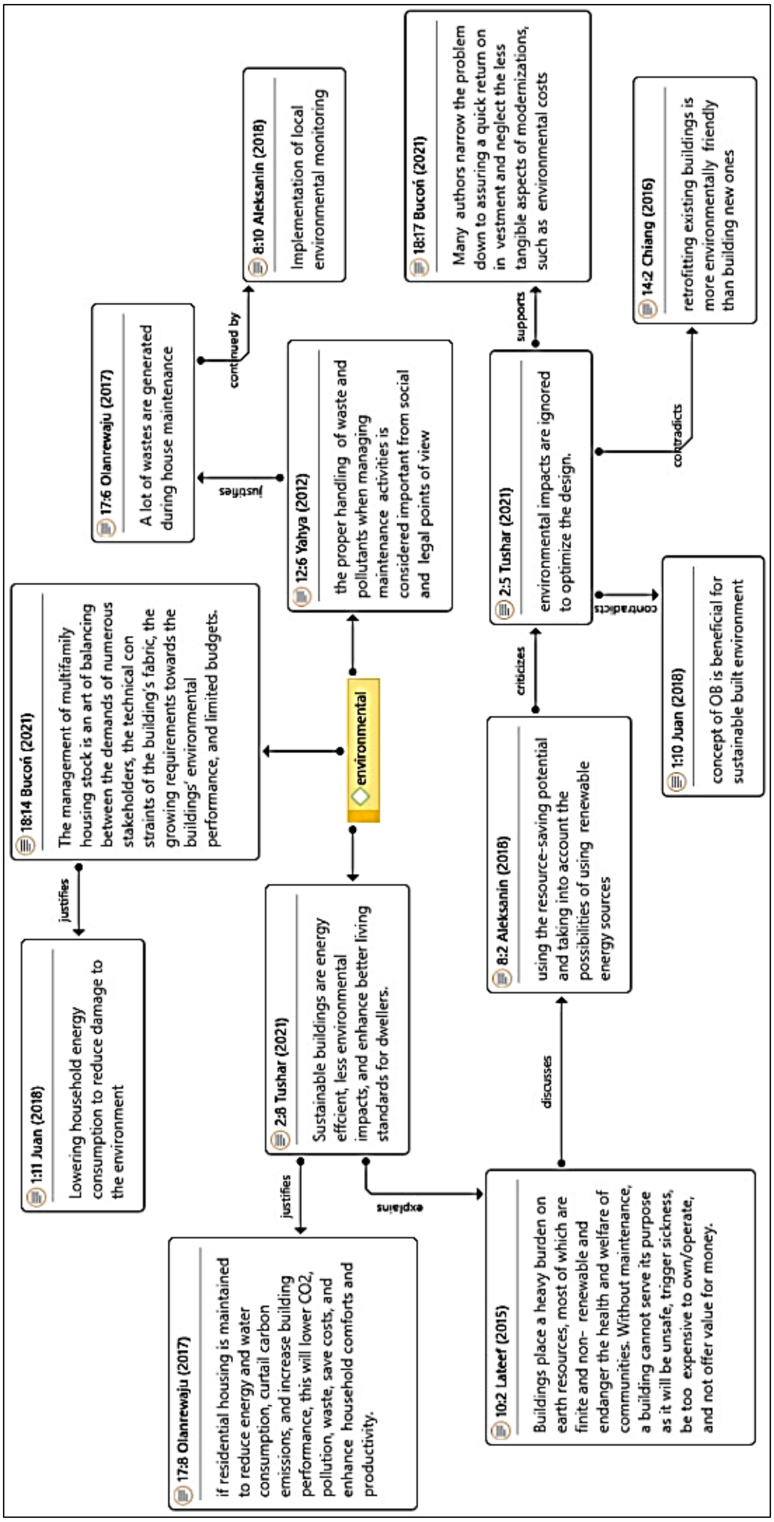


Figure 9. Network View for Environmental Indicator

Tenancy management is one of the important roles in maintaining and managing high-rise properties (Khalid et al., 2019). This has been supported by Bucoń and Czarnigowska (2021b) where proper management is one of the basic needs related to the residential buildings, and other basic needs are health and comfort, safety and security, and facilitating function. Lateef et al. (2015) spotted that poor understanding of the maintenance management towards sustainable residences is the major factor that impacts the sustainability behaviour of tenancy. (2019) even discussed that the tenancy problem could affect the marketing of the property due to poor management of the building. Society tends to be interested with buildings that can deliver a proper service and provide comfortable living to the tenant. On the tenant's behalf, the control on the energy usage of the facility, such as lighting and water consumption is depends on their awareness on sustainability behaviour (Aleksanin & Sborshikov, 2018).

According to the network view in Figure 10, the social indicator that can measure the maintenance and operation impacts on high-rise residential buildings are basically on customer category, which is the buyer or tenant of the high-rise residential buildings, employee or the management of parties involved in high-rise residential buildings and the law and regulations on social area. In the customer category, the contribution to maintenance and operations of high-rise residential buildings impacts are based on their satisfaction and behaviours (awareness). Lack of awareness on the sustainability of buildings from the customer point of view is unable the maintenance and operation management to contribute to the sustainability goals of the buildings. Employee or the management of maintenance and operation of high-rise residential buildings related with the maintenance and operations impacts based on the support and management process where the education and training for the employee to limit the risk during work and their skills and performance to decide the best maintenance and operation activities for the buildings. While for law and regulations, the government construct a significant fine to the resident or the owner of the buildings that didn’t comply with the law and regulations in the social category.

Maintenance and Operation Impacts

Yahya and Ibrahim (2012) mentioned that building performance is evaluated by the effectiveness of the facility, the standard of cleanliness, the quality of indoor air, efficiency of the energy, thermal comfort of the tenant, and safety of the tenants, which have been enhanced with the maintenance and operation activities. The role of the government in spreading awareness on the usage of recyclable and reused materials for maintenance need to be implemented in the household by creating a market for recycled products that directly or indirectly helps to cut the cost of green materials (Olanrewaju et al., 2017). Liu and Ramadhan (2017) explain in their studies that many buildings are unable to operate well and provide optimum services to tenants due to a lack of maintenance and operation planning. Improper planning leads to an increase in maintenance and operation costs due to the inappropriately selected solution and action for maintenance and operation activities. Olanrewaju et al. (2017) also discussed that global environmental problems can be resolved by proper maintenance and operation activities. Chiang et al. (2016) support this by indicated that the balance of three sustainability pillars and the resources needed for the maintenance and operation activities could possibly achieve a vibrant economic and high-quality environment through the effort of the community of the building and the government.

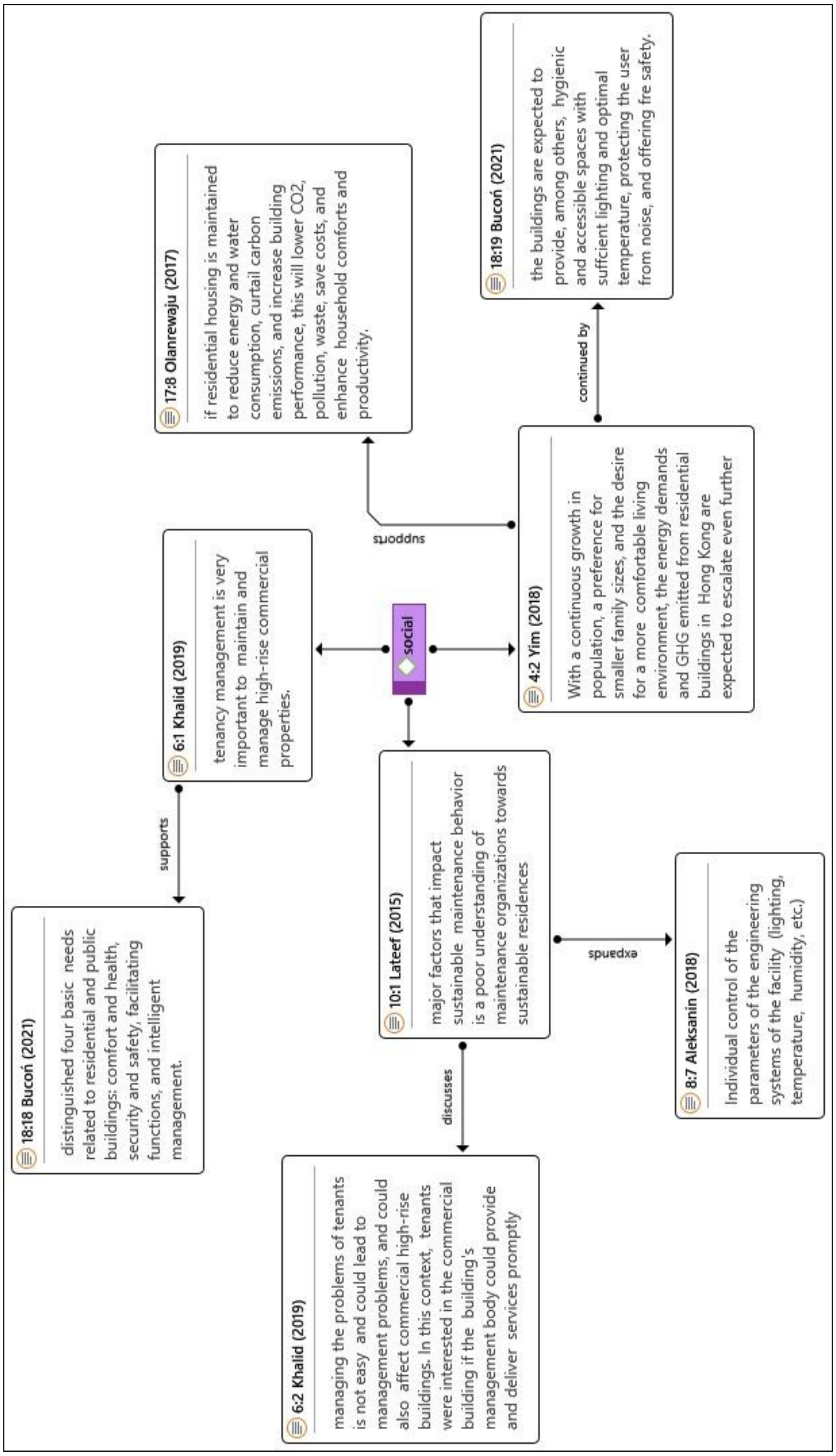


Figure 10. Network View for The Social Indicator

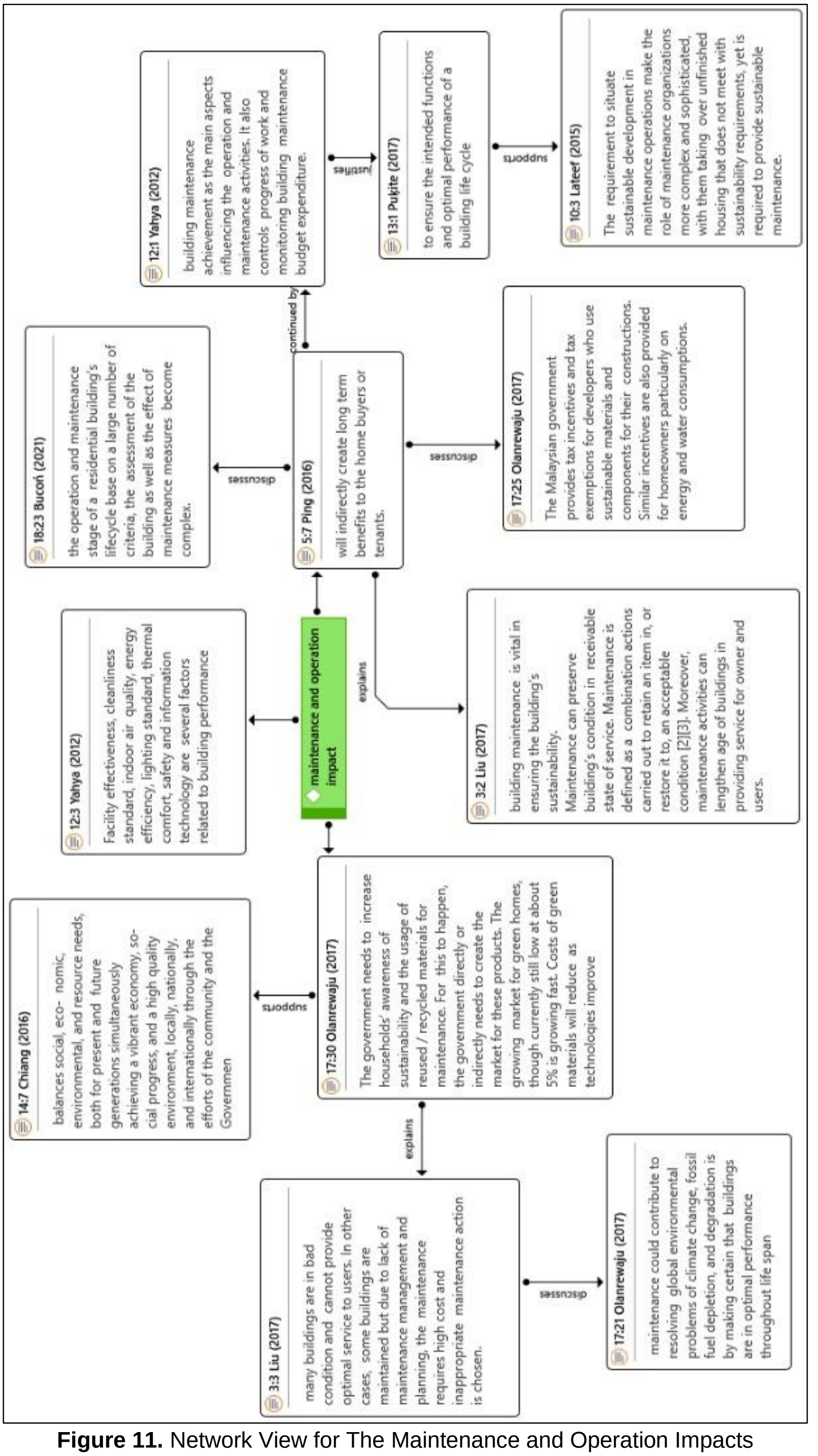


Figure 11. Network View for The Maintenance and Operation Impacts

Ping and Chen (2016) highlighted that the maintenance and operation impact indirectly create a long -term advantages to the tenants. This been explained by Liu and Ramadhan (2017) where in their study stated that the building maintenance and operations is important to ensure the sustainability of the buildings and the maintenance and operations activities indirectly lengthen the age of the buildings to provide services to the tenant of the buildings. Retained an item or restore to an acceptable condition is the well definition of maintenance where that can preserve the building's condition. The government of Malaysia provide good incentives to developer that indicated sustainable materials in their construction, and homeowner have also not been left out with great tax incentives and tax exemptions on energy and water consumption (Olanrewaju et al., 2017). Progress of work and budget on maintenance and operation have been controlled by the achievement of maintenance and operation of buildings (Yahya & Ibrahim, 2012) and been justified by Puķite and Geipele (2017) that the achievement of the maintenance and operation activities can lengthen the age of building performance and functions. Bucoń and Czarnigowska (2021b) stated that the measuring of the impact of maintenance and operation of high-rise buildings are more complex due to the large number of criteria that have been assessed on. This has been supported by Lateef et al. (2015) where in their study mentioned that the demand on sustainability development make the management of the maintenance and operations becomes more sophisticated and complex.

The relationship between maintenance and operation impacts of high-rise residential buildings with the sustainability pillars which economic, environmental, and social are well shown in Table 3 with the sources and category listed for all three pillars of sustainability.

Table 3. The Relationship Between Maintenance and Operation Impacts of High-Rise Residential Buildings with The Sustainability Pillars

Sustainability Pillars	Category	Maintenance and Operation Process (Management, Realisation, Support)	Sources
Economic	Economic performance	• Cost on implementation of sustainable buildings • Cost of materials of green buildings	(Olanrewaju et al., 2017)
		• Limited budget on maintenance and operation activities lead to higher cost in future • Selection on necessary parts only that need to be maintenance and operation to minimise cost.	(Bucoń & Czarnigowska, 2021a)
		• Limited budget • Lack of skill in management in maintenance and operation leads to poor decision making	(Liu & Ramadhan, 2017)
		• Cost for proper equipment and tools for the operation of the buildings (LED lights) • Recycle system of water (rainwater harvesting system) • Construction stages (ventilation and natural lighting)	(Ping & Chen, 2016)
		• Cost of engineering equipment • Cost of maintenance	(Aleksanin & Sborshikov, 2018)
		• Governing services level as effective cost manner	(Cooper et al., 2020)
		• Money, expertise, and policy support are main factor for cost-effective buildings.	(Y. H. Chiang et al., 2016)
		• Cost of repair and inspections of buildings	(Aldairi et al., 2017)

Sustainability Pillars	Category	Maintenance and Operation Process (Management, Realisation, Support)	Sources
		• Cost of rebushing the buildings due to lack of maintenance and operation measures	(Radziejowska, 2020)
	Investment	• Development of open building that can reduce waste and damage caused by the construction • Development in energy efficiency equipment (innovative way)	(Juan & Cheng, 2018)
		• Cost for managing the management of maintenance and operation • Investment in development of sustainable infrastructure and support for maintenance and operation management	(Yahya & Ibrahim, 2012)
Environmental	Emission	• GHG emission (direct and indirect) due to the maintenance and operation activities	(Yim et al., 2018)
		• Noise emission during the maintenance and operation activities • Air pollutant occurred during maintenance and operation activities such as Pollutant Matters (PM2.5 and PM10)	
	Rules and regulations	• Policy to comply sustainability initiative in maintenance and operation activities	(Yim et al., 2018)
		• Fines for the responsible institution that unable to adopt green building criteria and comply the law and regulations and cause the environmental pollution	(Ping & Chen, 2016)
	Energy consumption	• Energy consumptions can be reduced with natural lighting and ventilation where it reduces the usage of cooling system when the buildings are indirectly to the sun.	(Ping & Chen, 2016)
		• Initiatives to reduce the energy consumptions with energy efficient equipment.	
	Material resources	• Non-renewable materials endanger the earth resources.	(Lateef et al., 2015)
		• Recycle the secondary material for maintenance and operations activities	(Aleksanin & Sborshikov, 2018)
	Sewage and wastes	• Proper management on sewage and wastes of maintenance important in law point of view	(Yahya & Ibrahim, 2012)
		• The destination of waste produces by the maintenance and operation activities • Proper waste management (treated or non-treated waste)	
Social	Customers /tenants	• Awareness on sustainability • Customer concern on maintenance and operation activities	(Lateef et al., 2015)
		• Behavioral issues in sustainable maintenance and operation of high-rise residential buildings	(Olanrewaju et al., 2017)
	Employees	• Skill management could provide and delivered service promptly	(M. S. Khalid et al., 2019)
		• Design and space planning for maintenance and operation activities • Adjustment parameters of the facility (lighting, temperature)	(Aleksanin & Sborshikov, 2018)

Sustainability Pillars	Category	Maintenance and Operation Process (Management, Realisation, Support)	Sources
		• Safety measures adopted during maintenance and operation activities • Revitalisation suggestion of maintenance and operation improvement	
		• Guide and advise the tenant on the adoption of sustainable practices	(Lateef et al., 2015)
		• Create long-term advantages for both owner and tenant	(Ping & Chen, 2016)
	Law and regulations	• Fines for not compliance the law and regulations in maintenance and operation in social area	

The Development of Conceptual Framework of Measuring Maintenance and Operation Impacts of High-Rise Residential Buildings

This section represents the creation of conceptual framework that aimed to give a holistic view in graphical form to answering all the research questions of this research. Which to review the relationship between maintenance and operation of high-rise buildings with the sustainability issues, to review the maintenance and operations of high-rise residential buildings impacts on sustainability and to identify the sustainability indicators that influenced by the maintenance and operation activities on high-rise residential building.

Figure 12 provides a 2D view of the conceptual framework which illustrated the correlation of the sustainability pillars with the maintenance process and maintenance and operation impacts on high-rise residential buildings that be listed on Table 3.

Figure 12. Conceptual Framework of Relationship Between the Maintenance and Operations Impacts Towards Sustainability in 2D View

For example, in social category will have all those three-maintenance process:

- support process: the employee gives guide and advise to tenant on the adoption of the sustainability practices.
- realisation process: awareness on sustainability on tenant increase concern and reduce behavior issues in sustainability maintenance and operation adoption to the residential building.
- management process: adjustment parameter and safety measures adopted during the maintenance and operation activities.

This framework is well defined in cube shape where the first column is the sustainability pillars which is economic, environmental, and social. While for the second column would be the maintenance and operations impact that might be direct or indirect on the targeted output and the third column is the maintenance process which is the management, realisation, and support.

Franciosi et al. (2020) indicated the selected indicators for economic category are the economic performance and investment; environmental more effluents to energy consumptions, wastes, emission, material resources for the maintenance and operation activities and non-compliance with the law and regulations of green buildings; and for social are on the customer, stakeholders, management, and non-compliance with the regulations which answering the third research question of this research.

The example on considering all the classified indicator in Figure 13 is shown in listed at Table 3 and well shown in Figure 14 on the sustainability pillars of environmental and management process for maintenance and operation process on maintenance and operation impacts towards sustainability.

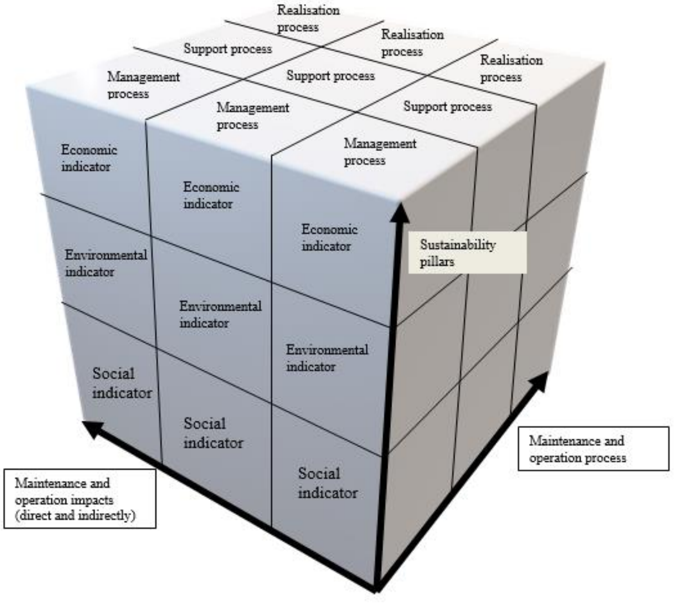


Figure 13. Conceptual Framework on Measuring the Maintenance and Operation Impact of High-Rise Residential Building Towards Sustainability

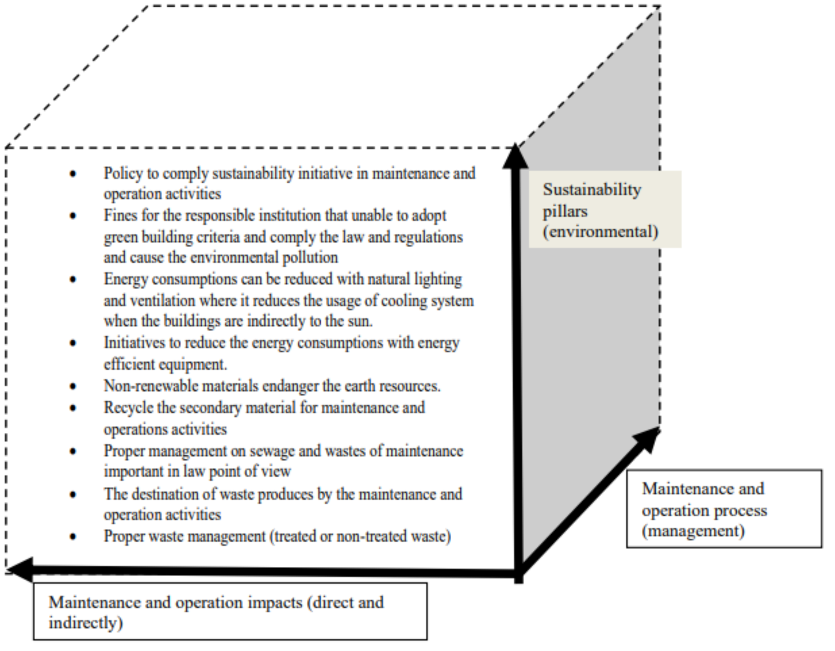


Figure 14. Example of Relationship of Environmental Pillars and Management Process on Maintenance and Operation Impacts

This conceptual framework is beneficial to help the stakeholder to decide on which action or indicators that they should focusing on in maintenance and operation of high-rise residential building. For example:

- Maintenance and operation would be interested in maintenance and operation activities that contribute impacts to environment. These can help them to monitor and ensure a better decision and action to be taking care off.
- Marketing manager would be focusing on the economic impacts on maintenance and operation activities to implement a better action to lower the cost and gain profit from the investment of the building.

Other than that, this conceptual framework can be consulted by external stakeholder which is customer/ tenant, government, and investors. This also increase the awareness of maintenance and operation impacts towards sustainability among the stakeholders. Different stakeholders focus on different process according to their main focus on the sustainability category.

CONCLUSION

The development of the conceptual framework in measuring the maintenance and operation impacts on high-rise residential buildings towards sustainability is relevant to provide a holistic view to the future research in order to fulfil the research gap from previous researcher. Most of the previous researcher more focusing on the one indicator of the sustainability which limited to measure the specific aspects of the sustainability of high-rise residential buildings. This research aimed to identify the relationship between maintenance and operation of high-rise residential building and sustainable issues and the impacts of maintenance and operation on sustainability. Systematic literature review was conducted by following the three steps of screening and Atlas.ti software is used to give network view to future researchers. From 18 research papers that been selected after the third screening, there are three sustainability indicators which are economic, environmental, and social which focus more on the tenant and management behaviours that been used to assess the maintenance and operations impacts of high-rise residential buildings on sustainability.

The correlation between maintenance and operations of high-rise residential building and sustainable issues are based on the three indicators of sustainability which are economic that focus on maintenance cost of the buildings, environmental were focusing on the environmental impacts and the usage of recycle materials and renewable energy in maintenance and operation activities, and social which focus more on the tenant and management behaviours such as the awareness on sustainability behaviours where minimum the usage of energy and implement the green criteria to provide a comfortable living in the buildings.

Maintenance still use conventional measures to evaluate the impact of maintenance and operation performance towards sustainability and until 2015, most of the papers does not provide any sustainability indicators for measuring maintenance and operation impacts on those three sustainability pillars. Recent studies that provided first classification on measuring maintenance and operation performance somehow do not provide general classification or the exhaustive framework of sustainability performance on sustainability indicators that affected by maintenance and operation process. To consider the gaps studies that mentioned above, a few recommendations need to be implemented in future research where more research is needed in measuring maintenance and operation of high-rise residential buildings since the demands of high-rise properties increasing followed by the increasing of populations, broaden the scope of maintenance and operations impacts by relate with the government involvement in sustainability management and consider the details and make comparison on challenges of measuring maintenance and operation impacts in selected countries due to their level of awareness on sustainability.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of this study under the Special Incentive for Supervision in Geran Penyelidikkan Khas (GPK) by Universiti Teknologi MARA, Malaysia [Ref. No: 600-RMC/GPK 5/3 (261/2020)].

REFERENCES

Aksah, H., Isnin, Z., Rahim, S. H., & Safiee, L. S. (2016). Challenges in achieving functional performance criteria on refurbished historical building. Advanced Science Letters, 22(5–6), 1517–1521. https://doi.org/10.1166/asl.2016.6664

Aldairi, J., Khan, M. K., & Munive-Hernandez, J. E. (2017). Knowledge-based Lean Six Sigma maintenance system for sustainable buildings. International Journal of Lean Six Sigma, 8(1), 109–130. https://doi.org/10.1108/IJLSS-09-2015-0035

Aleksanin, A., & Sborshikov, S. (2018). Interrelation the life cycle of an object and the concept of sustainable development. IOP Conference Series: Materials Science and Engineering, 365(6). https://doi.org/10.1088/1757-899X/365/6/062006

Alhouli, Y. (2011). Development of Ship Maintenance Performance Measurement Framework to Assess the Decision Making Process to Optimise in Ship Maintenance Planning. https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:32016R0679&from=PT%0Ahttp://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52012PC0011:pt:NOT

Bucoń, R., & Czarnigowska, A. (2021a). A model to support long-term building maintenance planning for multifamily housing. Journal of Building Engineering, 44(February). https://doi.org/10.1016/j.jobe.2021.103000

Bucoń, R., & Czarnigowska, A. (2021b). A model to support long-term building maintenance planning for multifamily housing. Journal of Building Engineering, 44(July). https://doi.org/10.1016/j.jobe.2021.103000

Chew, M. Y. L., Conejos, S., & Azril, F. H. Bin. (2019). Design for maintainability of high-rise vertical green facades. Building Research and Information, 47(4), 453–467. https://doi.org/10.1080/09613218.2018.1440716

Chiang, Y. H., Li, V. J., Zhou, L., Wong, F., & Lam, P. (2016). Evaluating Sustainable Building-Maintenance Projects: Balancing Economic, Social, and Environmental Impacts in the Case of Hong Kong. Journal of Construction Engineering and Management, 142(2), 06015003. https://doi.org/10.1061/(asce)co.1943-7862.0001065

Chiang, Y. H. Y. H., Li, V. J. V. J., Zhou, L. L., Wong, F., & Lam, P. (2016). Evaluating Sustainable Building-Maintenance Projects: Balancing Economic, Social, and Environmental Impacts in the Case of Hong Kong. Journal of Construction Engineering and Management, 142(2), 06015003. https://doi.org/10.1061/(asce)co.1943-7862.0001065

Chohan, A. H., Irfan, A., & Awad, J. (2015). Development of quality indicators of housing design (QIHD), an approach to improve design quality of affordable housing. Open House International, 40(4), 10–17.

Cooper, J., Lee, A., & Jones, K. (2020). Sustainable built asset management performance indicators and attributes: A UK social housing case study example. International Journal of Building Pathology and Adaptation, 38(3), 508–522. https://doi.org/10.1108/IJBPA-08-2019-0069

De Silva, N., & Ranasinghe, M. (2010). Maintainability risks of condominiums in Sri Lanka. Journal of Financial Management of Property and Construction, 15(1), 41–60. https://doi.org/10.1108/13664381011027971

Eslami, Y., Dassisti, M., Panetto, H., & Lezoche, M. (2019). Sustainability assessment of manufacturing organisations based on indicator sets: A formal concept analysis. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 11231 LNCS, 36–44. https://doi.org/10.1007/978-3-030-11683-5_4

Franciosi, C., Voisin, A., Miranda, S., Riemma, S., & Iung, B. (2020). Measuring maintenance impacts on sustainability of manufacturing industries: from a systematic literature review to a framework proposal. Journal of Cleaner Production, 260, 121065. https://doi.org/10.1016/j.jclepro.2020.121065

Jasiulewicz-Kaczmarek, M., & Stachowiak, A. (2016). Maintenance Process Strategic Analysis. IOP Conference Series: Materials Science and Engineering, 145(2). https://doi.org/10.1088/1757-899X/145/2/022025

Juan, Y., & Cheng, Y.-C. (2018). Improving Building Longevity, Adaptability, and Sustainability: Examination of Multi-Unit Residential Building Regulations in Taiwan. Civil Engineering Journal, 4(2), 394. https://doi.org/10.28991/cej-030999

Kampamba, J., Kachepa, S., Majingo, M., & Babitseng, K. P. (2020). An Assessment of Property Maintenance in high rise buildings in Gabrone (CBD). American Research Journal of Civil and Structural Engineering, 4(1), 1–11. https://doi.org/10.21694/2577-5944.20002

Khalid, E. I., Abdullah, S., Hanafi, M. H., Said, S. Y., & Hasim, M. S. (2019). The consideration of building maintenance at design stage in public buildings: The current scenario in Malaysia. Facilities, 37(13–14), 942–960. https://doi.org/10.1108/F-04-2018-0055

Khalid, M. S., Ahmad, A. H., & Sakdan, M. F. (2019). The challenges of maintaining and managing high rise buildings: Commercial vs residential buildings. International Journal of Recent Technology and Engineering, 7(6), 193–196.

Lateef, O. A., Tat, L. L. L. L., & Yeow, T. S. T. S. (2015). Analysis of sustainable maintenance behaviors in housing operation. ISEC 2015 - 8th International Structural Engineering and Construction Conference: Implementing Innovative Ideas in Structural Engineering and Project Management, December, 895–900. https://doi.org/10.14455/isec.res.2015.39

Lingard, H., Warmerdam, A., & Shooshtarian, S. (2017). The Definition of a Construction Project. August, 1–245. https://doi.org/10.13140/RG.2.2.21215.89765

Liu, S. S., & Ramadhan, G. (2017). Condition-based building maintenance strategy selection using constraint programming. ISARC 2017 - Proceedings of the 34th International Symposium on Automation and Robotics in Construction, 345–351. https://doi.org/10.22260/isarc2017/0047

Olanrewaju, A., Tan, S. Y., Tat, L. L., & Mine, N. (2017). Analysis of Homeowners' Behaviours in Housing Maintenance. Procedia Engineering, 180, 1622–1632. https://doi.org/10.1016/j.proeng.2017.04.325

Ping, L. Z., & Chen, C. H. (2016). A Study to Compare the Cost of Operation and Maintenance in Green Building Index (GBI) and Non-Green Building Index (Non-GBI) Rated Building in Malaysia. MATEC Web of Conferences, 66. https://doi.org/10.1051/matecconf/20166600028

Puķite, I., & Geipele, I. (2017). Different Approaches to Building Management and Maintenance Meaning Explanation. Procedia Engineering, 172, 905–912. https://doi.org/10.1016/j.proeng.2017.02.099

Radziejowska, A. (2020). Method for assessing maintenance and maintainability in residential buildings-one of the basic categories of the social aspect of sustainable construction. International Journal for Engineering Modelling, 33(3–4), 97–109. https://doi.org/10.31534/engmod.2020.3-4.ri.06m

Safa, M., Sabet, A., Macgillivray, S., Davidson, M., Kaczmarczyk, K., Haas, C. T., Gibson, G. E., & Rayside, D. (2015). Classification of Construction Projects. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, 9(6), 625–633.

Samsudin, N. S., Khalil, N., Mohammad, M. Z., Md Ajis, A., Hamzah, H., Che Ibrahim, C. K. I., & Manu, P. (2023). An Ontology to Represent the Prevention through Design (PtD) Concept in Integrated Project Delivery (IPD) in the Construction Industry from an Architectural Perspective. Buildings, 13(5). https://doi.org/10.3390/buildings13051128

Samsudin, N. S., Mohammad, M. Z., Khalil, N., Nadzri, N. D., & Khairil, C. K. I. C. I. (2022). A thematic review on Prevention through design (PtD) concept application in the construction industry of developing countries. Safety Science, 148(December 2021), 105640. https://doi.org/10.1016/j.ssci.2021.105640

Silva, N. De, Ranasinghe, M., & Silva, C. R. De. (2016). Risk analysis in maintainability of high-rise buildings under tropical conditions using ensemble neural network. Facilities, 34(1), 2–27.

Ta, T. L. (2006). Managing High-Rise Residential Building in Malaysia: Where Are We? Naprec Conference, Inspen, 1–25.

Tushar, Q., Bhuiyan, M. A., Zhang, G., & Maqsood, T. (2021). An integrated approach of BIM-enabled LCA and energy simulation: The optimised solution towards sustainable development. Journal of Cleaner Production, 289, 125622. https://doi.org/10.1016/j.jclepro.2020.125622

Yahya, M. R., & Ibrahim, M. N. (2012). Building maintenance achievement in high rise commercial building: a study in Klang Valley, Malaysia. OIDA International Journal of Sustainable Development, 4(6), 39–46.

Yim, S. Y. C., Ng, S. T., Hossain, M. U., & Wong, J. M. W. (2018). Comprehensive evaluation of carbon emissions for the development of high-rise residential building. Buildings, 8(11). https://doi.org/10.3390/buildings8110147

AN OBSERVATION ON THE IMPLEMENTATION OF BIOPHILIC DESIGN STRATEGIES IN MALAYSIAN PLATINUM-RATED GREEN OFFICE BUILDINGS

Asniza Hamimi Abdul Tharim[1*], Sitinur Kamilah Mohd Idris[1], Asmalia Che Ahmad[1,2], Edi Purwanto[3] and Issa Tafridj[4]

[1]Centre of Studies for Quantity Surveying, Department of Built Environment Studies & Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, Seri Iskandar, 32610, Perak, MALAYSIA

[2]Green Safe Cities Research Group, Universiti Teknologi MARA, Shah Alam Campus, 40450, MALAYSIA

[3]Department of Management and Jaya, Universitas Pembangunan Jaya, Indonesia, Universitas Pembangunan Jaya, INDONESIA

[4]Department of Architecture and Center for Urban Studies, Universitas Pembangunan Jaya, INDONESIA

**Corresponding Email: asniz286@uitm.edu.my*

Abstract

Nowadays, construction in Malaysia has been growing rapidly and continuously developing. It promotes economic growth increasing goods prices and competition for occupation. Thus, this requires occupants to work diligently, resulting in spending most of their time working indoors. Due to these circumstances, occupants are required to work longer hours to fulfill the employer's expectations, such as meeting the deadline and doing the tasks required. Focusing on their work nonstop can develop different health issues, such as stress, unstable emotions, unproductive, and well-being, thus bringing the degradation of occupants' psychology. Maintaining personal psychology is crucial to enhancing their work performance. One of the ways to do so is by being closer to nature. However, their work nature limits their interaction with the natural environment. Hence, this is where biophilic design comes to the rescue. This research aims to identify the implementation of biophilic design strategies in Malaysia's platinum-rated green office buildings. This objective was achieved through an observation checklist on the biophilic design strategies of Malaysia's two platinum-rated green office buildings. The data gathered from observation were analysed, tabulated, and graphed using Microsoft Excel. The result from the observation on biophilic design strategies indicates that the offices only have a general and basic application of the biophilic design strategies. Subsequently, there is no module to access the biophilic design strategies in Malaysia's built environment. Hence, it is hoped that this research can contribute to biophilic design strategies knowledge enhancement, and professionalism.

Keywords: *Biophilic, Design Strategies; Green Rating; Office Building*

INTRODUCTION

The natural environment in the world is getting sickening day by day as many issues related to the environment keep on occurring constantly such as climate change, global warming, increasing sea water levels, and floods. Due to this, the quality of people's lives will be affected if these issues keep growing each day. Hence, this issue has given rise to the concept of the green environment which has become the globe's main agenda to make sure that sustainability can be a standard of living while maintaining nature from further damage caused by the economic growth of rapid developments in the city.

In the present day, people are starting to be aware of the current environmental situation, thus there is boundless apprehension about protecting the environment all across the globe. U.S. Green Building Council conducted a survey, and the result shows that many people believe sustainability design will become a more common practice and tradition in the world once humans realize its benefits. Principally, the productivity gains are believed to be linked with the arrangement of high-quality interior design which is highly related to green building features that are likely to influence the indoor environmental quality including Natural ventilation systems and advanced mechanical ventilating systems that can increase airflow and reduce occupants contact with airborne microbial agents; Building material and furniture that have low toxicity; Increased the usage of natural daylighting so that can reduce energy demands and enhance interior lighting quality while maintaining visual comfort; and heighten contact with the natural environment through opening window to the outdoors and inclusion of indoor plants for a psychological reason and also for air quality enhancement.

Interior environmental quality can improve individual performance, health, comfort, and moods and also for satisfaction. Thus, designers are starting to implement and appreciate a sustainable approach in every design solution to create a sustainable future for the later generations. Hence, the interior environment quality or indoor environmental quality (IEQ) has a strong relationship with the biophilic design strategies as the term Biophilia is also known as the love of nature derived from the environmental movement. IEQ can be defined as building signs' environmental quality which links to the health and well-being of the occupants in the space. To achieve high IEQ must include good lighting, comfortable temperature, and good space management. A fruitful biophilic design able to convey our ethics and relationship to nature then reflects the love of living and the beauty of nature. These components in the society in which human beings are characterized by health and productivity. The connection between biophilic design and sustainable design is one of the strategies for human re-linking to the natural environment as they can experience nature in the interior space (Makram & Abou Ouf, 2019, Fadda et al., 2023). Human participation through an interactive approach of natural elements such as plants, air, land, animals, water, and sky, also by adding a new essence to interior design and furniture could benefit the health of users. The approach and implementation of biophilic strategies in interior design is an advanced framework and is intended to be practical practice for the more effective design of the built environment. The success of the application depends on the consciousness towards nature as much as on constructing a new design technique. In the modern context, humans spent 90% of their life indoors like in office and school, due to the modern lifestyle.

Green Building Index (GBI) and biophilic design strategies are two different assessment frameworks. However, there is one criterion of GBI that links to the biophilic design strategies, which is the indoor environment quality. One of the sub-elements of indoor environment quality is biophilia and views (Al Horr, Ariff, et al., 2016). Hence, that is the major reason to conduct the research to identify the biophilic design strategies, occupants' perception towards biophilic design strategies, and occupants' perceived psychological performance in green-rated office buildings. Furthermore, international ranking systems, such as LEEDS, have already integrated the green building criteria and biophilic elements, to accredit the built environment as a green building. In contrast, Malaysia is still far from adopting these biophilic strategies with the green building criteria. By that, this is one of the main reasons for the researcher to research this topic.

From the observation conducted and the distribution of the questionnaire during the data collection phase, many people are not aware of the definition of biophilic design and the importance of biophilic design to a built environment and to a worker to sustain the mental well-being, maintaining their work performance, stable mood, and boost the cognitive function. The questionnaire structure can aid in acknowledging the benefits of biophilic design. Nevertheless, there is a broad study of biophilic design in the international context, but not in the Malaysian context. Therefore, this research acts as an eye-opener to the layman out there. It is crucial to determine the relationship between biophilic design strategies and occupants' perceived psychological performance to sustain Malaysia's economic growth. However, for this paper, this paper aims to identify biophilic design strategies implementation in Malaysia's green-rated office buildings.

Green Rating System in Malaysia

As Malaysia grows toward a higher level of urbanization, it is expected to face the increased demand for housing associated with the environmental impact. Malaysia is experiencing an increase in construction waste materials, energy waste, deforestation, landslides, and soil erosion. Due to these problems, Malaysia has developed its green building rating tools. Malaysia has four (4) main green building rating tools that were developed since 2009 which were Green Building Index (GBI), Green Real Estate (GreenRE), Skim Penilaian Penarafan Hijau Jabatan Kerja Raya (PH JKR), and Green Performance Assessment System (Green PASS). GBI and GreenRE were established by professional associations, meanwhile, PH JKR and Green PASS are government-driven. Currently, GBI has achieved its maturity as it frequently releases several tools for specific building types and applications. Hence, practically it is widely used for many buildings compared to other rating tools. Meanwhile, the other rating tools are not well preferred and have a lower awareness among the public. The reason for that might be because they were newly launched and still in the final stage of refinement.

Green Building Index

Over four decades ago the birth of green building concept because of awareness on the issue of sustainability (Yahaya, 2014). Besides that, green buildings also known as sustainable buildings are environmentally responsible and resource-efficient throughout the building lifecycle. According to previous research, it states that green buildings can reduce energy by up to 30% to 60% compared to the conventional building (Pandey, 2015). Furthermore, it is to make efficient use of resources, have significant operational savings, and increase workplace productivity. In 2009 Malaysian experts like Pertubuhan Arkitek Malaysia (PAM) and the Association of Consulting Engineers Malaysia (ACEM) developed local assessment tools called Green Building Index (GBI). GBI is Malaysia's Green Rating Tool for towns and buildings. It is a body to assesses and accredits whether the building or town can be certified as a green building or not. GBI is one of the pioneers and well-established assessments in Malaysia. It was created to foster sustainability in a built environment and elevate awareness of environmental issues among the multidisciplinary practitioners in Malaysia such as developers, architects, engineers, designers, planners, and contractors. This is to sustain a brighter and greener future for Malaysia. There are six criteria in the GBI (2022) which is:

1. Energy Efficiency (EE)
2. Indoor Environmental Quality (IEQ)
3. Sustainable Site Planning and Management (SM)
4. Material and Resources (MR)
5. Water Efficiency (WE)
6. Innovation (IN)

The GBI Rating Tools are specifically developed in parallel with Malaysian tropical climates, environmental and development context, and finally, for the cultural and social needs. The concept of GBI is the same as international rating systems such as BREEAM (Building Research Establishment Assessment Method), USA's LEED (Leadership in Energy and Environmental Design) and has been evaluated to be adapted to Malaysian climate conditions (Samari, Godrati et al., 2013). Table 1 below shows the rating points of GBI.

Table 1. GBI Ratings

Points	GBI Rating
86+ points	Platinum
76 to 85 points	Gold
66 to 75 points	Silver
50 to 65 points	Certified

(Source: GBI, 2022)

Green-Rated Office Building

The concept of a green office building is to provide a high-quality workplace and comfortable working environment. Kwon et al. (2019), that green-rated office buildings could contribute to the satisfaction of the physiological and psychological of the occupants. Past research has proved that green building office can boost productivity, lower the absence, and improves the occupants' emotions. In Malaysia, governments, and business organizations have started the implementation and approach of the green office concept because of the eagerness to sustain a healthy. According to the GBI, there are around 300 buildings that have been certified as green buildings and the majority of the buildings are from commercial buildings. To scope down the numbers and areas, there are around 78 green-rated office buildings in Kuala Lumpur and ten of them are from the government offices (GBI). Every green office building has its own distinctive, innovative, and unique features that make a difference from the normal and conventional buildings, hence, improving the building's performance. The features can be seen on the façade of the buildings and the material used for the building. Furthermore, green buildings must have a specialty such as green water harvesting (Isa et al., 2013). Previously, Delmas and Pekovic (2012) surveyed green office buildings and showed that they have 16% higher productivity compared to conventional offices. However, there are several challenges in implementing green building such as limited knowledge, budget allocation, high maintenance budget, mindset, high initial cost, liability for design risk, and many others (Andreucci et al., 2021; Zhong et al., 2021; Clancy, 2014).

Biophilic Design Strategies

The practice and the application of the biophilic design are associated with various design strategies that can refer to attributes and experiences. There are three types of biophilic design strategies framework which are the direct experience of nature, the indirect experience of nature, and the experience of space and place. The direct experience is the actual connection with the natural environmental features in the built environment while the indirect experience refers to contact with the imitation of nature images from its original condition. Lastly, the experience of space and place indicates spatial features characteristic of the natural environment (Kellert & Calabrese, 2015). Table 2 shows items of attributes and experience of biophilic design strategies.

Table 2. The Attributes and Experience of Biophilic Design Strategies

Direct Experience of Nature	Indirect Experience of Nature	Experience of Space and Place
Light	Image of nature	Prospect and refuge
Air	Natural materials	Organized complexity
Water	Natural colours	Integration of parts to wholes
Plants	Simulating natural light and air	Transitional Space
Animals	Naturalistic shapes and forms	Mobility and wayfinding
Weather	Evoking nature	Cultural and ecological attachment to place
Natural landscape and ecosystem	Information richness	
Fire	Age, change, and patina of time	
	Natural geometries	
	Biomimicry	

(Source: Kellert & Calabrese, 2015)

Apart from the above attributes of Biophilic Design Strategies, various design elements can be taken as an example of biophilic when designing a space, interior, exterior, or building for biophilic design as described in the following Table 3.

Table 3. Design Element of Biophilic

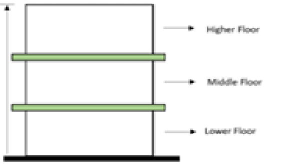
Design Elements	Description
Rooftop Garden	The benefits of a roof garden include ecological benefits, such as improved local microclimate, regulating the temperature and humidity of the city, blocking dust, and purifying the air. Rooftop garden helps to complement the landscape of the city by growing trees, shrubs, and grass flowers on the roof (Jafari, Yunos, Utaberta & Ismail, 2015).
Green Wall	Vertical greening or green walls is an effective merger of nature and structure. Green walls can improve the occupants' well-being around the building and also have positive influences on social and aesthetic values (Rakhshandehroo & Yusof, 2015). Nevertheless, the green wall system acts as a passive design solution that can contribute to building sustainability (Manso & Gomes, 2015).
Green Courtyard	The characteristic of a courtyard is having an enclosed area surrounded by buildings or walls and it has an open-air space (Almhafdy, Ahmad & Ibrahim, 2013). In the modern era, a courtyard can function as a meeting place or area for gardening, working, playing, sleeping, and cooking. Green courtyards increase positive impacts on plant physiology and the psychology of occupants.
Opening Window	The opening window's application utilizes the full capacity of daylighting. This is crucial in a built environment. This is because daylight can improve occupants' emotions, and performance, and avoid visual discomfort. Furthermore, daylight can create a dynamic space while reducing a building's energy needs (Kaya, Yucedag, & Asikkutlu, 2018).
Indoor Potting Plants	Indoor potting plants can increase the comfort and attractiveness of a built environment. Additionally, plants are the basic natural elements that represent the natural world. Effects of indoor potting plants on outcomes relevant to the effectiveness and well-being of office workers have been carried out in several research, as stated by (Bringslimark, Hartig & Patil, 2007).
Water Features	A waterscape can be defined as a small landscape in an indoor environment that combines small plants, rocks, water devices, and other materials to replicate the river.

METHODOLOGY

OBSERVATION FORM

RELATIONSHIP BETWEEN BIOPHILIC DESIGN STRATEGIES AND OCCUPANTS' PERCEIVED PSYCHOLOGICAL PERFORMANCE IN GREEN RATED OFFICE BUILDING

Name of the Office	
Date of the Observation	
Duration of the Observation	
Observation Floor	
Numbers of Occupants	



Section 1: Please tick (/) to relevant box.

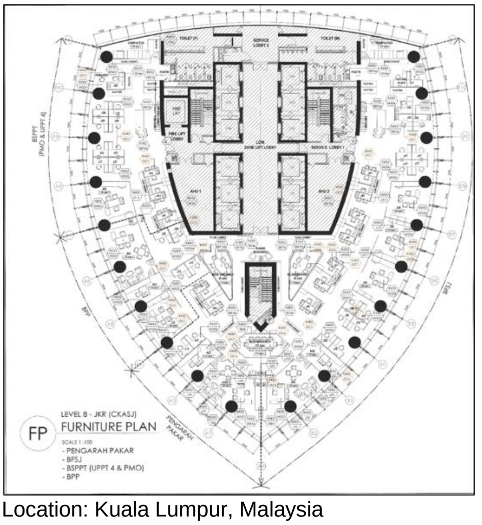
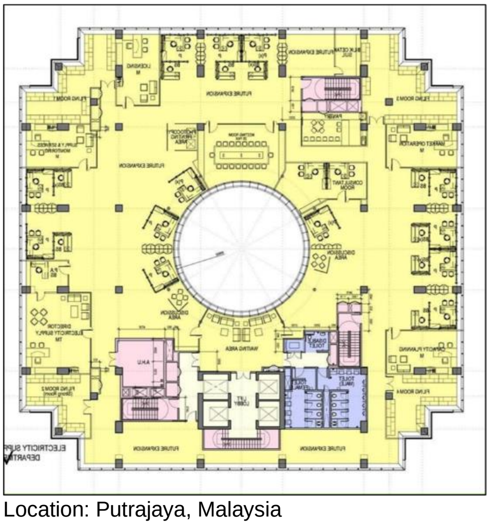
STRATEGIES	ELEMENTS	MAXIMUM POINTS	SCORE
Direct Experience of Nature	Light	10	
	Air	10	
	Water	5	
	Plants	15	
	Animals	5	
	Natural Landscape and Ecosystem	5	
	Fire	5	
	TOTAL	50	
Indirect Experience of Nature	Image of Nature	5	
	Natural Materials	5	
	Natural Colour	5	
	Simulating of Natural Lights and Air	5	
	Naturalistic Shapes and Forms	2	
	Evoking Nature	2	
	Information Richness	2	
	Age, Change, and Patina of Time	1	
	Natural Geometries	2	
	Biomimicry	1	
	TOTAL	30	
Experience of Space and Place	Prospect and Refuge	4	
	Organized Complexity	2	
	Integrating of Parts to Whole	4	
	Transitional Space	3	
	Mobility and Wayfinding	3	
	Cultural and Ecological Attachment to Place	4	
	TOTAL	20	

Figure 1. Observation Template

According to Ajayi (2017), observation can be defined as a technique for obtaining information by accurate vision and experience as they occur in nature concerning cause-and-effect relations. It can measure the variables under investigation. Observation can be attended on any subject matter: this could include a description of the scene, behavior to observe, and overall conclusion of the events. Thus, the setting must be expressed, and self-conscious notations of how observing is done. Systematic observation requires deliberate planning on what to observe (Kabir, 2016). For this research, observation just took three (3) hours during the weekday at the selected office, due to the office standard of procedure (SOP) during the pandemic of Covid-19. In this research, the reason for conducting observation was to identify biophilic design strategies that have been applied to the office building. During the observation period, many occupants were not aware of the concept of biophilic design. They do not know what the strategies of biophilic design are, even though the strategies are there. Biophilic designs were not well-known in Malaysia compared to Western countries, especially in the United Kingdom and the United States of America. As for Asian countries, Singapore is Asia's only biophilic city followed by South Korea who starting to adapt biophilic design strategies to the interior of offices, houses, and shopping complexes. For the observation form, there is a list of checklists and detailed score indicators based on the observer's point of view for the observation form. The documentation phase will be made after the observation period. Each building will be divided into two zones of floor which are classified as lower floor and upper floor. All the observation checklist data for this research were analysed using Microsoft Excel. Figure 1 shows all the main strategies and sub-elements of each strategy. Direct experience of nature is the main sub-element with a total of fifty (50) points, followed by the indirect experience of nature with a total of thirty (30) points, and lastly, the experience of space and place with a total of twenty (20) points. The total maximum points for all sub-elements are 100 points. These points are adapted from GBI Assessment Criteria for Non-Residential New Buildings (NRNB), 2011. All the elements are straight from Kellert and Calabrese, 2015.

FINDINGS AND DISCUSSION

This observation of biophilic design strategies was conducted for direct experience of nature, indirect experience of nature, and experience of space and place. The observation procedure was carried out on weekdays for three (3) hours. All the checklist score was tabulated using Microsoft Excel to compare each strategy and element for two (2) zones of floor. Two (2) government offices that have green-rated scores by GBI were permitted for the researcher to conduct the observation at their respective offices. For this observation method, the score point was adapted from GBI assessment criteria for Non-Residential New Construction (NRNC), 2011.

BUILDING A	**BUILDING B**
	
Location: Kuala Lumpur, Malaysia GBI Rating: Platinum No of Storey: 37 Facade: Slanting Facade (Low e) Shading: Vertical and Horizontal Fins Steel Frame *Air Conditioning System: set at 24°C	Location: Putrajaya, Malaysia GBI Rating: Platinum No of Storey: 7 Facade: Double Glazing/ Tilting Façade Shading: Self-Shading (Slanting Design) *Air Conditioning System: set at 24°C

Building A

Direct Experience of Nature

Table 4 shows the result of observation for the direct experience of nature in the lower zone and Upper Zone which was on the eighth (8) floor and thirty-one (31) floors of Building A.

Table 4 shows a comparison of direct experience of biophilic design attributes between the lower zone and upper zone. Both zones have the same score points for light (f=10), air (f=8), water (f=0), animals (f=0), fire (f=3), and natural landscape and ecosystem (f=2). What makes the difference between these two (2) zones is the implementation of plants. The occupants in the lower zone took the initiative to make use of the plants to boost their performance. Plants' scores point for the lower zone was (f=10), while the upper zone was only (f=2). Hence, the total score for direct experience of nature for the lower zone was thirty-three (33) points Meanwhile, the score for the upper zone was twenty-five (25) points.

Table 4. Direct Experience of Nature for Building A

Direct Experience of Nature	Lower Zone (8th Floor)	Upper Zone (31st Floor)
Light	10	10
Air	8	8
Water	0	0
Plants	10	2
Animals	0	0
Fire	3	3
Natural Landscape and Ecosystem	2	2
Total	**33/50**	**25/50**

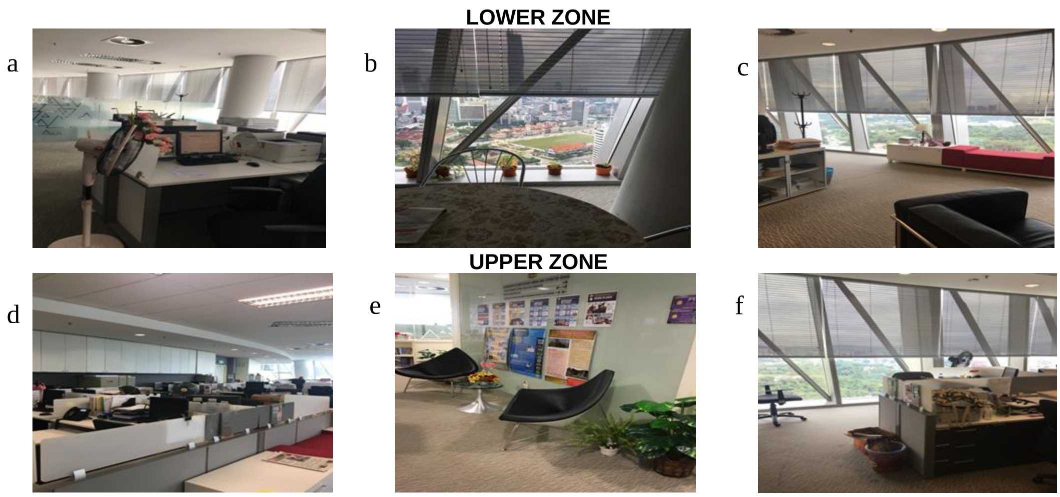


Figure 2. Direct Experience in Building A

Based on Figure 2 above, there is enough source of natural light. The office ambiance is enhanced with the addition of mechanical lights. According to the facilities manager, the office building is using sensory mechanical lights. The mechanical lights are automatically switched on based on the sun's orientation. This approach can save the energy of the whole office building. As you can see, the comparison between Figure 2 (a) and (d), where Figure 2 (a) was on the east side, thus, the lights were switched off. Meanwhile, Figure 2 (d) was on the west side that lacked the morning sun, hence, the mechanical lights were automatically switched on. The office is fully using mechanical ventilation which is air-conditioned. From the observation, the lower zone implements the application of potting plants as most of the workstations have at least one potting plant. The application of potting plants makes the environment look more energetic and serene. The upper zone was lacking with the implementation of potting plants. The office layout and the furniture position for both floors are quite the same. There is no significant difference in terms of the office design and floor plan. With the full utilization of wide windows, occupants can enjoy the outdoor view of the city center of Kuala Lumpur. They can reap the benefits of the natural landscapes and ecosystem also able to receive sensory information about nature.

Indirect Experience of Nature

Table 5 shows the result of observation for the indirect experience of nature in the lower zone and Upper Zone which was on the eighth (8) floor and thirty-one (31) floors.

Table 5. Indirect Experience of Nature for Building A

Indirect Experience of Nature	Lower Zone (8^{th} Floor)	Upper Zone (31^{st} Floor)
Image of Nature	5	0
Natural Material	3	3
Natural Colour	5	5
Simulating Light and Air	5	5
Naturalistic Shape and Form	2	2
Evoking Nature	0	0
Information Richness	0	0
Age, Change, and Patina of Time	0	0
Natural Geometries	2	2
Biomimicry	0	0
Total	**22/30**	**17/30**

LOWER ZONE UPPER ZONE

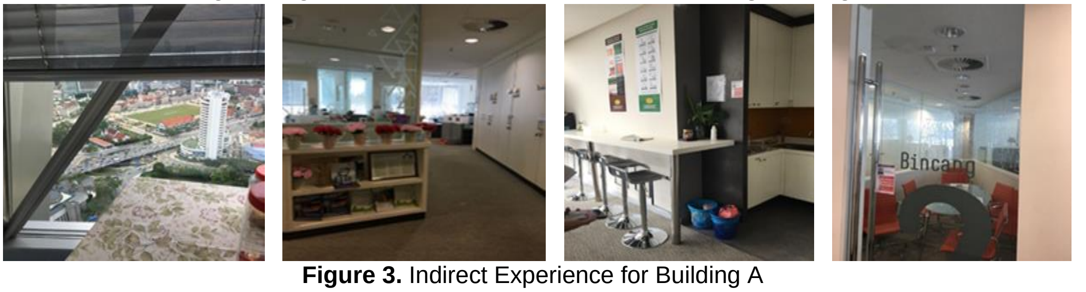


Figure 3. Indirect Experience for Building A

The application of the office's color for both zones is using a natural and monotone color scheme such as white, gray, and black. However, most of the furniture's colors use warn-tone colors such as red, and orange as shown in Figure 3. Both tones play an important role in occupants' moods and emotions. There was a hint of the image of nature for the lower zone as shown in Figure 3 Lower Zone. The natural geometrical attributes and naturalistic shape and form can be found in the design of the floor plan and the total building façade as the architects and designers chose a diamond motif for the concept. Thus, the triangular footprint tapers for the lower zone and then sifts to the leaf shape for the upper floor. Besides, there was also a triangular geometrical shape and motif for the glass wall or window inside the office building. As the office building was completed in 2014, there is no sign of age, change, or patina of time. Furthermore, the materials of the office building are mostly using natural materials. For instance, they use fabric and leather for the chairs, glasses, and partitions or space dividers, wood for the tables, and service door and file cabinets.

Experience of Space and Place

Table 6 shows the result of observation for the experience of space and place in the lower zone and Upper Zone which was on the eighth (8) floor and thirty-one (31) floors.

Table 6. Experience of Space and Nature Building A

Experience of Space and Place	Lower Zone (8th Floor)	Upper Zone (31st Floor)
Prospect and Refuge	4	4
Organized Complexity	1	1
Integrating Part to Whole	4	4
Transitional Space	3	3
Mobility and Wayfinding	3	3
Cultural and Ecological Attachment to Place	4	4
Total	**19/20**	**19//20**

Table 6 shows the comparison of the experience of space and place for the lower and upper zones at Building A. Each attribute got the same score for the lower and upper zones. Prospect and refuge (f=4), organized complexity (f=1), integrating part to whole (f=4), transitional space (f=3), mobility and wayfinding (f=3), and lastly, cultural, and ecological attachment to place (f=4). By all right, both zones got nineteen (19) points for the experience of space and place strategies.

LOWER ZONE **UPPER ZONE**

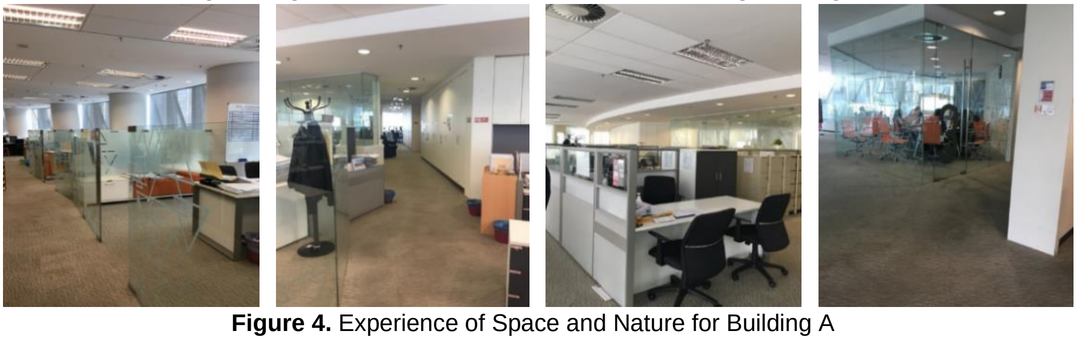


Figure 4. Experience of Space and Nature for Building A

For the experience of space and place strategy, all attributes managed to score perfect points except for organized complexity attributes. As shown in Figure 4 Lower Zone, occupants have their cubicles with the clear glass partition. This ability for occupants to perceive and oversee their surrounding situation whether to detect opportunities or even danger. Moreover, the office building provides high security for each floor. Only assigned occupants can enter the respective floor and department. The integration of parts to wholes are properly designed as there were clear linking space for each section. It was easy to access from one space to another space. Followed by the transitional space and mobility and wayfinding, occupants can overlook the whole space while standing. They can move freely, talking and discussing with their colleagues easily. There is a clear direction of the pathways and points of ingress and egress. Hence, the following Table 7 concludes the summary of observation analysis in Building A.

Table 7 shows the total percentage of biophilic design strategies at Building A, Lower Zone managed to get 74%. On the other side, the Upper Zone managed to get 61%. The difference between these two zones is only 13%.

Table 7. Summary of Biophilic Design Strategies Implementation in Building A

Biophilic Design Strategies	**Lower Zone (8th Floor)**	**Upper Zone (31st Floor)**
Direct Experience of Nature	33	25
Indirect Experience of Nature	22	17
Experience of Space and Place	19	19
Total	**74%**	**61%**

Building B

Direct Experience of Nature

Table 8 shows the result of observation for the direct experience of nature in the lower zone and Upper Zone which was on the ground floor and fifth (5) floor.

Table 8. Direct Experience of Nature for Building B

Direct Experience of Nature	**Lower Zone (Ground Floor)**	**Upper Zone (5th Floor)**
Light	10	7
Air	15	15
Water	5	0
Plants	10	10
Animals	0	0
Fire	3	3
Natural Landscape and Ecosystem	4	5
Total	**47/50**	**40/50**

Table 8 shows the comparison of direct experience of biophilic design attributes between the lower zone and upper zone. For the light attribute, the upper zone managed to score (f=10), and the lower zone only got (f=7). Both zones got the same score for air and fire attributes respectively (f=15), and (f=3). However, in the lower zone, water attributes were able to score perfect points (f=5), but for the upper zone none (f=0). Plants score points for lower and upper zones be head of the same score (f=10). Fire attribute score (f=3) for both zones. Lastly, natural landscape and ecosystem, lower zone (f=4), and upper zone (f=5). Thus, the total score for the lower zone is forty-seven (47) points, and the upper zone is forty (40) points. There is only a slight difference for both which is only by seven (7) points).

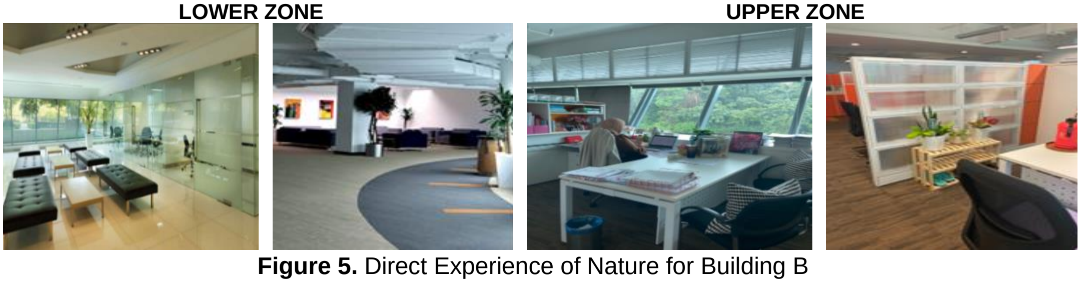


Figure 5. Direct Experience of Nature for Building B

Based on Figure 5, both zones have sufficient sources of natural lighting. For the upper zone, the designer(s) fully utilize and integrate the glass dome area by putting the glass panels. The spaces have a bright and warm environment because of the natural light in the large open space. The glass window can allow occupants to receive and observe the changes in the natural ecosystem. Furthermore, occupants can enjoy the outdoor views to release the stress from work by resting their eyes on the outside view and experiencing the diverse and healthy changes of nature by adapting the landscape character in their own space. Because of the slanted glass window, they are not exposed to direct sunlight which can make occupants' eyes hurt. There is the application of indoor potting plants for both zones. Plants can release extra supporting oxygen in the built environment which is good for occupants' health. Plants give comfort and serene visuals for the occupants as they can bring life to the office environment.

Indirect Experience of Nature

Table 9 shows the result of observation for the indirect experience of nature in the lower zone and Upper Zone which was on the ground floor and fifth (5) floor.

Table 9. Indirect Experience of Nature for Building B

Indirect Experience of Nature	Lower Zone (Ground Floor)	Upper Zone (5^{th} Floor)
Image of Nature	0	0
Natural Material	5	5
Natural Colour	5	5
Simulating Light and Air	5	5
Naturalistic Shape and Form	2	2
Evoking Nature	0	0
Information Richness	0	0
Age, Change, and Patina of Time	0	0
Natural Geometries	2	2
Biomimicry	0	0
Total	**19/30**	**19/30**

Table 9 shows a comparison of the indirect experience of biophilic design attributes between the lower zone and upper zone. The lower and upper zones have the same score for each design attribute. Image of nature (f=0), natural materials (f=5), natural color (f=5), simulating light and air (f=5), naturalistic shape and form (f=2), evoking nature (f=0), information richness (f=0, age, change and patina of time (f=0), natural geometries (f=2), and lastly biomimicry (f=0). Hence both zones managed to score only nineteen (19) points.

LOWER ZONE **UPPER ZONE**

Figure 6. Indirect Experience of Nature for Building B

The natural geometrical attributes and naturalistic shape and form can be found in the design of the floor plan and the total building façade. Same as the Building A architects' team and designers chose a diamond motif for the concept of the building. The diamond shape shows durability to ensure that the building is environmentally friendly, responsible for Putrajaya's landscaping, and resource efficient. Besides, as seen in the picture, the office building uses monotone colors such as white and gray to naturalize the working environment. For the lower zone, there is an organic shape of the sculpture. Furthermore, the office uses natural materials like fabrics, glass, and leather.

Experience of Space and Place

Table 10 shows the result of observation for the experience of space and place in the lower zone and Upper Zone which was on the ground floor and fifth (5) floor.

Table 10. Experience of Space and Place for Building B

Experience of Space and Place	Lower Zone (Ground Floor)	Upper Zone (5^{th} Floor)
Prospect and Refuge	2	2
Organized Complexity	1	1
Integrating Part to Whole	4	4
Transitional Space	3	3
Mobility and Wayfinding	3	3
Cultural and Ecological Attachment to Place	0	0
Total	**13/20**	**13//20**

For the experience of space and place strategies, all attributes for the lower and upper floor got the same score point, in which prospect and refuge (f=2), organized complexity (f=1), integrating part to whole (f=4), transitional space (f=3), mobility and wayfinding (f=3), and cultural and ecological attachment to place (f=0).

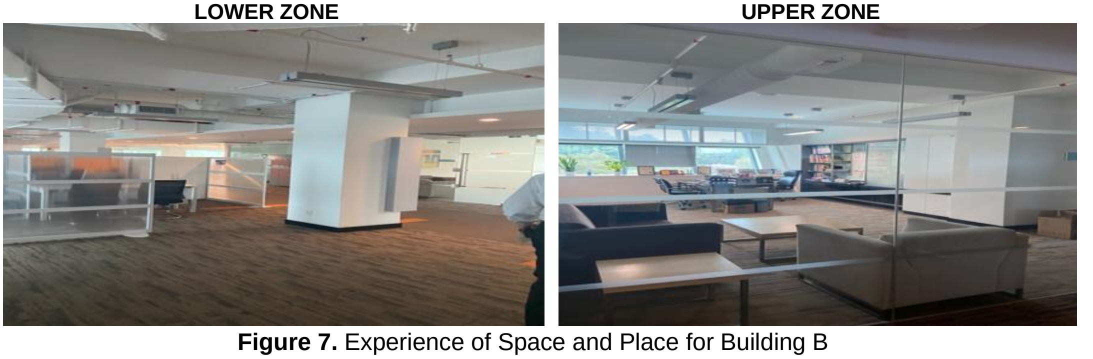


Figure 7. Experience of Space and Place for Building B

Each occupant has a partition in their workstation. This can make occupants feel secure and have their privacy when doing their work, but still able to move around freely from one space to another space as it has an open interior concept. Hence, there are clear prospect and refuge design attributes in the office building. There was a clear linking space that could easily be accessed from their workstation to the meeting room and toilets. Hence, Table 11 concludes the summary of the observation analysis in Building B.

Table 11. Summary of Biophilic Design Strategies Implementation in Building B

Biophilic Design Strategies	Lower Zone (Ground Floor)	Upper Zone (5^{th} Floor)
Direct Experience of Nature	47	40
Indirect Experience of Nature	19	19
Experience of Space and Place	13	13
Total	**79%**	**72%**

Table 11 shows the total percentage of biophilic design strategies at Building B, Lower Zone managed to get 79%. On the other side, the Upper Zone managed to get 72%. The difference between these two zones is only 7%.

Discussion: To Identify the Biophilic Design Strategies in Malaysia's Platinum-Rated Office Building

Table 11 summarizes the biophilic design strategies: direct experience of nature, indirect experience of nature, and experience of space and place of the selected case study in Malaysia green-rated office building. Before anything else and to highlight in this section, the researcher was using GBI index classification: platinum, gold, silver, and certified for the findings as the researcher was adopting the assessment criteria to measure the index or score point of biophilic design in Malaysia green rated office building. This is because Malaysia does not have the proper tools and modules to measure or assess biophilic design strategies.

Table 12. Biophilic Design Strategies in Malaysia's Platinum-Rated Office Building

Strategies	Building A		Building B	
	GBI Rating: Platinum		GBI Rating: Platinum	
	Lower Zone (points)	Upper Zone (points)	Lower Zone (points)	Upper Zone (points)
Direct Experience of Nature	33	25	47	40
Indirect Experience of Nature	22	17	19	19
Experience of Space and Place	19	19	13	13
Total Score	**74%**	**61%**	**79%**	**72%**
Findings	**Silver**	**Certified**	**Gold**	**Silver**

Based on the table above, Building B has the highest score points of biophilic design strategies for both zones compared to Building A. For the direct experience of nature Building B managed to achieve 47 points for the lower zone and 40 points for the upper zone. Building A only managed to get 33 points for the lower zone and 25 points for the upper zone. For the indirect experience of nature, Building B Putrajaya achieved 19 points for both zones. Meanwhile, Building A achieved 22 points for the lower zone and 17 points for the upper zone. Next, for the experience of space and place, Building B was able to score 13 points for both zones, and Building A able to score 19 points for both zones.

It was clear from this observation method that both buildings do not achieve the same as per their GBI ranking, which is platinum. This might be due to the lack of knowledge and awareness among the designers, architects, contractors, or users towards the biophilic design strategies. Lack of awareness from the architects, consultants, and clients is the key issue to the slow progress in implementing biophilic design (Esa, Hassan & Marhani, 2011).

CONCLUSION

The first research objective is achieved by observing biophilic design strategies for the direct experience of nature, the indirect experience of nature, and the experience of space and place. The observation has been conducted in two (2) selected case studies of Malaysian platinum-rated green office buildings. The office buildings have the same GBI score which is Platinum. The observation was conducted in a short period, and it was only given three (3) hours. For Case Study 1 at Building A, the total biophilic percentage for the lower zone is 74% which equals the silver score of the GBI rating, On the Other size, the upper zone managed to score only 61% which is equivalent to certified for the GBI Rating. For Case Study 2 in Building B, the total biophilic design strategies for the lower zone are 79% indicated as gold in the GBI rating. Meanwhile, the upper zone managed to score 72%, which is as far as silver certification for the GBI rating. From the finding, both office building for the lower zone has the highest score compared to the upper zone. However, the application of biophilic design strategies is more dominant in the Building B office building.

The research findings are mostly gained from the collective data of the observation phase and distribution of the questionnaire survey. This study is conducted over a short period. There is some point that can be highlighted to improve the research's outcome in the future. Previously, the observation data and score points were solely adopted from the GBI Assessment Criteria. Hence, future research can be conducted through an interview with the expert to come out with the module of assessment of the biophilic design strategies that specifically comply with Malaysian climates. Furthermore, future research can also consider the effect of the application of biophilic design strategies on the indoor environment quality whether for housing, schools universities, and hospitals.

ACKNOWLEDGEMENT

We gratefully acknowledge the financial support for this research by the International Exchange Grant (IEG) of Universitas Pembangunan Jaya (UPJ) Indonesia.

REFERENCES

Abdulbasit Almhafdy, Norhati Ibrahim, Sabarinah Ahmad, Josmin Yahya (2013). Courtyard Design Variants and Microclimate Performance, Procedia - Social and Behavioral Sciences, Volume 101, 170-180.

Ajayi, V. O. (2017). Primary Sources of Data and Secondary Sources of Data, (September).

Alhorr, Yousef & Arif, M. & Katafygiotou, Martha & Mazroei, Ahmed & Kaushik, Amit & Elsarrag, Esam. (2016). Impact of Indoor Environmental Quality on Occupant Well-being and Comfort: A Review of the Literature. International Journal of Sustainable Built Environment

Andreucci, M.B, Loder, A, Brown, M, Brajković, J. (2021). Exploring challenges and opportunities of biophilic urban design: evidence from research and experimentation, Sustainability 13 (8) (2021) 4323.

Andreucci, M, & Loder, A, & Brown, M, & Brajkovic, J. (2021). Exploring Challenges and Opportunities of Biophilic Urban Design: Evidence from Research and Experimentation. Sustainability. 13. 4323.

Bringslimark, T., Hartig, T., & Patil, G. G. (2007). Psychological Benefits of Indoor Plants in Workplaces: Putting Experimental Results into Context. HortScience horts, 42(3), 581-587.

Clancy, J.O (2014). Identifying Opportunities and Constraints for the Implementation of Biophilic Design Patterns in UK Landscape Architecture, University of Gloucestershire.

Esa, M.R., Marhani, M.A., Yaman, R., Rashid, A.A., & Adnan, H. (2011). Obstacles in Implementing Green Building Projects in Malaysia. Australian journal of basic and applied sciences, 5, 1806-1812.

Fadda, R.; Congiu, S.; Roeyers, H.; Skoler, T. (2023) Elements of Biophilic Design Increase Visual Attention in Preschoolers. Buildings 2023, 13, 1160.

Green Building Index (2022), Retrieved from https://www.greenbuildingindex.org/

Isa, M., Abd Rahman, M. M. G., Sipan, I., & Hwa, T. K. (2013). Factors Affecting Green Office Building Investment in Malaysia. Procedia- Social and Behavioral Science 105 (2013) 138 -148.

Jafari, Neda & Utaberta, Nangkula & Mohd YUNOS, Mohd Yazid & Ismail, Nor & Ismail, Sumarni & Mohd Ariffin, Noor & Jafari, Nastaran & Valikhani, Mahkameh. (2015). Benefits of Roof Gardens in Order to Usage of Urban Agriculture at Roof Gardens in High-Rise Buildings in Malaysia. Advances in Environment Biology. 9. 86-91.

Kabir, S.M.S. (2016) Basic Guidelines for Research an Introductory Approach for All Disciplines. Book Zone Publication, Chittagong.

Kaya Latif & Yücedağ, Cengiz & Aşıkkutlu, Hüseyin & ÇOKYİĞİT, Hale. (2018). Spatial Design Approaches to Prevent Damages from Earthquake inside the Buildings. Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi. 9. 55-62.

Kellert, S. R., & Calabrese, E. F. (2015). The Practice of Biophilic Design. Retrieved from www.biophilic-design.com

Kwon, M., Remoy, H., & Dobblelsteen, A. V. D. (2019). User-focused office renovation: a review into user satisfaction and the potential for improvement. Property Management Vol. 37 No. 4, 2019, 470-489.

Makram.A & Abou Ouf.T (2019). Biomimetic and biophilic design as an approach to the innovative sustainable architectural design. Conference: AR-UP 2019: Third International Conference of Architecture and Urban PlanningAt: Department Faculty of Engineering, Ain Shams University, Cairo

Manso, Maria & Castro-Gomes, João. (2015). Green wall systems: A review of their characteristics. Renewable and Sustainable Energy Reviews. 41. 863–871.

Pandey, A.K., Pandey, M. and Tripathi, B.D. (2015) Air Pollution Tolerance Index of Climber Plant Species to Develop Vertical Greenery Systems in a Polluted Tropical City. Landscape and Urban Planning, 144, 119-127.

Rakhshandehroo, Mehdi & Mohd Yusof, Mohd Johari & Mohd Tahir, Osman & Mohd Yunos, Mohd Yazid. (2015). The Social Benefits of Urban Open Green Spaces: A Literature Review. Management Research and Practice. 7. 60-71.

Samari, M, Ghodrati, N, Esmaeilifar, R, Olfat, P, & Mohd Shafiei, M.W. (2013). The Investigation of the Barriers in Developing Green Building in Malaysia. Modern Applied Science. 7. 10.5539/mas. v7n2p1.

Zhong, W, Schröder, T, Bekkering, J. (2021) Biophilic Design in Architecture and its Contributions to Health, Well-Being, and Sustainability: A Critical Review, Frontiers of Architectural Research.

SPATIAL RISK ASSESSMENT OF SICK BUILDING SYNDROME IN A UNIVERSITY SPACE: A GIS-BASED PHYSICAL CONTEXT MAPPING APPROACH

Syed Mohammad Asyraf Syed Mohammad Anuar[1], Abdul Rauf Abdul Rasam[1]*, Nawfal Kamarul Bahrain[1], Mawar Masri[2], Jamalunlaili Abdullah[3] and Colonius Atang[4]
[1]School of Geomatics Science and Natural Resources, College of Built Environment, Universiti Teknologi MARA (UiTM), Shah Alam Selangor, Malaysia
[2]School of Architecture and Interior Architecture, College of Built Environment, Universiti Teknologi MARA (UiTM), Shah Alam Selangor, Malaysia
[3]School of Town Planning and Landscape Architecture, College of Built Environment, Universiti Teknologi MARA (UiTM), Shah Alam Selangor, Malaysia
[4]Geography Programme, Faculty of Social Science and Humanities, University Malaysia Sabah, Malaysia

**Corresponding Email: rauf@uitm.edu.my*

Abstract
Sick building syndrome (SBS) is common in poorly maintained buildings due to poor air conditioning, ventilation, lighting, and others. Due to the building's construction and age, this study investigates the spatial risk level of SBS at the administration building of the College of Built Environment (CBE) at UiTM Shah Alam using the Geographical Information System-Multi Criteria Decision-Making (GIS-MCDM) method and the JKR's SBS criteria in a physical context. The study interviewed staff and the original owners of the space to obtain the estimated risk level of the SBS, while ArcGIS Pro visualised a 2D risk map based on the floor plan and the risk level. Based on the survey questionnaire, the respondents agreed that ventilation and air conditioning systems are the dominant criteria or factors for SBS. The finding revealed that before the 2020 renovation, there were many issues with ventilation and air conditioning, but after the renovation, the issues decreased. Although the CBE space is still relevant as a secure workplace, SBS still had an impact on some of the CBE spaces. Therefore, regular maintenance activities should be conducted with sustainable solutions towards a healthier campus and a safe space for building construction. The proposed map is also valuable for guidelines in CBE's occupational safety and health administration building.

Keywords: *Sick building syndrome (SBS); Spatial risk assessment and map; Physical context; Geographical Information System (GIS); multi criteria decision-making (MCDM)*

INTRODUCTION

The sick building syndrome (SBS) is an environmental illness affecting people in particular buildings more frequently and with a broader range of non-specific symptoms, normally without obvious clinical indicators or quantifiable symptoms (Gomzi & Bobi, 2008). It results from environmental, occupational, and psychological factors, with poor indoor air quality likely not the only factor contributing to complaints. SBS typically affects individuals working in offices or structures with proximity to workers.

SBS was first proposed in the mid-1970s to describe a building in which complaints of ill health are more common than expected. The WHO defined it in 1983 as a collection of non-specific symptoms, including eye, nose, and throat irritation, mental fatigue, headaches, nausea, dizziness, and skin irritations, which appear to be linked with the occupancy of specific workplaces (Palacios et al., 2020). These are typical symptoms among the general population, and they are classified as SBS because they have a temporal relationship with work in, or occupation of, a specific building (Crook & Burton, 2010).

Most people are also more likely to spend more than 80% of their time indoors, including at school and work (Norimichi et al., 2021). Besides, SBS is one of the health issues induced by poor indoor air quality (IAQ). IAQ difficulties in tropical regions such as Singapore, Thailand, and Malaysia are complicated to address in building design, engineering, and facility management. A previous study by the United States Environmental Protection Agency (US EPA) states that indoor air pollution is among the top five environmental health risks.

The WHO report on global health risks: mortality and burden of disease attributable to selected major risks (Norhidayah et al., 2013) explained that indoor air pollutants are made by both building materials and people doing things inside. One of the main effects of these is the spread of SBS. SBS has been observed to occur at a rate of 57% in offices, 31% in university laboratories, and 23–41% in university administration buildings, and it has become a primary environmental health concern (Wang et al., 2022).

Every factor for disease spreading to an individual in a space needs to be proven with multi-analysis such as spatial analysis, spatial risk assessment, shape analysis, and others. By looking at the data collection and analysis process, it is demonstrable. In addition, it needs to think about how to balance conservation, transformation, and development, and we need to use complementary approaches and combinatorial assessment methodologies. It is possible to think of these methodologies as flexible tools. They can be used to get around each method's limitations and ensure that the evaluation process is credible and consistent (Cerreta et al., 2010).

Previous research has mostly looked at how SBS is connected to the amount of pollution in the air inside using a population-based sample and specific environmental instruments in cross-sectional or descriptive-analytical studies (Lu et al., 2017; Fard et al., 2018; Reuben et al., 2019; Hoang Quoc et al., 2020). Lu et al. (2017) discovered that various SBS symptoms are linked with various personal, psychosocial, and environmental factors. Relationships between psychosocial factors and lower respiratory symptoms were more substantial than those with other SBS symptoms. Decent ventilation can lower risk factors and alleviate the symptoms of SBS.

Similarly, several studies have also been conducted in Malaysia related to the association between SBS and personal factors, psychosocial factors, and environmental factors in academic offices using questionnaires and environmental instruments (Zarith et al., 2019; Nurfarina et al., 2022). A worker's demographics, the indoor office environment, and indoor air pollutants were all found to be major risk factors for SBS (Zarith et al., 2019). Nurfarina et al. (2022) found that indoor air quality and psychosocial factors affected the prevalence of SBS among office workers. The studies have suggested implementing additional assessment and preventative measures to reduce workplace risk factors, especially a spatial approach.

To date, there is no practical study report linking physical environment factors with SBS risk assessment using GIS-MCDM approaches in the country. Although a GIS is commonly associated with outdoor building spatial analysis, combining traditional GIS methods and indoor positioning technologies can also be effectively used for indoor environments, while

MCDM is used as a set of systematic techniques to support decision-making processes and identify the most suitable option. For example, GIS can be used to create 3D detailed indoor maps that depict the layout, structure, and features of a building, as studies by local researchers (Hairuddin et al., 2022; Sha'aban, 2021; Othman et al., 2020; Mohd Hasmizi et al., 2020; Abdul Basir, 2019; Rasam et al., 2013; Bazlan, 2012). Having an accurate indoor map makes it easier to analyze potential risks and plan for emergencies. For instance, the ArcGIS Indoor tool offers a comprehensive indoor mapping solution for intelligent building management, including health risk mapping. It creates and shares maps, monitors facility operations, facilitates workplace safety, and views building space and floor plans (GISGeography, 2022).

This study uses GIS and spatial risk analysis techniques to identify SBS's risk level and map in the CBE's administration building at UiTM Shah Alam. Potential SBS in the CBE may influence SBS at a high rate due to some physical building effects with the leaky roof, poor air conditioning, and poor ventilation. Based on the experience of several CBE lecturers, it was also stated that the situation of SBS in the building is risky, especially since the renovation activities were not completed yet in 2020. The study also utilizes the checklist criteria form applied by the Public Works Department (JKR) for assessing the physical context of SBS. From the checklist, it can be analysed by using the GIS-MCDM approach to evaluate the SBS that can be potentially dangerous among the staff and students. The proposed 2D risk map of SBS can also create awareness among the community about the campus health building and environment.

MATERIAL AND METHOD

Study Area

This study was conducted in a selected building of the main administration office in CBE, UiTM Shah Alam (Block A, floor 3), as shown in Figure 1. This building was selected because of its age, which was developed 57 years ago. This condition is a suitable criterion for identifying the SBS potential and the risk level of the measured risk factors. The experienced technical staff also agreed with the selection of the building as a case study due to the physical condition of the building and data availability.

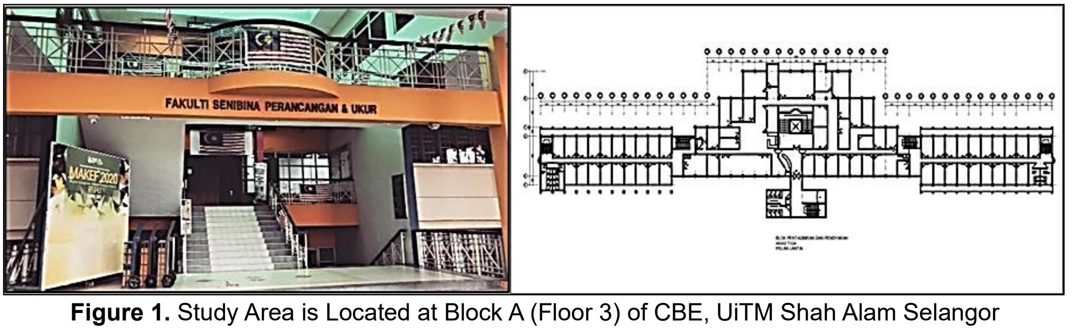


Figure 1. Study Area is Located at Block A (Floor 3) of CBE, UiTM Shah Alam Selangor

Research Methodology

A research workflow was systematically created to achieve the aim and objectives of the study, namely to evaluate and map the spatial risk level of SBS at the administration building of CBE. The workflow was divided into five (5) phases of research, including a preliminary study, data collection, data processing, data analysis, mapping, and results, as illustrated in Figure 2.

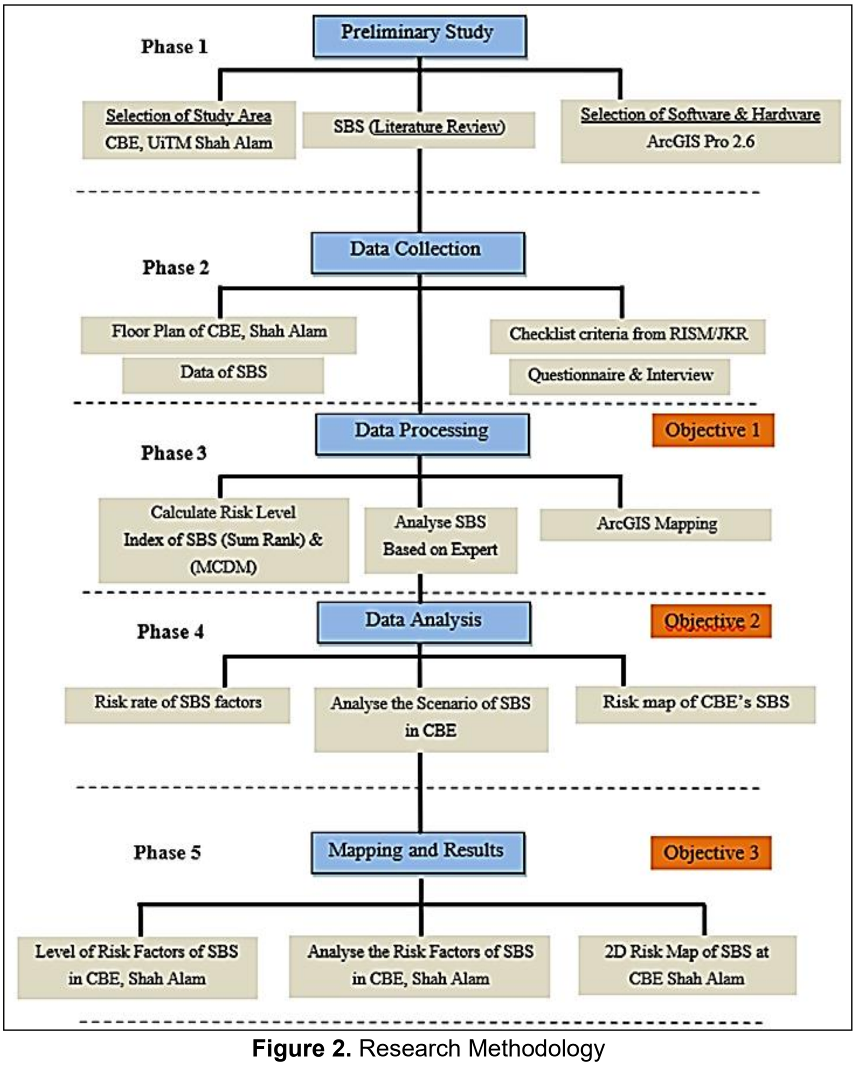


Figure 2. Research Methodology

Preliminary Study

The preliminary study is the first step of the research that helps better understand the many sources accessible about the study. Although preliminary studies are not performed in all systems, they can highlight critical issues that must be addressed in the quality process, including site selection, software selection, site preparation, and equipment availability for surveying and tools. This study adopted GIS-MCDM techniques and JKR's SBS criteria to investigate the spatial risk assessment and map of SBS in the CBE.

Data Collection and Risk Calculation

The data collected is a crucial part of the study. This phase was conducted with several appropriate approaches and instruments, comprising survey questionnaires and interviews. The criteria based on the JKR, as shown in Table 1, and MCDM (sum rank) techniques were also applied to estimate the risk level of SBS:

Survey Questionnaire and Interview

All participants in this questionnaire were academic, technical, and administrative staff in the CBE. This exploratory study used non-probability sampling due to the researcher selecting samples based on subjective judgment, relying heavily on the staff experience and expertise of the building (purposive sampling for simulating a risk map) and ease of availability of the respondents (convenience sampling for finalizing or verifying a risk map). Selected staff gave feedback on SBS due to their technical and working experiences at the college. The questionnaire was distributed manually to the respondent. The survey comprises four (4) main sections: A to D. Section A asks the respondent about their profile. Section B seeks to describe the experiences related to SBS in the building. Meanwhile, Section C requires the criteria of SBS that respondents feel by using a linear scale from very safe (risk score 1) to high-risk (risk score 5), and lastly, Section D requires the conceivable solution to SBS in the CBE.

Floor Plan

The floor plan was used to visualise the final output of the study. The floor plan of CBE was obtained from the facility technician at the college. From the floor plan, it was easier to remark on and identify the cases and issues in the selected space of the building.

Criteria of SBS

The criteria of SBS are shown in Table 1, which consists of five (5) specific criteria according to those suggested by the JKR in 2021 (JKR Standard JKR/SIRIM X:2021 Indoor Environmental Quality (IEQ) for office buildings) and based on previous studies (Abdulaali et al., 2020). The criteria include ventilation, air conditioning systems, air conditioning, the brightness of the lights, cleanliness, and other related factors.

Table 1. The Suggested Criteria of SBS Based on The Physical Building Context

No.	Criteria
1.	Ventilation and air-conditioning system (e.g., maintenance and others.)
2.	Condition of dust, smoke, fumes or fabric fibres in the air
3.	Bright or flickering lights
4.	Room’s cleanness and furniture layout (e.g., Crowded desks)
5.	Other (depends on the knowledge/experience respondent)

(Source: Adapted from the Public Works Department [JKR] Malaysia)

Risk Level Calculation

A five-point colour-coded risk level has been developed based on the sum rank techniques of the MCDM approach, as shown in Table 2. This is a standard and easy method of spatial risk assessment that the staff or inspector also uses in identifying the risk level in the CBE, making reports more user-friendly and easier to interpret, saving time, being comprehensive, and making the information accessible to non-technical users. The risk level is rated on a 5-point scale: Score 1 to 5 with a very safe condition (green), and the action matrix to be taken is preventive maintenance, 6 to 10, safe condition with condition-based maintenance (blue), and normal condition with a score from 11 to 15 required for repair work (grey). Meanwhile, rehabilitation work is needed for risky conditions with range scores from 16 to 20 (yellow). A score from 21 to 25 is high-risk and needs replacement work (red).

Table 2. The Risk Level of SBS Based on The Sum Rank Technique

Rating	Physical Condition	Action Matrix	Score
1	Very Safe	Preventive Maintenance	1 to 5
2	Safe	Condition Based Maintenance	6 to 10
3	Normal	Repairs	11 to 15
4	Risk	Rehabilitation	16 to 20
5	High-Risk	Replacement	21 to 25

(Source: Adapted from the Public Works Department [JKR] Malaysia)

Data Processing and Analysis

The acquired information is considered raw data and processed using specific methods and software. The main datasets were collected from a survey questionnaire and then used to analyse the current scenario of SBS and create a risk map with ArcGIS Pro. The risk level and the current scenario were identified using the sum rank and the MCDM, as explained in Table 1 and Table 2. MCDM is the relevant method for making the criteria decision since the opinion of every respondent has a different perspective on SBS. The risk map of SBS was processed using ArcGIS Pro, while the risk level from JKR's criteria was implemented to estimate the spatial risk assessment of SBS. The risk level was located in the space/zoning in the administration building of the CBE, based on the estimated risk level of SBS in Table 2.

RESULTS AND ANALYSIS

The Profile of Respondent

Table 3. Respondent Profile of The Study

Variables	Item	Frequency	Percentages
Position	Academic staff (final risk map)	4	28.57
	Technical Staff (Simulation risk map)	4	28.57
	Admin Staff (final risk map)	6	42.86
Years of Working Experience	Below three years	2	14.29
	3 – 7 years	3	21.43
	Seven years and above	9	64.29

Table 3 illustrates the respondent profile of the survey questionnaire using non-probability sampling as an exploratory study. There are 14 respondents involved in this survey, and the respondents also agreed with the selected study area and techniques applied in the study for identifying the risk factor of SBS at CBE. Most of the respondents have worked for 7 years and above. The respondents mostly have experience with before and after scenarios of SBS at CBE's space. The selection and number of respondents are sufficient to assess the risk level of SBS in the building in an exploratory study.

The Spatial Risk Level of SBS: A Comparative Analysis Before and After the Renovation

Based on the result obtained as displayed in Figure 4, all respondents agreed on the first and third criterion, which are ventilation and flickering lights, as leading factors that cause SBS in the CBE's space, but after the renovation completed in 2020, they are considered safe on scale 2. For the second criterion of SBS, the respondents agreed that dust, smoke, or fabric fibres are the factors of SBS in the CBE and, after 2020, are considered safe on scale 2, but respondent number 3 answered that it is still at a risk level, which is on scale 4.

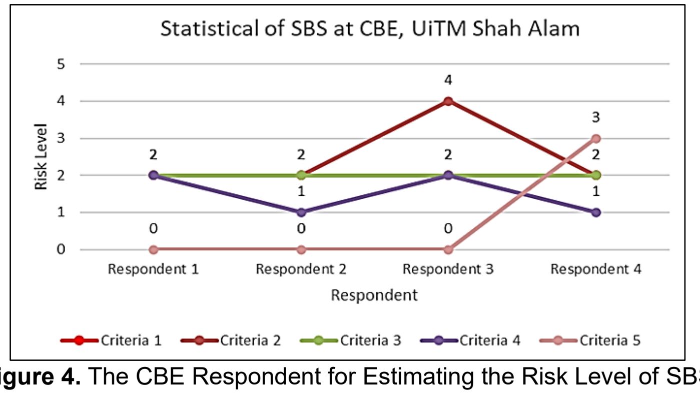


Figure 4. The CBE Respondent for Estimating the Risk Level of SBS

In the 4th criterion or factor, the cleanliness of the rooms shows respondent numbers 1 and 3 answers for safe, which is a scale of 2; it may be that the surrounding workplace is still crowded with stuff and other things, but respondent number 2 and 4 agree with the answer very safe on a scale of 1, meaning that respondents can see the difference in the year 2020 after the cleaning and renovation in CBE are completed. Last but not least, the fifth criterion of SBS is open to the respondents to answer if other (specific) factors of SBS happen to themselves or the individuals around them. However, only respondent number 4 answered this question, in which the setting of the temperature of the air conditioning affects the individual in CBE. However, the graph shows that SBS is affected differently by every individual based on the questionnaire result.

The respondents agreed to select criterions 1 and 3 as the dominant factors of SBS in CBE's space before the 2020 renovation, in which criterion 1 mentions the ventilation and air conditioning system. With these criteria, it can be concluded that there were many issues with ventilation and air conditioning before the renovation happened in CBE. However, after the renovation was completed in 2020, the issue of this factor was resolved when the maintenance team took drastic action. Maintenance is about 3 to 6 months every year, but it depends on the daily usage in the administration building of CBE. However, another criterion of SBS in CBE's space is the brightness of the flickering lights. Based on this criterion, the previous study already mentioned that lighting is critical in the workplace, where a lack of natural daylight or mechanical lighting can cause employees to feel discomfort. Lighting should be evenly distributed, not flicker or be too bright, and emit the appropriate lighting for employee comfort.

This SBS risk level decision refers to the opinion of selected staff with extensive experience with CBE buildings' technical conditions. However, other opinions should be considered for the subsequent study to get diverse views and issues for a more holistic solution for SBS at the CBE. Besides this, other key criteria or indexes such as energy efficiency (EE), indoor environmental quality (EQ), and sustainable site planning and management (SM) in the Malaysian Green Building Index (GBI) could be included in the subsequent study (Abdulaali et al., 2020).

The Current Scenario of SBS after the Renovation Activities

The SBS in CBE's space is getting worse before the year 2020, namely when the renovation activities were not completed yet. It happens when 10% of the staff in the administration building get affected, and several of them are admitted to the hospital. This statement is based on the interview session with four (4) CBE staff. All respondents agree that CBE's space before 2020 was at a high-risk level for SBS and, worst of all, affected individual health and physical building. This scenario of SBS happened in or before the year 2020, but after the year 2020, the issue of SBS in CBE, Shah Alam, decreased due to renovations completed. It was an excellent action to prevent many factors, such as the physical or structural structure of the building, human health, and others. It can be recapped during the interview session. Not all the space in CBE is at a high-risk level; mainly, the affected area is in lecturer rooms, meeting rooms, and others.

The risk level still needs to be at a perfect level, which is very safe because the respondents agree that the temperature level of the air conditioning still cannot be appropriately controlled. Even if the air conditioning can be controlled, as shown in Figure 5, Besides, the effects of air conditioning actually relate to moisture disease. Air conditioning started being repaired and replaced with a new one in September 2019, with this process completed by December 2021. After the action was taken seriously, the moisture disease decreased among staff in the administration building in the CBE. This is one of the good alternatives to preventing harm to human health.

Figure 5. The Physical Effects of SBS at The CBE Spaces

The Simulation Risk Map of SBS (Feedback from the Technical Staff)

Figure 6 indicates the qualitative risk maps of SBS, showing that every colour is selected based on the JKR's standard. This simulation map was produced based on early feedback from the selected technical staff to gain an overall view of the SBS condition in the building. In CBE's risk space, there are no high-risk spaces with the red colour level of SBS. The main reason is that the SBS condition improved after the renovation (e.g., air-conditioned ventilation) activities in 2020. However, there is a specific space that is still at-risk with a yellow colour; it is because the factor of SBS still affects the individual there, such as cough, runny nose, tiredness, and others. CBE's space is also still relevant as a safe place to work; the risk maps above show that this particular space is still very safe with a dark green colour, safe with a blue colour and normal with a grey colour. Effective maintenance will keep the space safe.

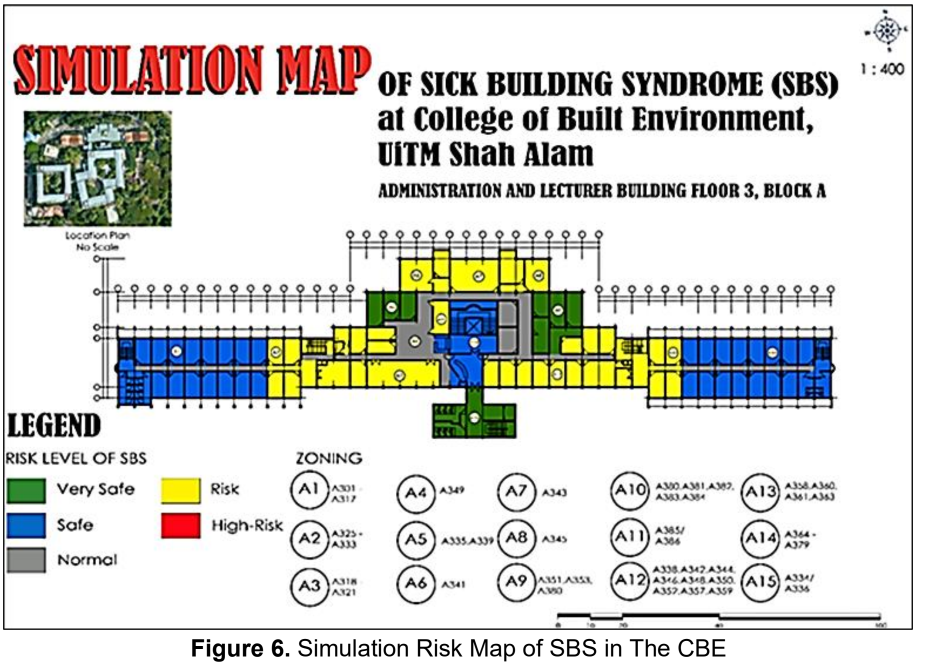


Figure 6. Simulation Risk Map of SBS in The CBE

Based on a previous study conducted by GISGeography, (2022), indoor mapping is beneficial with GIS for customers' usage. In shopping malls in Tokyo, for example, indoor mapping is implemented to display the inside of buildings and make it easier for customers to find shops or departments they want to visit. This statement is similar to the implementation of risk mapping of SBS in CBE's space, in which every individual will use the map to know the space that has a high risk of SBS and act as a guide or manual for others about SBS.

The Validation Process of the Final Risk Map of SBS (Feedback from The Original Occupant)

Table 4 shows the sum rank for every SBS criteria those respondents answered using a questionnaire form provided during the interview session. In this validation process, ten respondent participants (original occupants or owners of the rooms) ethically participated in the session to evaluate the simulation risk map before using it in the administration building. The feedback of these original owners of the space or room is vital to creating the SBS's finalised risk map. In the respondent's opinion, they thought criterion number 2, with 3.6%, which conditions include dust, smoke, fumes, or fabric fibres in the air in CBE's space, is still a risk level on the Likert scale on scale 4. In the respondent's opinion, the cleaning workers in CBE are understaffed to cover the whole space.

Table 4. Rank for Criteria SBS by The Owner of The Room

Respondent	Criteria				
	1	2	3	4	5
1	4	4	3	4	0
2	3	4	2	2	0
3	1	2	2	2	0
4	4	4	3	3	0
5	3	3	4	3	0
6	4	4	4	3	0
7	3	3	4	2	0
8	3	3	4	3	0
9	4	4	3	3	0
10	5	5	3	3	0
Sum	**34**	**36**	**32**	**28**	**0**
Mean	**3.4**	**3.6**	**3.2**	**2.8**	**0**

For criterion 1, with 3.4%, ventilation and air-conditioning systems in CBE's space are in the average range of risk based on the result obtained. Ventilation in specific spaces on floor 3 needs better functioning due to the old infrastructure. For air-conditioning, based on the opinions of respondents who said that the air-conditioning system is not stable when wing A drops the temperature of the air conditioner, wing B will be affected by the opposite temperature. Besides, in criterion number 3, with 3.2% brightness or flickering lights, respondents think that the lighting in specific spaces in CBE is still within the normal range because even if the building is not exposed to enough sunlight, the lighting provided or the type of lamp used helps them when they are inside the building. For criterion number 4, with 2.8%, which is room cleanliness and furniture layout, average respondents think that cleanliness depends on the individual for their area.

Figure 7 indicates a statistical movement trend of SBS criteria in the CBE's space during the validation process among the original occupants. These criteria were evaluated by the occupant of the risk zone. Criteria 1, 2, and 3 are dominant factors of SBS at CBE, which mentioned air conditioning and ventilation, dust, smoke, fumes, fabric fibres and brightness, and flickering lights. Three (3) dominant factors affected them. The dominant factor of SBS will affect human health, especially technical, academic, and administrative staff since the study area is in the administration building at the CBE, Shah Alam, and SBS may affect in the long-term or short-term. It has been proven in previous studies that indoor air quality and psychological variables have an impact on the incidence of SBS among office employees (Zarith et al., 2019; Nurfarina et al., 2022). It needs to maintain infrastructure and facilities frequently to maintain a clean environment.

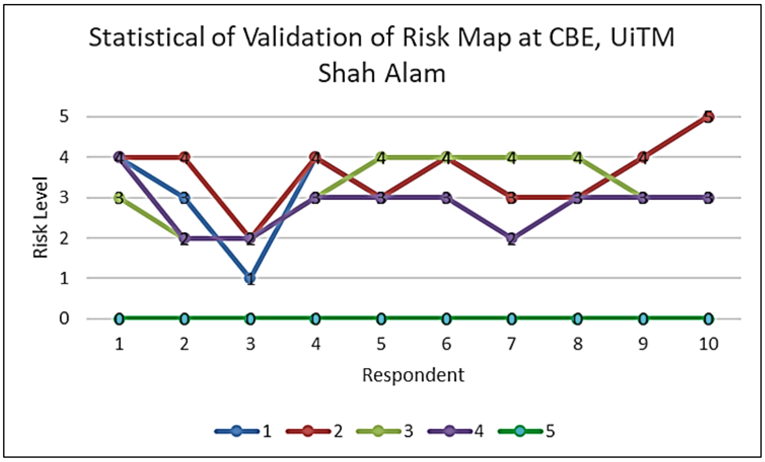


Figure 7. Overall Risk Level of SBS from The Selected Original Occupants of The Rooms in The CBE

The Applications of Final Risk Map of SBS in the CBE Building Construction

The final risk map of SBS has been verified according to the original owner of the space. Figure 8 shows that this approved risk map of SBS is now being used for Sub-Occupational Safety and Health Committee (SOSCHo) applications at CBE, Shah Alam. It would be used as guidelines and an awareness tool among the staff and students for the alert warning system of SBS. The colour of the risk level in the risk map is already updated for specific spaces in CBE, which are A1, A6, A7, A8, and A14. The changes (from the simulation risk map) happen because the individual's opinion of zoning differs from the previous interview session with the expert in the early data collection stage. Identifying accurate information based on the individual representing the area or zoning is a crucial process.

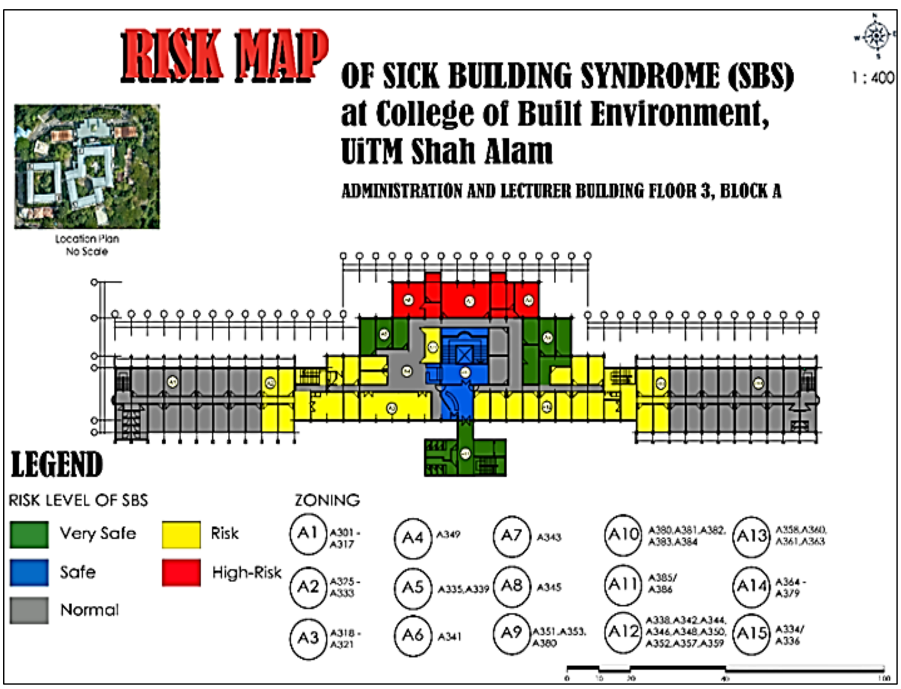


Figure 8. The Finalised Risk Map of SBS at The CBE

This indoor risk map, sometimes called an indoor risk assessment or a floor plan analysis, is a vital tool for guaranteeing the safety and security of occupants within a CBE structure. It offers insightful information and assistance regarding possible dangers, emergency evacuation zones, and crucial regions that could need particular attention. It is also an excellent investment that enhances the confidence and well-being of everyone who uses the space. Implementing this assessment and preventative measures could reduce workplace risk factors, as suggested by local researchers (Zarith et al., 2019; Nurfarina et al., 2022).

CONCLUSION

Sick building syndrome (SBS) will affect the individual's long-term or short-term health. Failure to take fast and effective action to address the issue of inadequate indoor air quality might have devastating effects on human health. This GIS-based physical context study has assessed the spatial SBS condition in the CBE based on the college's experienced respondents perceptions of the building's physical environment factors. The finding has shown that some of the CBE's spaces were affected by SBS, especially in the central region of the administration building of block A, due to some physical effects with the leaky roof, poor air conditioning, and poor ventilation. The CBE's space is still within range, but not very safe. Thus, ideal green-based solutions need to be introduced in the college to prevent human health and the physical effects of the building. It also needs to sustain the maintenance of the building's construction by monitoring the CBE's Sub-Occupational Safety and Health Committee (SOSCHo). Having an accurate GIS-based risk map of SBS makes it easier to analyze potential risks and plan for emergencies in the building. Socio-physiology: environmental and biomedical approaches are also recommended for the following study to measure and verify indoor air quality and building conditions, and scientifically 3D GIS indoor risk analysis and mapping.

ACKNOWLEDGEMENT

The authors thank UiTM Shah Alam for financially sponsoring this research through Geran Kolaborasi Entiti Penyelidikan (KEPU - 600-RMC/KEPU 5/3 (015/2021). The College of Built Environment (CBE) is also acknowledged for allowing the authors to ethically conduct the research in the college. Besides, thanks to the SOSCHo team of the CBE for constructive feedback in the study. Lastly, many thanks to all the people and organisations (RISM and JKR) who helped in completing this exploratory research.

REFERENCES

Abdulaali, H. S., Usman, I. M. S., Hanafiah, M. M., Abdulhasan, M. J., Hamzah, M. T., & Nazal, A. A. (2020). Impact of poor indoor environmental quality (IEQ) to inhabitants' health, wellbeing and satisfaction. *International Journal of Advanced Science and Technology*, 29(4 Special Issue), 1284–1296.

Abdul Basir, B., & Abdul Rasam, A. R. (2019). Evaluating Potential Free Software for Web-Based Multimedia Cartography, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLII-4/W16, 3–9, https://doi.org/10.5194/isprs-archives-XLII-4-W16-3-2019

Bazlan, M.J., & Abdul Rasam, A.R. (2012). Development of geographical based library information system (GeoLIS). In: *IEEE control and system graduate research colloquium*. Shah Alam, Selangor, pp 248–252. https://doi.org/10.1109/ICSGRC.2012.6287170

Crook, B., & Burton, N. C. (2010). Indoor moulds, sick building syndrome and building-related illness. *Fungal Biology Reviews*, *24*(3-4), pp. 106–113.

Cerreta, M., & De Toro, P. (2010). Integrated spatial assessment for creative decision-making: A combined methodological approach to strategic environmental assessment. *International Journal of Sustainable Development*, 13(1–2), 17–30.

Fard, R. F., Hosseini, M. R., Faraji, M., & Oskouei, A. O. (2018). Building characteristics and sick building syndrome among primary school students. *Sri Lanka Journal of Child Health*, 47(4), 332–337.

GISGeography, (2022). ArcGIS Indoors: See Your Digital Floor Plans in 3D. Retrieved from https://gisgeography.com/arcgis-indoors/

Gomzi, M., & Bobi, J. (2008). Sick Building Syndrome. Do we live and work in an unhealthy environment? *Period Biol,* 111 (1), 79–84. https://core.ac.uk/download/pdf/14408412.pdf

Hairuddin, F. I., Abdul Rasam, A. R., & Razali, M. H. (2022). Development Of A 3D Cadastre Augmented Reality and Visualization in Malaysia, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVI-4/W3-2021, 123–130, https://doi.org/10.5194/isprs-archives-XLVI-4-W3-2021-123-2022.

Hoang Quoc, C., Vu Huong, G., & Nguyen Duc, H. (2020). Working Conditions and Sick Building Syndrome among Health Care Workers in Vietnam. *International Journal of Environmental Research and Public Health*, 17(10), 3635. MDPI AG.

JKR, Garis Panduan Pemeriksaan Dan Penilaian Keadaan Bangunan Sedia Ada (JKR 21602 - 0004 - 13), JKR 21602-. Bahagian Senggara Fasiliti Bangunan, Cawangan Kejuruteraan Senggara Ibu Pejabat JKR Malaysia, 2013.

Lu, C.-Y., Tsai, M.-C., Muo, C.-H., Kuo, Y.-H., Sung, F.-C., & Wu, C.-C. (2017). Personal, Psychosocial and Environmental Factors Related to Sick Building Syndrome in Official Employees of Taiwan. *International Journal of Environmental Research and Public Health*, 15(1), 7. MDPI AG.

Mohd Hasmizi, N.S., Abdul Rasam, A.R., & Mohamed Saraf, N. (2020). E-Mosque Tourism: Discovering Mosques via Geodigital Mapping in Kuala Lumpur, Malaysia. In: Alias, N., Yusof, R. (eds) *Charting the Sustainable Future of ASEAN in Science and Technology*. Springer, Singapore. https://doi.org/10.1007/978-981-15-3434-8_44

Norhidayah, A., Lee, C. K., Azhar, M. K., & Nurulwahida, S. (2013). Indoor air quality and sick building syndrome in three selected buildings. *Procedia Engineering*, 53, 93–98.

Norimichi, S., Yoshitake, N., Hiroko, N., Kohki, T., Kayo, T., Masamichi, T., Tatsuya, H., & Chisato, M. (2021). Risk factors for the onset of sick building syndrome: A cross-sectional survey of housing and health in Japan. *Building and Environment*, 202, 107976. https://doi.org/10.1016/j.buildenv.2021.107976.

Nurfarina, Z., Juliana, J., & Irniza, R. (2022). Indoor Air Quality and Psychosocial Factors Related to Sick Building Syndrome among Office Workers in New and Old Buildings of a Public University in Klang Valley, *Malaysia. Mal J Med Health Sci*, 18(SUPP5), 1–9.

Othman, H., Abdul Rasam, A.R., Jaini, N. (2020). *GeoPark Management and GIS: Geospatial Tree Information Inventory System. In: Alias, N., Yusof, R. (eds) Charting the Sustainable Future of ASEAN in Science and Technology*. Springer, Singapore. https://doi.org/10.1007/978-981-15-3434-8_48

Palacios, J., Piet, E., & Nils, K. (2020). Moving to Productivity: The Benefits of Healthy Buildings. *PLoS One 15 (8),* e0236029.

Rasam, A. R., Hanif, F. A., Samad, A. M., & Hadi. R. A. (2013). Spatial information management system for building energy consumption. 2013 IEEE *3rd International Conference on System Engineering and Technology,* Shah Alam, Malaysia, 295-299. doi: 10.1109/ICSEngT.2013.6650188.

Reuben, U. (2019). Indoor air quality and sick building syndrome among Nigerian laboratory university workers. *J. Phys. Sci.,* 30(1), 179–195, https://doi.org/10.21315/jps2019.30.1.13

Sha'aban, S.N. (2021). A 3D GIS mapping for landscape geovisualisation and park management: A case study in Kuala Keniam Station, Taman Negara Malaysia. IOP Conf. Ser.: Earth Environ. Sci. 685 012010. doi:10.1088/17551315/685/1/012010

Suzuki, N., Nakayama, Y., Nakaoka, H., Takaguchi, K., Tsumura, K., Hanazato, M., Hayashi, T., & Mori, C. (2021). Risk factors for the onset of sick building syndrome: A cross-sectional survey of housing and health in Japan. *Building and Environment*, 202(April).

Wang, M., Li, L., Hou, C., Guo, X., & Fu, H. (2022). Building and Health: Mapping the Knowledge Development of Sick Building Syndrome. *In Buildings*, 12 (3). MDPI.

Zarith, A. Z., Zailina H., Juliana, J., Lim, F.L., & Jamal, H. H. (2019). Sick Building Syndrome among Office Workers about Office Environment and Indoor Air Pollutants at an Academic Institution, Malaysia. *Mal J Med Health Sci*, 15(3), 126-134.

EXPLORING THE BARRIERS TO ECO-INNOVATION IMPLEMENTATION IN CONTRACTOR FIRMS

Siti Sarah Mat Isa[1]*, Nazirah Zainul Abidin[2], Wan Norizan Wan Ismail[1], Norhafizah Yusop[1] and Norsyazwana Jenuwa[1]

[1]Department of Built Environment Studies and Technology, College of Built Environment Studies, Universiti Teknologi MARA, Perak Branch, 32610 Seri Iskandar, Perak, Malaysia

[2]School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, USM Penang, Malaysia

**Corresponding Email: sitis366@uitm.edu.my*

Abstract

Increased urbanisation has generated serious environmental pollution and ecological destruction, resulting in the global deterioration of the ecosystem. The construction industry needs to be eco-innovative to mitigate the negative environmental effects of construction development. In the construction industry of developing countries, the term eco-innovation (EI) is not adequately perceived. Recent literature has explored the determinants of EI but has rarely addressed the barriers to its implementation. The lack of previous studies accounts for the various perceived barriers. Thus, this paper aims to explore the barriers to EI implementation faced by large contractor firms in the Malaysian construction industry. A qualitative approach is adopted in this research using semi-structured interviews with 14 respondents, consisting of Grade G7 contractor firms. The results reveal that the barriers to EI come from internal and external sources. Four main barriers that hinder the implementation of EI by contractor firms are: i) firm-specific barriers; ii) cost difficulties; iii) people-related barriers, and iv) external pressures. The results obtained from this study on the barriers to EI may guide contractor firms to pursue sustainable competitive advantage effectively and explore a value-creation strategy to enhance EI implementation at the firm level. This study is practical and relevant for contractor firms undertaking both green and large-scale construction projects.

Keywords: *Eco-innovation; Barriers; Contractor firms; Construction industry; Malaysia*

INTRODUCTION

Malaysia is well known as a developing Asian country that has experienced rapid social and economic growth. The Malaysian construction industry has contributed wealth with constant progress of 3%–7% to the Gross Domestic Product (GDP) over the past 20 years and has played a vital role in the country's development by assisting other sectors to grow (Department of Statistics Malaysia, 2021). Unfortunately, increased urbanisation has generated severe environmental pollution and ecological destruction, resulting in the global deterioration of the ecosystem (Goi, 2017; Song & Yu, 2017). Furthermore, despite rapid advancements in the construction industry, most construction projects in Malaysia continue to use outdated methods that are no longer viable. Environmental degradation is inseparable from the development of new buildings and infrastructures. Construction activities produce construction waste, high pollution and carbon emissions and consume substantial amounts of energy and resources that contribute to the most significant share of the total negative impact on the environment (Bamgbade, Kamaruddeen & Nawi, 2017; Isa & Abidin, 2021). Continuing to deliver this development with a conventional approach and unsustainable construction practices will not solve the environmental concerns.

Malaysia is shifting towards sustainable development objectives, and national construction development is expected to change significantly. The construction industry embraces the Fourth Industrial Revolution (IR 4.0) in ways that would transform its productivity and competitiveness towards smart construction and advanced technologies (Yousif et al., 2022). Therefore, dealing with such complexity is not possible with the traditional view of construction practices. Dynamic changes are necessary for the 4.0 industrial era to align with the technological evolution that will eventually face shortly. This situation calls for efficient governance and excellent cooperation amongst various parties in ensuring continuous efforts are made to transform the construction industry to achieve more sustainable approaches. Thus, innovation is a key to improving productivity and environmental performance within the construction industry (Kamal, Yusof & Iranmanesh 2016; Davis, Gajendran, Vaughan & Owi, 2016). Innovation is creating value by using relevant knowledge and resources to convert an idea into a new product, process, or practice or improve an existing product, process, or practices (Varadarajan, 2018).

The increasing negative impact of construction activities on the environment has triggered greater environmental consciousness among construction firms, and innovation has become one of the most essential means for firms to achieve sustainable business growth. During the construction phase, the contractor firm's activities can negatively impact the natural environment are mainly determined by the types of materials or energy used during construction process, methods of construction, plants and machinery, and their firm's environmental strategies (Bamgbade et al., 2017; Waris, Liew, Kamidi & Idrus, 2014). Increasing environmental pressure and support for modernisation mean that innovation has become a primary means for firms to achieve sustainable development (Cai & Li, 2018). However, innovation is insignificant because it may put pressure on the environment. To mitigate any unfavourable environmental effects of the construction process, contracting firms must adopt new approaches. Innovations that can positively impact the environment are one way for firms to incorporate environmental concerns into their business strategies while enhancing their competitive advantage. An eco-friendly construction process and improvements in construction and management practices are required to attain higher regard for the environment.

Hence, eco-innovation (EI) has emerged as an imperative paradigm propelling the contractor firms towards the green growth to shift traditional construction practices that are inefficient, labour-intensive, slow, high in construction waste and carbon emissions (Hazarika & Zhang, 2019). In addition, the government had pledged to protect the natural environment and provide a better quality of life for future generations. The increasing awareness of sustainability in the construction industry has influenced business firms to improve their environmental performance and efficiency. Environmental sustainability must be incorporated into the firm's objectives, policies, and standards, and effectively communicated to all levels of management. Firms adopt EI in the form of new or enhanced versions of products and services, processes, and organisational management that result in better or more efficient practices and positively impact environmental development. EI can increase the competitiveness of construction firms while preserving the environment and its valuable resources for future generations. EI is valuable for reconfiguring the existing innovation system within the business growth model for an economy to embrace green growth characteristics (Singh & Chandran, 2017). Firms are capitalising on this transition by adding value to their businesses and carving out their niche to remain competitive and obtain a sustainable business orientation.

The literature on EI has been examined and explored from various perspectives throughout the last decade. Numerous studies have discussed the drivers of EI (Hazarika & Zhang, 2019; Bossle, Barcellos, Vieira & Sauvee, 2016), the dimensions of EI (Carrillo-Hermosilla, Del Río and Konnola, 2010; Kiefer, Carrillo-Hermosilla, Del Río and Barroso, 2017), the measurement of EI (Arundel & Kemp, 2009; Cheng & Shiu, 2012; García-Granero, Piedra-Munoz & Galdeano-Gomez, 2018). Studies on EI strategies conducted by Garcés-Ayerbe, Scarpellini, Valero-Gil & Rivera-Torres (2016), Tsai & Liao (2017), Jové-Llopis & Segarra-Blasco (2018) and Ge et al. (2018) enable firms to integrate environmental matters into their business operations. Unfortunately, the factors that hinder the EI implementation have been disregarded (Souto & Rodriguez, 2015; Szilagyi, Mocan, Verniquet, Churican & Rochat, 2018). In other words, firms in the construction industry that are suffering difficulties in EI implementation at the firm level have not yet received the necessary attention.

Furthermore, the construction industry frequently faces numerous problems when bringing new ideas and technology and understanding the innovation implementation process (Suprun & Stewart, 2015). Despite this, there is a knowledge deficit in studies that notably advocate for impediments to innovation adoption faced by contractor firms (Ozorhon, Oral & Demirkesen, 2016). Still, suppose these barriers are a chance to gain competitive advantages. In that case, they require changes in the services offered, construction methods, technology, and firm strategies (Ghisetti, Mazzanti, Mancinelli & Zoli et al., 2015). Thus, this paper aims to address the barriers to EI from a qualitative perspective to better understand the obstacles Malaysian contractor firms encounter. Understanding the barriers to EI may provide significant value to contractor firms in achieving competitive advantages and environmental sustainability in delivering their services.

LITERATURE REVIEW

Understanding the Eco-Innovation (EI) Concepts

Innovation is an important contributor to economic growth and is widely considered to improve the competitive advantage of a firm (Chen, Yin & Mei, 2018). Merging the concept of innovation to support environmental sustainability is directing the innovation to include environmental concerns to benefit both economic and environmental outcomes (Souto & Rodriguez, 2015). This objective can be reached by encouraging firms to implement eco-innovation (EI), especially in sectors with considerable environmental impacts in terms of pollution and water and energy consumption, such as construction (Hazarika & Zhang, 2019). New environmentally friendly production methods and improvements in business practices, product characteristics, and organisational capabilities are required to achieve tremendous respect for the environment.

The term ‘eco-innovation’ was first coined by Fussler and James (1996, cited in He, Miao, Wong & Lee, 2018), referring to new products and processes that provide customer and business value while significantly decreasing environmental impacts. Since then, many definitions of EI have emerged. Kemp and Pearson (2007) definition of EI is the most favourable by other researchers in this field. According to their words, EI is defined as *“the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution* *and other negative impacts of re- sources use (including energy use) compared to relevant alternatives".* This study defines EI as innovation introduced to firms or projects through new or improved versions of products, services, processes, or organisational management practices that produce better or more efficient services and contributes to environmental improvement. The essential part of this definition is the positive environmental impact of innovation, as EI has both economic and environmental benefits.

The Components of Eco-Innovation (EI) in Contractor Firms

EI practices are critical to embedding within the contractor firm as they are accountable for delivering the construction project within the specified contract. This study highlighted three EI components (process, products, and organisational EI) relevant to the contractor firms. Many previous researchers have highlighted these three types of EIs, process, product and organisational innovation, which are essential in EI implementation (Cheng, Yang & Shue, 2014; Peng & Liu, 2016; Singh, 2017; García-Granero et al., 2017). According to Cheng et al. (2014) and Cheng and Shiu (2012), process EI refers to improving existing production processes or adding new processes introduced to a firm to reduce its environmental impact. In the construction industry, Suprun and Stewart (2015) and Horbach et al. (2012) observe that process EI are the improvements in construction methods and technologies that are designed or developed for the accomplishment of general construction operations or the enhancement in the efficiency of the construction process to increase the resources utilisation. EI also aims to reduce the overall impact on the natural environment. Their decision to use advanced technology to improve the efficiency of construction processes, such as conserving energy, water, and other resources during construction, effective waste, and pollution management, and how they perform their work on-site in ways that do not jeopardise the project budget or schedule, and significantly reduce cost and improve productivity (Hazarika & Zhang, 2019; Yusof, Awang & Iranmanesh, 2017).

Meanwhile, product EI is the introduction of new or significantly improved products (regarding their characteristics), such as advancements in technical components and materials (Carrillo-Hermosilla et al., 2010). In the construction industry context, product EI refers to adopting eco-innovative products or services with considerably improved environmental and performance qualities in delivering sustainable building and infrastructure. Product EI's environmental impact stems from their usage throughout the building life cycle and disposal rather than their production (Cheng et al., 2014; Yusuf et al., 2018). Thus, the contractors are liable to recommend to clients and consultants eco-innovative products and materials that will increase the durability and quality, energy efficiency, reduce the pace of replacement and lower carbon emission during the operation of the building (Hazarika & Zhang, 2019; Bohari et al., 2015). This will protect the environment and provide end-users with a better quality of life.

Organisational EI refers to new or significantly improved routines, business models, methods and actions that change firms' practices, relations, and decisions (Marcon et al., 2017). Organisational EI facilitates and aligns technical knowledge to eco-innovate and transform the entire infrastructure's organisational structure and coordination to promote green practices. Several researchers (Triguero et al., 2013; Kesidou & Demirel, 2012) have identified organisational EI as the driving force of product and process EI. The fundamentals of organisational EI in the contractor firm focus on the motivating aspects such as adherence to environmental regulations and standards or complying with green rating tools, developing a good relationship and collaboration in the supply chain, and improving the firm human resources to enhance EI adoption (Triguero et al., 2013; Cheng et al., 2014; Kesidou & Demirel, 2012).

As a result, EI presents an opportunity for contractor firms to innovate in a more environmentally friendly manner. The primary focus of EI is on increasing resource efficiency and productivity while also safeguarding the environment. Even though increasing focus and attention have been placed on EI adoption in developing countries, including Malaysia. However, compared to other Asian countries, EI research in Malaysia has received little attention. Numerous studies have been conducted to understand EI practices better; however, most of these works have primarily focused on the manufacturing industry (Singh, 2017; Salim et al., 2018; Dahan & Yusof, 2019), the automotive industry (Rashid et al., 2015; Zailani et al., 2015), and green technology sector (Ch'ng et al., 2021; Fernando et al., 2019). In the local context, the construction industry has received little attention in EI research compared to other industries, even though the construction industry is responsible for shaping the built environment that underpins all social and economic activities (Rashid et al., 2015). Even though the contractor firms, relatively, have increasingly engaged, but rather slowly, in new practices or green-related innovation activities. They have focused more on primary and low-cost activities such as conserving energy and complying with the minimum environmental concerns requirements, mainly focusing on what had been stated in the contract. Hence, this study has gained insights into how the management of contractor firms can be improved by exploring the barriers that hinder EI implementation within their organisations.

Barriers to Eco-Innovation (EI) Implementation

The path forward for eco-innovative firms is full of barriers to overcome, preventing their creation and subsequent development and consolidation. These barriers include problems and challenges in the innovation process that may stop firms from investing in innovation if not properly addressed (Marin, Marzucchi, & Zoboli, 2015; Ozorhon et al., 2016). Contractor firms encountered pressing challenges in constructing buildings and infrastructure with fewer resources while generating less pollution and waste (Carrillo-Hermosilla, Del Río & Könnölä, 2010). They also have confronted pressures such as government green requirements and project stakeholders' needs to improve their environmental performance (Bamgbade et al., 2017; Bohari et al., 2015). They need to respond and take the necessary actions to improve the firm's competitiveness and environmental performance. The literature on eco-innovation distinguishes between internal and external determinants and barriers to its performance (Horbach, 2008).

Meanwhile, an empirical study by Pinget, Bocquet, and Mothe (2015) examines three significant perceived barriers to EI: cost, knowledge, and the market. First, cost barriers indicate a firm's inability to finance innovative endeavours. During the innovation process, the available financial resources may not cover the necessary investments; therefore, excessive costs and a lack of financial resources (internal and external sources) are significant obstacles to EI. Souto and Rodriguez (2015) mentioned that the high cost of innovation, a lack of external funding, and restricted internal financial resources pose a significant challenge to developing innovative businesses. In the meantime, Hanelt et al. (2017) also stated that a lack of a firm's internal and external funding would hamper the adoption of green technology, R&D activities, investments in advanced software, or any EI practices. Hanelt et al. (2017) revealed that the most widely perceived difficulty is the potentially high initial cost of switching from current technologies to new eco-technologies.

Second, knowledge barriers pertain to limited access to information on technology and skilled staff. As supported by Souto and Rodriguez (2015) and Marin et al. (2015) that lack of experienced, competent, and qualified staff, and limited knowledge and information on green technology and green products due to inadequate information on green markets and customer demand. In other words, EIs involve specific information and knowledge, so qualified personnel and associated skills are essential for exploring new environmental technologies. Ozorhon et al. (2016) emphasised that lack of knowledge, experience, and qualified technical staff are technological barriers to conducting technical tasks when adopting innovations. Thus, knowledgeable managers and employees who can incorporate and support EI as a business strategy attain a competitive advantage.

Third, the ability to connect a technical opportunity to a market opportunity encourages successful innovations; however, the inability to do so may inhibit innovative activity. Hanelt et al. (2017), Martin et al. (2015), Pinget et al. (2015), and Souto and Rodriguez (2015) highlighted that difficulty in finding collaboration partners for EI, a market dominated by well-established eco-innovative firms, market uncertainty for eco-innovative goods and services. The technology and markets associated with EI tend to be complex and rapidly evolving; therefore, firms pursuing EI must address these two issues even more intensively. Furthermore, Triguero et al. (2013) believe collaboration with external partners positively promotes EI practices. However, finding external partners that collaborate in developing business innovation activities can also be a significant obstacle to innovation, as innovative companies in constant contact with their environment need to cooperate and update available knowledge and technology (Souto, 2012). Additionally, existing regulations and structures not providing incentives to eco-innovate and insufficient access to subsidies and fiscal incentives contribute to impeding EI practices (Marin et al., 2015; Ozorhon et al., 2016; Souto & Rodriguez, 2015). The lack of need for eco-innovations in the construction industry and the deficiency of clear benefits of EI continue to interpret EI to be an added burden to the firms. Table 1 presents the summary of barriers to EI based on previous studies.

Table 1. Summary of Barriers to Eco-Innovation (EI)

Authors (Year) / Barriers to Eco-Innovation (EI)	Hanelt et al. (2017)	Triguero et al. (2013)	Marin et al. (2015)	Ozorhon et al. (2016)	Souto & Rodriguez (2015)	Souto (2012)	Pinget et al. (2015)
Unsupportive organisational culture	/	/	/	/			
Lack of knowledge and awareness of EI	/	/	/	/	/	/	/
Financial difficulties	/	/	/	/	/	/	/
Lack of skills and competence staff		/	/	/	/	/	
Difficulties in collaboration		/	/	/	/	/	
Market uncertainty of EI	/	/	/	/	/	/	/
Insufficient access to incentives and subsidies		/	/	/	/	/	

RESEARCH METHODOLOGY

An interview with grade G7 contractor firms was conducted to investigate the barriers encountered by the firms in implementing EI in their construction services. The semi-structured interview gave a frame of specified topics to be covered while offering the interviewees some leeway in their responses (Bryman & Bell, 2015). Purposive sampling was used to ensure that the participants chosen for the study had a wide range of relevant experience and knowledge (Sekaran & Bougie, 2013). Previous researchers had recommended that qualitative studies require a minimum sample size of at least 12 respondents to achieve data saturation (Braun & Clarke, 2013). Therefore, 14 contractor firms (labelled R1 to R14) were interviewed and deemed sufficient to satisfy the saturation process in this study's qualitative analysis and scale. Apart from sharing their thoughts and experiences, the participants also served as key informants to provide rich information about the barriers to eco-innovative practices within the firms to achieve environmental sustainability and competitive advantages.

This study employed an interview approach based on the preference of the potential respondents. The researcher made an effort to contact and ask the respondents about the approach of interviews they would prefer. In this study, telephone and online interviews were the most preferred approaches especially when it involves hard-to-reach and busy respondents. A set of interview questions, a written list of questions that need to be covered in a particular order, was prepared. It is essential to identify the optimal interview length, especially when dealing with respondents with busy schedules. According to Achtenhagen et al. (2013), most qualitative interviews are between one and two hours long. Therefore, one-hour interview questions were designed to fully satisfy the needed information. To help increase the likelihood of cooperation, a letter was sent through email to each potential respondent requesting their consent to be interviewed. A follow-up call was made to each respondent a week later to confirm the interview arrangement and their preferred interview approach. The time for the interview was decided to ensure respondents were ready by the time the interview took place. The interview forms were emailed earlier to have ample time to review the interview questions. After every session of an interview, the audio recording was transcribed to ensure a comprehensive analysis of the information could be done while the discussion was fresh.

Data gathered from the interviews was analysed qualitatively as the information was in the form of opinions, comments, and statements with exceptions. The qualitative data analysis was conducted using Atlas.ti Version 22, which handles rich text-based information, were deep levels of analysis on small and large volumes of data. Atlas.ti provides a perfect solution to the tedious processes of data analysis such that it removes many of the manual tasks associated with the analysis, such as classifying, sorting, and arranging information (Creswell, 2014). The inductive approach was adopted in analysing the data, in which the data drove the themes and patterns of analysis (Yahaya, 2017). The respondents were coded in the data analysis process to ensure their anonymity in the study. To ensure the reliability of the participants, the interview was conducted with firm representatives holding positions ranging from top management to middle management (Hojnik & Ruzzier, 2016). They were selected as firm representatives because they were directly involved in the process, making them knowledgeable, experienced in all operations, and engaged in firm management issues and decision-making (Bamgbade et al., 2017). As shown in Table 2, all firms have more than 15 years of experience in the construction industry. Meanwhile, respondents had more than five years of working experience with their respective firms.

Table 2. Detail of the Contractor Firm's Representative

Respondent's Designation in The Current Firm	Years of The Firms Operating in The Construction Industry	Years Of Respondents Working with The Current Firm	Respondents Label
Director	16 years	7 years	R1
General Manager	29 years	14 years	R2
Senior Manager	38 years	21 years	R3
Senior Project Manager	47 years	8 years	R4
Senior Project Manager	30 years	10 years	R5
Senior Project Manager	39 years	6 years	R6
Project Engineer	45 years	5 years	R7
Project Manager	45 years	14 years	R8
Project Manager	40 years	6 years	R9
Project Manager	28 years	5 years	R10
Senior Quantity Surveyor	50 years	5 years	R11
Senior Quantity Surveyor	35 years	7 years	R12
Senior Quantity Surveyor	29 years	8 years	R13
Environmental Officer	19 years	5 years	R14

RESULTS AND DISCUSSION

Based on the interview with 14 contractor firms G7, the main barriers that hinder the EI implementation are i) firm-specific barriers, ii) cost difficulties, iii) people-related barriers and iv) external pressures. All these four main barriers will be elaborated on accordingly.

Firm-Specific Barriers

The finding shows that a lack of support from the firm's top management, whether in guidance or other supporting resources, can inhibit EI implementation. The contractors' lack of responsibility in adopting eco-practices in delivering their services was explained by the absence of green resources regarding green technology, eco-friendly plants, and machinery, including environmental knowledge provided by their firm management in facilitating them in EI practices. This challenge has been highlighted by most of the respondents. Respondent R1 mentioned, *"A lack of support from the top management to implement these practices because of the lack of awareness on the benefits it can bring to the environment and the firm's productivity"*. Most top management are unaware of the long-term benefits and are unwilling to change because eco-practices incur high initial costs. Half of the respondents conclude that most top management only sees the short-term consequences rather than long-term benefits, which leads them to be uninterested in implementing eco-practices due to the high initial cost. This finding is consistent with Jones, Jackson, Bates, and Tudor (2016), who identify these constraints as related to a lack of top management support and guidance. In addition, it is well appreciated that the commitment of top-level management is the pillar behind the environmental strategy formulation, execution, and success within firms (Singh, 2017) and is a crucial factor affecting the adoption of EI practices toward minimising environmental impacts (Hazarika & Zhang, 2019).

Furthermore, whenever the top management has implemented environmental policies and guidelines within their firm, they must be communicated to all departments or management levels to ensure effective implementation. For example, when a firm implements EMS, inadequate specialist staff, a lack of training, insufficient technical knowledge, and a competent team lead to failure in complying with the EMS requirement (Mazzi, Toniolo, Mason, Aguiari & Scipioni, 2016). In such cases, contractor firms fail to develop robust environmental capabilities despite implementing EMS. Similarly, shallow, unauthentic EMS implementations solely for tendering requirements fail to establish a strong firm's sustainability-oriented capabilities. Demirel and Kesidou (2019) find that various studies have also argued that EMS needs time to mature to provide firms with green-oriented capabilities. Also supported by Thu, Paillé & and Halilem (2019), EI is a state-of-the-art problem solution representing the organisation's efforts to execute eco-initiatives and create competitive advantages, engaging top management and staff at all levels. Thus, the top management of the contractor firm needs to commit effectively to these matters. Other challenges defined in the interview are managing multiple parties within the firms. Considering that a contractor firm target integrating EI into their business operations, they require the engagement of top management and contributions from all staff within different departments.

Cost Difficulties

Most profit-driven firms' mindset and actions have influenced their interest in green-related practices. This study reveals that the majority of respondents agreed that the major constraint is cost. Respondent R4 highlighted, *"The contractors to spend more money to outsource specialist or lease eco-friendly technology, plant and machinery to implement green practices and to make the work done with minimum adverse impact to the environment. As a result, these incurred additional costs".* This was echoed in an interview with a few respondents of this study, who opined that their firm does not seek to use green technologies because the firm expects higher costs and the difficulty of finding suppliers for eco-products and green materials. Respondents R3, R4, R7 and R8 also indicated that *"Malaysian suppliers still lack in providing eco-product and green materials for green building projects. Most of these eco-products with green criteria are obtained from an international supplier, and cost becomes more expensive, leading to difficulties the main contractors face".* Therefore, all these matters led the contractors to other problems such as project delays, high costs because they cannot meet the client requirements, etc., and in the end, they are demotivated to adopt green practices.

The result from the interview indicates that all respondents confirmed that inadequate cost allocation for EI practices had hindered EI adoption at the firm and project levels. Cost constraint is noted as one of the critical reasons why top management is reluctant to eco-innovate. Furthermore, the top management is unwillingly spending high costs on green technology or eco-friendly plants and machinery due to the high price. To a great extent, the nature of most profit-driven organisations' thinking, and behaviour has influenced their interest in green-related activities or practices. These results are in line with those of previous studies. They tend to view a firm's spending in providing sufficient resources and capabilities toward eco-practices as burdensome because it incurs high initial costs (Yusof et al., 2016; Hashim, 2018). Furthermore, when dealing with large, complex, or green building projects, the contractors must comply with the environmental requirements stated in the contract. The crucial involvement of the client in incorporating the environmental values from the beginning of the project is also mentioned in Son, Kim, Chong, and Chou (2011). High costs are incurred when the need to outsource most environmental provisions, such as appointing environmental specialists, cleaner technology, or eco-friendly machinery and equipment, especially when the project location is in a prime area.

Apart from that, based on the local context, the cost of eco-products and green materials is still higher than non-green products. This result is consistent with Bohari, Skitmore, Xia and Teo (2017), which reveal that clients must spend more on eco-products, green materials, and green technology in their projects. Moreover, the high price is also incurred whenever clients demand eco-product use from overseas. An inexperienced contractor typically needs help identifying the cost to be allocated for providing all the environmental provisions in a project, finding relevant suppliers for eco-products, or outsourcing environmental specialists or eco-friendly machinery. Therefore, they tend to take this matter lightly during the tendering process, especially when the contractors allocate lower costs for environmental requirements. In pricing the environmental provisions for the project, the contractors must consider not only the initial cost but also the maintenance cost throughout the project duration. Cost constraints due to low budget allocation at the tendering stage. Non-compliance with environmental requirements will impose penalty charges on the contractor.

People Related Barriers

The finding shows that a poor level of awareness of the importance of environmental knowledge among the employees has led to inconsistent practices of EI as the contractors tend to treat the environment as less of a priority. The need for knowledge about environmental practices among Malaysian contractors was also mentioned in Yahaya (2017), making them more reluctant to implement any form of waste management plan effort. A lack of understanding of EI adoptions can cause the firm's management trouble. EI adoptions need cooperation from all the staff from different departments to ensure the environment is protected in delivering construction services.

EI practices are a new practice by most contractor firms more prominent with conventional construction practices. The lack of skill and competent managers to undertake the EI practices had become a challenge to contractors, as highlighted by Respondent R14, *"When they want to implement environmental practices, many things that need to be considered that affected by the requirement of other departments. Lack of cooperation among the multiple parties led to the dispute, leading to delay in work progress and high cost incurred"*. Thus, the adoption of EI practices at the level of the contractor firm required the participation of all groups of management and all departments. Environmental concerns must be included at every level of corporate governance. The interview finding also shows that their poor environmental attitude leads to lower EI implementation among the staff. Respondent R3 states, *"The main challenges are always people. We can develop a system or standard. Challenges are always in the sense of getting that level of commitment or awareness from the people"*. Several respondents argued that due to a lack of competence and knowledgeable managers to influence employees' behaviours and attitudes toward environmental concerns and motivate them to adopt EI within the firm and project level [R3, R4, R5, R12 and R13].

This result reveals that top managers' attitudes and behaviours toward environmental management are critical to the firm's effectiveness in adopting EI practices, which promote their human capital to resolve environmental issues and contribute to green innovation (Song, Yang, Zeng & Feng, 2020). In addition, although investments are made in training, particularly for the management team, the strategic impact of such instruction is not considered when planning it (Pellicer, Yepes & Rojas, 2010). Participating in training programmes connected to the latest market trends may be prudent. Consequently, the firm has limited or no expertise in up-and-coming fields such as smart home systems, green buildings, low-carbon buildings, etc. In turn, the lack of experience in these areas restricts the firm's ability to participate in large-scale projects offered mostly through public projects.

External Pressures

The external challenges relate to finding external partners to collaborate in EI initiatives. In the scope of contractor firms, the demand for green practices is very much influenced by the clients and the consultants for the proposed project. If they deal with green-oriented clients, the way the contractor firm delivers their services is also more towards embracing the environment. Like Hwang and Ng (2013), the findings have also shown that a lack of participation from the consultant team has impeded the implementation of green practices. As the contractors perceive that the consultant does not care for the environment, this will influence the contractors themselves not to bother about the environment.

However, the need for local green suppliers also hindered the EI implementation. More supplies will lead to the cost of eco-products to be much higher than conventional products. Moreover, the eco-products proposed in the contract were not available locally. As a result, high costs are incurred for acquiring the products. Mainly when they deal with international clients, Respondent R7 mentioned, *"Typically, the contractor will adhere to the client's requirements and the specifications outlined in the contract. The difficulties encountered while dealing with international clients who insist on using most products and materials from other countries".*

Furthermore, the government must play a crucial role in promoting these green practices since many public projects have been awarded, as well as private projects. The products and materials used for the project should have quality standards and green certification. Thus, before the construction begins, the designers should have already implemented the green design and eco-products at the design stage. Then, the authorities should enforce the green practices effectively to ensure that all parties involved in the project will take considerable action, especially the contractor firms, because they are liable for constructing the buildings. They should not be tainted with unsustainable construction practices in delivering the services. As a result, the EI adoption could have been improved by the absence of enforcement, as most contracting firms found it more convenient to deliver their services conventionally. An empirical study by Fernando and Wah (2017) reveals that each type of innovation responded to a different factor related to environmental compliance and the penalties imposed for non-compliance. Regulations are present, but more effort needs to be made to ensure compliance with these regulations. This is because there is no regulation related to green technology, EMS, green rating, etc., which is still based on a voluntary approach. There needs to be more enforcement; thus, more effort is needed to encourage firms to comply with environmental standards and regulations.

CONCLUSION

This study contributed to the literature on EI by focusing on barriers to EI implementation at contractor firms in the Malaysian construction industry. Highlighting all these barriers to EI implementation is crucial and can facilitate the contractor firm's adoption of green-related practices in their rendered services. It provides a panoramic understanding of the main barriers as local conditions to enhance EI practices. This study enriches the literature on EI within the construction industry, which is currently dominated by the manufacturing industry. It can be concluded that significant and mature contractor firms (G7) engaged proactively in protecting the environment have unavoidably experienced barriers and difficulties. According to the interview findings, four major impediments to EI implementation among contractor firms have been identified: firm-specific, cost difficulties, people-related, and external pressure. Based on the discussion, the result indicates that contractor firms' main barriers were firm-related and cost difficulties. The decision to eco-innovate mostly relies on the executives and top management of the contractor firms. They make critical decisions in determining the firm's target to remain relevant and competitive. Environmental degradation is inseparable from the development of new buildings and infrastructure.

Continuing to deliver this development with a conventional approach and unsustainable construction practices will not solve the environmental concerns. Recognising the barriers to EI from contractor perspectives will help other stakeholders, policymakers, and the government develop economic instruments that encourage the development and implementation of EI practices in the construction industry. In addition, the government had pledged to protect the natural environment and provide a better quality of life for future generations. Therefore, the top management of the contractor firms needs to contribute to this sustainability agenda. They must include environmental sustainability as part of the firm's goal, policy, and standard and communicate it effectively to all management levels. However, in doing so, the cost constraint is another challenge for contractor firms to successfully implement EI practices. Firms embrace EI through new or improved versions of products and services, processes, and organisational management that produce better or more efficient practices and positively impact environmental improvement. However, this transaction involved high costs. To address these issues, contractor firms should improve their existing capabilities and resources to embrace EI practices. In addition, the contractor firms must seize any opportunity for collaboration with external actors and maximise available grants and government incentives to advance their EI efforts. Thus, understanding the barriers hindering EI implementation in contractor firms opens an avenue for effective strategies to be outlined and recommended to enhance EI implementation.

REFERENCES

Achtenhagen, L., Melin, L., & Naldi, L. (2013). Dynamics of Business Models – Strategizing, Critical Capabilities and Activities for Sustained Value Creation. *Long Range Planning*, 46(6), 427–442. https://doi.org/10.1016/j.lrp.2013.04.002

Arundel, A., and Kemp, R. (2009). Working Paper Series: Measuring Eco-innovation. Unu - Merit, 31, 40.

Bamgbade, J. A., Kamaruddeen, A. M., and Nawi, M. N. M. (2017). Towards Environmental Sustainability Adoption in Construction Firms: An Empirical Analysis of Market Orientation and Organizational Innovativeness Impacts. *Sustainable Cities and Society*, 32, 486–495. https://doi.org/10.1016/j.scs.2017.04.015

Braun, V. and Clarke, V. (2013) *Successful Qualitative Research: A Practical Guide for Beginners*. SAGE Publication, London.

Bryman, A. and Bell, E. (2015) *Business Research Methods*. Oxford University Press, Oxford

Bohari, A. A. M., Skitmore, M., Xia, B., and Teo, M. (2017). Green Oriented Procurement for Building Projects: Preliminary Findings from Malaysia. *Journal of Cleaner Production*, 148, 690–700. https://doi.org/10.1016/j.jclepro.2017.01.141

Bohari, M., Alia, A., Skitmore, M., Xia, B., Teo, M., Zhang, X., and Adham, K. N. (2015). The Path Towards Greening the Malaysian Construction Industry. *Renewable and Sustainable Energy Reviews*, 52, 1742–1748. https://doi.org/10.1016/j.rser.2015.07.148

Bossle, M. B., Dutra De Barcellos, M., Vieira, L. M., and Sauvée, L. (2016). The Drivers for Adoption of Eco-Innovation. *Journal of Cleaner Production*, 113, 861–872. https://doi.org/10.1016/j.jclepro.2015.11.033

Cai, W., and Li, G. (2018). The Drivers of Eco-Innovation and its Impact on Performance: Evidence from China. *Journal of Cleaner Production*, 176, 110–118. https://doi.org/10.1016/j.jclepro.2017.12.109

Carrillo-Hermosilla, J., Del Río, P., and Könnölä, T. (2010). Diversity of Eco-Innovations: Reflections from Selected Case Studies. *Journal of Cleaner Production*, 18(10–11): 1073–1083. https://doi.org/10.1016/j.jclepro.2010.02.014

Chen, J., Yin, X., and Mei, L. (2018). Holistic Innovation: An Emerging Innovation Paradigm. *International Journal of Innovation Studies*. https://doi.org/10.1016/j.ijis.2018.02.001

Cheng, C. C. J., Yang, C. L., and Sheu, C. (2014). The Link Between Eco-Innovation and Business Performance: A Taiwanese Industry Context. *Journal of Cleaner Production*, 64, 81–90. https://doi.org/10.1016/j.jclepro.2013.09.050

Cheng, C. C., and Shiu, E. C. (2012). Validation of a Proposed Instrument for Measuring Eco-Innovation: An Implementation Perspective. *Technovation*, 32(6): 329–344. https://doi.org/10.1016/j.technovation.2012.02.001

Construction Industry Development Board Malaysia (CIDB), 2021. Construction 4.0 Strategic Plan (2021-2025) CIDB Malaysia. Available at: https://www.cidb.gov.my/en/construction-info/technology/ir40-construction

Creswell, J. W. (2014). *Research Design- Qualitative, Quantitative and Mixed Method Approaches* (4th ed.). SAGE Publication, Inc.

Dahan, S. M., & Yusof, S. M. (2019). Review and proposed eco-process innovation performance framework. *International Journal of Sustainable Engineering*, 13(2), 123–139. https://doi.org/10.1080/19397038.2019.1644387

Davis, P., Gajendran, T., Vaughan, J., and Owi, T. (2016). Assessing Construction Innovation: Theoretical and Practical Perspectives. *Construction Economics and Building*, 16(3): 104–115. https://doi.org/10.5130/ajceb.v16i3.5178

Demirel, P., and Kesidou, E. (2019). Sustainability - oriented Capabilities for Eco-innovation: Meeting the Regulatory, Technology, and Market Demands. *Business Strategy and the Environment*, 1–11. https://doi.org/10.1002/bse.2286

Department of Statistic Malaysia (DoSM). (2021). Quarterly Construction Statistics, Second Quarter 2021, Retrieved February 2022, Available at: https://www.dosm.gov.my

Fernando, Y., Jabbour, C. J. C., & Wah, W. X. (2019). Pursuing green growth in technology firms through the connections between environmental innovation and sustainable business performance: Does service capability matter? *Resources, Conservation and Recycling*, 141, 8–20. https://doi.org/10.1016/j.resconrec.2018.09.031

Fernando, Y., and Wah, W. X. (2017). The Impact of Eco-Innovation Drivers on Environmental Performance: Empirical Results from The Green Technology Sector in Malaysia. *Sustainable Production and Consumption*, 12, 27–43. https://doi.org/10.1016/j.spc.2017.05.002

Garcés-Ayerbe, C., Scarpellini, S., Valero-Gil, J., and Rivera-Torres, P. (2016). Proactive Environmental Strategy Development: from Laggard to Eco-Innovative Firms. *Journal of Organizational Change Management*, 29(7): 1118–1134. https://doi.org/10.1108/JOCM-05-2016-0081

García-Granero, E. M., Piedra-Munoz, L., and Galdeano-Gomez, E. (2018). Eco-innovation Measurement: A Review of Firm Performance Indicators. *Journal of Cleaner Production*, 191, 304–317. https://doi.org/10.1016/j.jclepro.2018.04.215

Ge, B., Yang, Y., Jiang, D., Gao, Y., Du, X., and Zhou, T. (2018). An Empirical Study on Green Innovation Strategy and Sustainable Competitive Advantages: Path and Boundary. *Sustainability*, 10(3631): 1–18. https://doi.org/10.3390/su10103631

Ghisetti, C., Mazzanti, M., Mancinelli, S., and Zoli, M. (2015). Do Financial Constraints Make the Environment Worse Off? Understanding The Effects of Financial Barriers on Environmental Innovations.

Goi, C. (2017). The Impact of Technological Innovation on Building a Sustainable City. *International Journal of Quality Innovation*, 3(6): 1–13. https://doi.org/10.1186/s40887-017-0014-9

Hanelt, A., Busse, S., Kolbe, L.M., 2017. Driving business transformation toward sustainability: exploring the impact of supporting IS on the performance contribution of eco-innovations. *Information System Journal*, 27, 463-502. https://doi.org/ 10.1111/isj.12130.

Hashim, R. (2018). Green Innovation Adoption in the Construction Sector: The Role of Absorptive Capacity and the Effect of Environmental Requirements. Ph.D. Thesis, The University of Edinburgh. 224pp.

Hazarika, N., and Zhang, X. (2019). Factors That Drive and Sustain Eco-Innovation in The Construction Industry: The Case of Hong Kong. *Journal of Cleaner Production*, 238, 117816. https://doi.org/10.1016/j.jclepro.2019.117816

He, F., Miao, X., Wong, C. W. Y., and Lee, S. (2018). Contemporary Corporate Eco-Innovation Research: A Systematic Review. *Journal of Cleaner Production*, 174, 502–526. https://doi.org/10.1016/j.jclepro.2017.10.314

Hojnik, J., and Ruzzier, M. (2016). The Driving Forces of Process Eco-Innovation and Its Impact on Performance: Insights from Slovenia. *Journal of Cleaner Production*, 133, 812–825. https://doi.org/10.1016/j.jclepro.2016.06.002

Hwang, B.G., and Ng, W. J. (2013). Project Management Knowledge and Skills for Green Construction: Overcoming Challenges. *International Journal of Project Management*, 31(2): 272–284. https://doi.org/10.1016/j.ijproman.2012.05.004

Isa, S. S. M., & Abidin, N. Z. (2021). Eco-innovation adoption in Malaysian contractor firms: Understanding the components and drivers. *Construction Economics and Building*, 21(3), 221–242. https://doi.org/10.5130/AJCEB.V21I3.7660

Jones, J., Jackson, J. I., Bates, M., and Tudor, T. (2016). Factors Influencing Corporate Pro-Environmental Behaviour - A Case Study from The UK Construction Sector. International *Journal of Environment and Sustainable Development*, 15(1): 1–15. https://doi.org/10.1504/IJESD.2016.073314

Jové-Llopis, E., and Segarra-Blasco, A. (2018). Eco-innovation Strategies: A Panel Data Analysis of Spanish Services and Manufacturing Firms. *Business Strategy and the Environment*, 55, 1–34. https://doi.org/10.1002/bse.2063

Kamal, E. M., Yusof, N., and Iranmanesh, M. (2016). Innovation Creation, Innovation Adoption, and Firm Characteristics in The Construction Industry. *Journal of Science and Technology Policy Management*, 7(1): 43–57. https://doi.org/10.1108/JSTPM-03-2015-0011

Kemp, R., and Pearson, P. (2007). Final report MEI project about measuring eco-innovation. http://www.merit.unu.edu/MEI

Kesidou, E., & Demirel, P. (2012). On the drivers of eco-innovations: Empirical evidence from the UK. *Research Policy*, 41(5), 862–870. https://doi.org/10.1016/j.respol.2012.01.005

Kiefer, C. P., Carrillo-Hermosilla, J., Del Río, P., and Callealta Barroso, F. J. (2017). Diversity of Eco-Innovations: A Quantitative Approach. *Journal of Cleaner Production*, 166, 1494–1506. https://doi.org/10.1016/j.jclepro.2017.07.241

Marin, G., Marzucchi, A., & Zoboli, R. (2015). SMEs and barriers to Eco-innovation in the EU: Exploring different firm profiles. *Journal of Evolutionary Economics*, 25(3), 671–705. https://doi.org/10.1007/s00191-015-0407-7

Mazzi, A., Toniolo, S., Mason, M., Aguiari, F., and Scipioni, A. (2016). What are the Benefits and Difficulties in Adopting an Environmental Management System? The Opinion of Italian Organizations. *Journal of Cleaner Production*, 139, 873–885. https://doi.org/10.1016/j.jclepro.2016.08.053

Ozorhon, B., Oral, K., and Demirkesen, S. (2016). Investigating the Components of Innovation in Construction Projects. *Journal of Management in Engineering*, 32(3): 1–10. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000419.

Pellicer, E., Yepes, V., and Rojas, R. J. (2010). Innovation and Competitiveness in Construction Companies: A Case Study. *Journal of Management Research*, 10(2):103-115.

Peng, X., and Liu, Y. (2016). Behind Eco-innovation: Managerial Environmental Awareness and External Resource Acquisition. *Journal of Cleaner Production*, 139, 347–360. https://doi.org/10.1016/j.jclepro.2016.08.051

Pinget, A., Bocquet, R., and Mothe, C. (2015). Barriers to Environmental Innovation in SMEs: Empirical Evidence from French Firms. *Management*, 18(2): 132–155.

Rashid, N., Jabar, J., Yahya, S., & Shami, S. (2015). Dynamic Eco Innovation Practices: A Systematic Review of State of the Art and Future Direction for Eco Innovation Study. *Asian Social Science*, 11(1), 8–21. https://doi.org/10.5539/ass.v11n1p8

Salim, N., Rahman, M. N. A., & Wahab, D. A. (2018). A systematic literature review of internal capabilities for enhancing eco-innovation performance of manufacturing firms. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2018.11.105

Singh, K., and Chandran, V. (2017). Eco-Innovation in Chemical Manufacturing Firms: Insights for Policy Response. *Institutions and Economies*, 9(1): 21–42.

Singh, K. S. J. (2017). Eco-Innovation in the Chemical Manufacturing Industry: Status and Its Determinants. Ph.D. Thesis, University Malaya. 336pp.

Son, H., Kim, C., Chong, W. K., and Chou, J. (2011). Implementing Sustainable Development in the Construction Industry: Constructors' Perspectives in the US and Korea. *Sustainable Development*, 19, 337–347.

Song, M., Yang, M. X., Zeng, K. J., and Feng, W. (2020). Green Knowledge Sharing, Stakeholder Pressure, Absorptive Capacity, and Green Innovation: Evidence from Chinese Manufacturing Firms. *Business Strategy and the Environment*, 29(3): 1517–1531. https://doi.org/10.1002/bse.2450

Song, W., and Yu, H. (2017). Green Innovation Strategy and Green Innovation: The Roles of Green Creativity and Green Organizational Identity. *Corporate Social Responsibility and Environmental Management*. https://doi.org/10.1002/csr.1445

Souto, J. E., and Rodriguez, A. (2015). The Problems of Environmentally Involved Firms: Innovation Obstacles and Essential Issues in The Achievement of Environmental Innovation. *Journal of Cleaner Production*, 101, 49–58. https://doi.org/10.1016/j.jclepro.2015.04.017

Suprun, E. V., and Stewart, R. A. (2015). Construction Innovation Diffusion in the Russian Federation. *Construction Innovation*, 15(3): 278–312. https://doi.org/10.1108/CI-07-2014-0038

Szilagyi, A., Mocan, M., Verniquet, A., Churican, A., and Rochat, D. (2018). Eco-innovation, a Business Approach Towards Sustainable Processes, Products and Services. *Procedia - Social and Behavioral Sciences*, 238, 475–484. https://doi.org/10.1016/j.sbspro.2018.04.026

Thu, P. D. D., Paillé, P., and Halilem, N. (2019). Systematic Review on Environmental Innovativeness: A Knowledge-Based Resource View. *Journal of Cleaner Production*, 211, 1088–1099. https://doi.org/10.1016/j.jclepro.2018.11.221

Tsai, K. H., and Liao, Y. C. (2017). Sustainability Strategy and Eco-Innovation: A Moderation Model. *Business Strategy and the Environment*, 26(4): 426–437. https://doi.org/10.1002/bse.1926

Varadarajan, R. (2018). Innovation, Innovation Strategy, and Strategic Innovation. *Innovation and Strategy*, 143–166. https://doi.org/10.1108/S1548-643520180000015007

Waris, M., Liew, M. S., Khamidi, M. F., and Idrus, A. (2014). Environmental Implications of Onsite Mechanization in The Malaysian Construction Industry. *WIT Transactions on Ecology and The Environment*, 18, 147–158. https://doi.org/10.2495/EID140131

Yahaya, I. (2017). The Attitudinal Commitment of Contractors for Site Environmental Practices in Malaysia. Ph.D. Thesis, Universiti Sains Malaysia. 307pp.

Yousif, O.S., Zakaria, R., Wahi, N., Aminudin, E., Abdul Tharim, A.H., Gara, J.A., Liyana Umran, N.I., Khalid, R. and Ismail, N., (2022). Monitoring the Construction Industry towards a Construction Revolution 4.0. *International Journal of Sustainable Development and Planning*, 17(2), 633–641. https://doi.org/10.18280/ijsdp.170228

Yusof, N., Awang, H., and Iranmanesh, M. (2017). Determinants and Outcomes of Environmental Practices in Malaysian Construction Projects. *Journal of Cleaner Production*, 156, 345–354. https://doi.org/10.1016/j.jclepro.2017.04.064

UNVEILING THE PATH TO SUSTAINABILITY: EXPLORING THE CURRENT PRACTICES OF CORPORATE REAL ESTATE SUSTAINABLE MANAGEMENT FOR GREEN OFFICE BUILDINGS

Nurul Sahida Fauzi[1*], Timothy Tunde Oladokun[2], Siti Nadiah Mohd Ali[1], Huraizah Arshad[1], Nor Nazihah Chuweni[1], and Nor Aini Salleh[1]

[1]Programme of Real Estate Management, Department of Built Environment Studies & Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610, Seri Iskandar, Perak, MALAYSIA

[2]Department of Estate Management, Obafemi Awolowo University, Ile-Ife, NIGERIA

**Corresponding Email: nurul839@uitm.edu.my*

Abstract

Studies related to green office buildings have gained significant attention in recent years due to the growing emphasis on sustainability and environmental concerns. This is driven by the increasing awareness of corporate companies on the importance of integrating sustainability into their business objectives and operational premises. This intensified awareness is also influenced by the preference of international companies to engage in businesses that prioritize sustainability in their operations. As the number of green office buildings continues to grow, the implementation of Corporate Real Estate Sustainable Management (CRESM) practices becomes crucial. However, the current practices of CRESM are less discussed. Therefore, it is imperative to conduct an in-depth exploration of the current practices of CRESM to enhance the awareness of corporate real estate managers regarding the existing approaches that are currently being adopted. This study aims to investigate the current practices of CRESM for green office buildings. The current research employs a qualitative approach involving semi-structured interviews with 13 participants who are experts in CRESM. The selected participants include real estate experts, sustainable corporate real estate (CRE) managers, and Green Building Index (GBI) facilitators. Thematic content analysis is used to analyse data. The findings reveal that a significant proportion of corporate companies outsource their CRESM practices with direct reporting to top management. Conversely, some organizations adopt in-house management approaches, while others implement a combination of in-house and outsourced CRESM practices. The study also identifies seven management approaches used in CRESM practice, including the Green Building Index (GBI) (as guiding element), Building Management Systems (BMS), Building Information Modelling (BIM), Performance Measurement Systems (PMS), and Sustainable Performance Measurement Systems (SPMS). The analysis demonstrates the widespread implementation of GBI, PMS, and SPMS, while BIM adoption remains relatively low due to its recent introduction. Ultimately, the findings contribute to the body of knowledge in CRESM and provide practical recommendations in enhancing the sustainability performance of green office buildings.

Keywords: *Corporate real estate sustainable management (CRESM); Current practice; Green office building*

INTRODUCTION

In recent years, there has been a growing recognition of the importance of sustainable practices in corporate real estate management, particularly in the context of green office buildings. As organizations strive to reduce their environmental impact and align their operations with sustainable principles, the implementation of effective CRESM practices becomes paramount. However, the current landscape of CRESM practices remains relatively under-explored and less discussed. With the various sustainable approaches available today, it is crucial for managers to stay informed. This is in line with the findings of Kaur and Solomon (2022) who discovered that the adoption of a green automated approach yields positive results. Nevertheless, not all CRE managers are aware of these approaches. This is evident from the study conducted by Abdullah et al. (2011), which highlighted that the lack of expertise, proper strategies, management procedures, and utilization of information technology in real estate management can contribute to poor management practices. Furthermore, many real estate managers get involved only in managing the building after it is completed, rather than from the blueprint stage. This often creates complications as they must determine the appropriate approach for an already completed building. Ideally, managers should be involved from the blueprint stage to allow for early planning and adoption of suitable approaches. As stated by Arditi and Nawakorawit (1999), the performance of buildings is likely to be enhanced if designers and property managers are given the authority to act starting from the design and operation phases. While the potential benefits of incorporating sustainability in corporate real estate practice are acknowledged in developed countries such as the United States of America (USA) and the United Kingdom (UK), the practice in many of the developing countries seems to focus on traditional practices. Nonetheless, sustainable management of CRE is essential to reduce its negative impact on the environment, particularly in view of global concerns about global warming and climate change. The current research aims to explore the sustainable approaches that are necessary for effective practice by CRESM practitioners. By understanding these sustainable approaches, it will help managers to deploy them in practice. In addition, it will also ensure the CREM managers' impact to be noticeable in the global context, potentially reducing the impact of buildings on the environment. Therefore, the findings of this study will provide valuable insights to CRE managers in selecting and identifying the most suitable approaches for managing their green office buildings, ensuring their long-term sustainability and performance.

CORPORATE REAL ESTATE SUSTAINABLE MANAGEMENT (CRESM)

UNEP FI (Lowe & Ponce, 2014) defines CRESM as the integrated management of economic, environmental, and social aspects in an organisation's property activities and investment decision-making. It is also sometimes referred to as CRE sustainability management (Lützkendorf & Lorenz, 2014), sustainable corporate real estate management (Ziemba et al., 2015) or sustainable CREM (Ziemba et al., 2015). Indubitably, CRESM bridges the gap between sustainable corporate real estate management and corporate sustainability, incorporating the triple bottom line principles of environmental, social, and economic sustainability (Fauzi et al., 2016).

THE DIFFERENCE IN CRESM

Before exploring the various management methods and approaches, it is important to establish a clear understanding and distinction between corporate real estate management (CREM) and corporate real estate sustainable management (CRESM). Since these terms may not be widely understood, they can also be confused with related terms such as property management (PM) and facilities management (FM) if there is no proper distinction.

CRESM, unlike other concepts such as property management, facilities management and CREM. CRESM is a new concept with a focus on sustainable use of real estate assets of organisations. While property management focuses on obtaining maximum return from real estate assets, facilities management integrates the people, place and process of an organisations for effective operational delivery.

With CRE being the property held as an operational asset to support the activities of the business occupying the property (Edwards and Ellison, 2004), While CREM is the management of real estate assets owned and/or used by corporations (Izyumov, 2023). In addition to site selection, other activities include facility design and space utilisation decisions, which inevitably impact a company's business operations and future cash flow in numerous ways beyond any investment return received from the ownership of real property (to include leasehold rights). Whereas, property management involves day-to-day property maintenance and management requiring personnel with more technical skills, CREM comprises the strategic use of real estate to support the business operation and requires personnel with more managerial skills (Ali et al., 2008, Oladokun and Aluko, 2015). It involves various complex and interrelated activities, such as property acquisition and disposal, lease management, space utilization, portfolio optimization, and strategic planning (Fauzi, 2021).

As the practice of CREM evolves, global challenges require the incorporation of sustainability, if the practice will continue to be relevant. Achieving this, Aliagha et al. (2013) emphasize that the design of sustainable buildings is a key criterion that sets CRESM apart from traditional CREM. Hence, managing these sustainable buildings require advanced knowledge and skills, as they involve unique and advanced technological systems (Lu et al. 2020). At the same time, while, managing sustainable buildings could be very challenging, particularly due to issues related to infrastructure compatibility and the need for non-chemical alternatives compared to CREM (McNeill, 2020) PM may or may not have access to information regarding long-term policy and strategic decisions before they are made (Pitt & Hinks, 2001). PM may not be directly involved in the development of long-term policies and strategies and may only receive instructions or decisions from higher-level management without being privy to the underlying information or rationale. However, FM is encompasses multiple disciplines to ensure functionality, comfort, safety, and efficiency of the built environment by integrating people, place, process, and technology (Xu & Li, 2019). The traditional approach to FM has focused on ensuring that facilities are well-maintained, operate smoothly, and meet the basic needs of an organization. This cost-centered perspective places a strong emphasis on controlling expenses, optimizing resource allocation, and minimizing operational risks. By recognizing and acknowledging these differences, CRE managers can better understand the specific requirements and complexities associated with CRESM. This understanding sets the foundation for designing appropriate methods and strategies tailored to the needs of CRESM.

CRESM APPROACHES

Considering the limited availability of studies specifically addressing CRESM practices, the current research incorporates the examination of related practices such as property management (PM), green property management (Green PM), and corporate real estate management (CREM). The examination of these related practices allows for an initial understanding of the research area and also provides a foundation for the current research before proceeding with further data collection and analysis. These related practices are found to be closely interconnected with CRESM and can provide valuable insights and a broader perspective on sustainable management practices, particularly in the corporate real estate domain. Several studies, such as Razali et al. (2015), Adnan et al. (2017), and Collins et al. (2019), have discussed several approaches used in managing green office buildings that can be adopted in CRESM practices. These approaches include green property management (GPM), green lease practice (GLP), building management systems (BMS), building management modelling (BIM), and performance measurement systems (PMS) and sustainable performance measurement systems (SPMS).

Razali et al. (2015) introduced the concept of Green Property Management (GPM) which involves the implementation of sustainable measures in the management of urban buildings. GPM incorporates the criteria set by the Green Building Index (GBI) for an effective management. However, sustainable site planning and management are excluded from GPM as they primarily pertain to pre-occupancy matters. Meanwhile, Adnan et al. (2017) discussed Green Lease Practice (GLP), which aligns with GPM and focuses on incorporating tenants' green management preferences in sustainable buildings.

In a different study, Collins et al. (2019) shed light on the technological aspect of sustainable building management and emphasize the importance of adopting a Building Management System (BMS) or building automation system. In the research, they highlight that BMS plays a critical role for facilities managers in monitoring building performance, controlling energy consumption, optimizing environmental conditions, and enhancing user satisfaction. Despite its numerous benefits, wider acceptance and implementation of BMS in building management are still a work in progress.

Building Information Modelling (BIM) has been the subject of investigation by several scholars, including Demirdoven (2015), Ohueri et al. (2018), and Olawumi and Chan (2019). The digital representation of building characteristics has proven to be a valuable asset for decision-making processes throughout the entire life cycle of a building. The aforementioned studies underscore the manifold advantages associated with BIM implementation, including improved indoor air quality, heightened energy efficiency, cost reduction, and the ability to predict and simulate energy performance. Importantly, there is a notable emphasis on the integration of BIM and sustainability, as this synergy holds the potential to facilitate energy-sufficiency and optimize the overall energy performance of sustainable buildings.

The present review underscores the significance of performance measurement systems (PMS) and sustainable performance measurement systems (SPMS) in assessing the enduring value generated by CRESM practices. Medel-gonzález et al. (2016) and Kumar (2013) emphasize the imperative of PMS. The integration of both financial and non-financial measures within the PMS framework is advocated, with particular attention to be given to internal process measures as a means to effectively overcome internal challenges. By adopting such approach, organizations can better gauge their progress towards sustainable goals and make informed decisions to enhance their overall performance in a holistic manner.

RESEARCH METHODOLOGY

This study employed a qualitative method involving semi-structured interviews. Semi-structured interviews were selected because interviews are deemed as a primary data source in qualitative research (Zilber & Meyer, 2022). For the interviews', purposive sampling technique was used to select 13 participants who are the experts in CRESM and come from diverse backgrounds (see Table 1). The selected participants were contacted via email and phone calls based on recommendations from the Board of Valuers, Appraisers, Estate Agents, and Property Managers (BOVEAP). Initially, five participants were proposed, however, data saturation was achieved after conducting interviews with 13 participants, ensuring that further data collection was unnecessary. It is important to note that all participants had extensive experience in real estate management, with more than 10 years of overall experience and more than five years of experience specifically in CRESM. Given that Malaysia is still in the early stages of green building development, it is understandable that the participants' experience in CRESM is relatively limited, with none of them have the experience exceeding 10 years. To ensure the confidentiality of the participants, they were coded as P1-P13 as follows.

Table 1. List of The Participants

Participants	Profession	Experience (Years)	Experience in CRESM (Years)
P1	Real Estate Experts I	28	7
P2	Real Estate Experts II	34	6
P3	Real Estate Experts III	28	5
P4	Real Estate Experts IV	31	5
P5	Real Estate Experts V	31	5
P6	Real Estate Experts VI	23	5
P7	Sustainable CRE Manager I	22	6
P8	Sustainable CRE Manager II	16	6
P9	Sustainable CRE Manager III	11	6
P10	Sustainable CRE Manager IV	11	7
P11	Sustainable CRE Manager V	10	5
P12	GBI Facilitator I	23	9
P13	GBI Facilitator II	20	8

(Source: Researchers' Own, 2021)

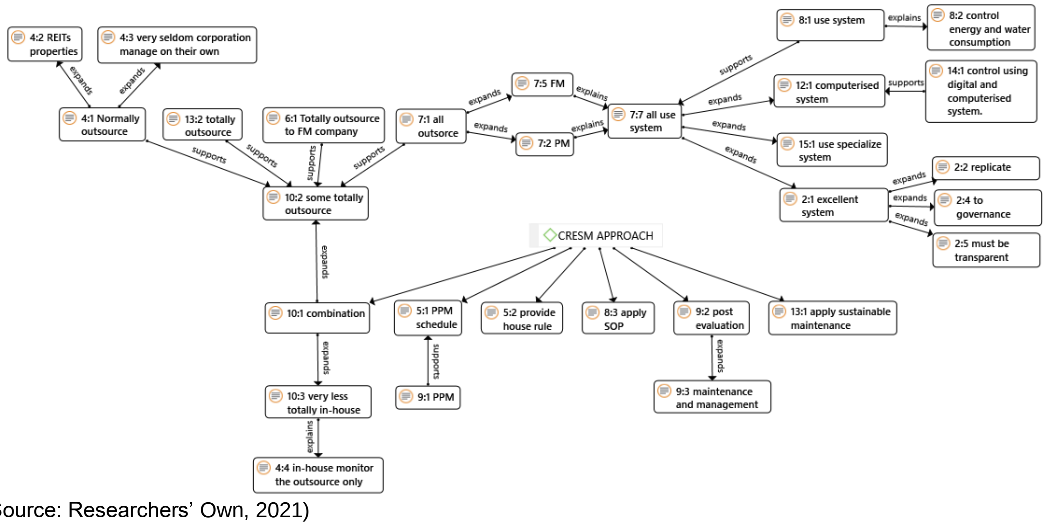
DATA ANALYSIS

Before the data were analysed, the recordings of the interview sessions were initially transcribed. Then, the transcribed data were analysed using thematic content analysis. This analysis involved identifying key themes within the data to gain insights into the approaches employed by CRE managers related to CRESM practice. ATLAS.ti, i.e., a software that allows coding, annotating, and analysis of qualitative data, was utilized to facilitate the analysis process.

RESULTS AND DISCUSSION

Drawing from the evidence, corporations and their management have a range of available approaches that can be employed to effectively manage sustainable office buildings. Nevertheless, these approaches may vary as some management teams chose to adopt a single approach of either in-house management or outsource management, while others opted for combined strategies of both in-house and outsource management. The findings from the interviews shed light on the different approaches that corporations have implemented in the management of their sustainable office buildings. These findings are depicted in Figure 1.

The finding can be divided into two which is type of management approach and the approach's indicators. Two distinct categories emerged which is outsourced CRESM, and a combination of both in-house CRESM and outsource CRESM.



(Source: Researchers' Own, 2021)

Figure 1. CRESM Approach and Their Indicators

CRESM Approach

Based on the analysis, it was found that one of the participants, i.e., P10, highlighted the adoption of a combination approach in CRESM. This indicates that very few corporations opted for in-house management approach. This notion is supported by P4, who mentioned that in-house management primarily monitors the outsourced CRESM activities, suppliers, and sub-contractors. This finding aligns with the findings made by Manning and Roulac (1997) who suggested that the management functions of "entrepreneur" and "business strategist" are more likely to be carried out more effectively by internal managers.

On the other hand, participants P1, P2, P5, P6, P7, P8, P9, P12, and P13 stated that they adopted a fully outsourced CRESM practice. This feedback indicates that they rely entirely on outsourced companies for managing their sustainable real estate. For example, P4:Q1 explained that corporations often opt for outsourced management, particularly for properties owned by Real Estate Investment Trusts (REITs), as this is a requirement for REITs. P4:Q3 added that corporations rarely manage their own buildings as their primary focus is on managing their core business activities. This view was supported by Gim and Jang (2020) who reiterated that outsourcing property operations to third-party operators is a crucial business aspect in the lodging REITs industry due to the regulation outlined in the Internal Revenue Code. According to this regulation, REITs are not allowed to operate their own properties. Therefore, REITs rely on external property operators to manage and oversee the day-to-day operations of their properties. This sentiment was echoed by P13:Q2 and P7:Q1 who stated that all management functions are outsourced to PM companies and FM companies. Furthermore, P6:Q1 mentioned that the management of buildings is outsourced to an FM company. This is in line with the finding made by Fauzi et al. (2015) that outsourcing real estate management is the most popular property management practice, especially when the management demanded a portion of skilled labor.

Meanwhile, P7:Q7 shared that both FM and PM currently utilize systems for managing sustainable buildings. This observation was supported by P8:Q1, who mentioned that management teams typically employ updated and advanced computerized systems. These systems are specifically designed to assist in the efficient management, monitoring, and control of various aspects of sustainable buildings, including energy and water consumption (P8:Q2). P2:Q1 added that these systems align with the global management revolution. Additionally, P12:Q1 highlighted the importance of computerized systems in the management of sustainable buildings. These systems provide comprehensive functionality and are tailored to meet specific management needs (P12:Q1). The adoption of digital computerized systems was also emphasized by P14:Q, indicating that it is a prevalent practice among management teams. Importantly, these systems are designed to ensure governance and transparency (P2:Q4 and P2:Q5). Besides, they are also replaceable, meaning that they can be easily transferred or utilized by other personnel in the event of a change in management (P2:Q2). This ensures continuity and minimizes disruptions in the management process. This notion was supported by Støre-Valen (2019) who found that the integration of digital technology, such as BIM in FM, can greatly enhance the understanding of the possibilities and utilization of facilities. The author added that by embracing BIM, municipalities and public owners can optimize their FM practices, leading to improved operational efficiency, cost savings, and enhanced user experiences. In addition, the use of Information and Communication Technology (ICT) can play a significant role in supporting and justifying essential building renovation aimed at improving a building's performance and reducing annual energy costs (Yin, 2010). Conclusively, ICT solutions offer various tools and technologies that can assist in the planning, implementation, and monitoring of energy-efficient building upgrades.

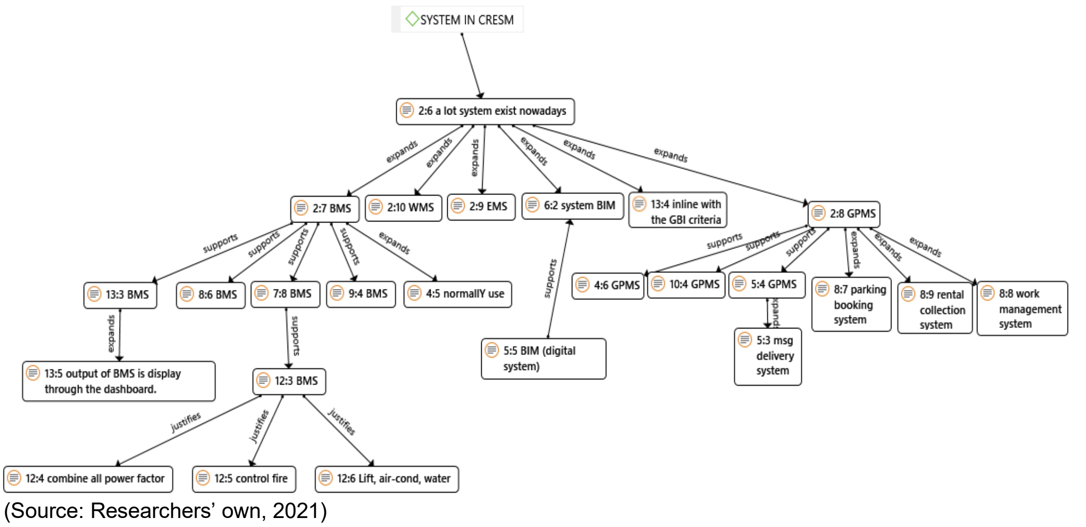
CRESM Approach's Indicators

Another category of practices identified from the participants' responses is the inclusion of various indicators in CRESM approaches. These indicators serve as guidelines and measures to ensure effective and sustainable building management. One indicator mentioned by P5:Q1 and P9:Q1 is the implementation of preventive management schedules (PPM). These schedules involve planning and carrying out preventive maintenance activities to proactively address potential issues and maintain the building's sustainability. Implementing a Preventive Property Maintenance (PPM) program offers benefits beyond cost savings for property managers (Sidney, 1992). Additionally, house rules are commonly incorporated under green lease practices for incoming and new tenants (P5:Q1). These rules outline specific guidelines and regulations that promote environmentally-friendly practices within the building. However, Adnan et al. (2017) found that many managers have expressed a lack of complete understanding when it comes to the concept of a green lease.

Standard operating procedures (SOP) also play a significant role in CRESM, as highlighted by P8:Q3. These procedures provide a set of guidelines for all building occupants to follow in handling equipment and conducting sustainable maintenance activities. Compliance with these procedures ensures that the building operates in accordance with green certification requirements (P13:Q1). Furthermore, post-evaluation of management and maintenance practices is conducted to identify potential problems and propose solutions for improvement (P9:Q2:Q3). This evaluation process is often part of a performance measurement system, particularly for green buildings, known as sustainable performance measurement systems. These systems allow management to assess the effectiveness of their practices and identify best practices for future implementation. It is important to note that each building may yield different results based on various factors specific to the building.

System Use in CRESM

Referring to Figure 2, the findings highlight the various systems employed by corporations to efficiently manage and control the physical operations and administration of sustainable buildings. The results indicate the presence of multiple systems that facilitate efficient and controlled building operations. These systems include the Building Management System (BMS), Building Information Modelling (BIM), Water Management Systems (WMS), Energy Management Systems (EMS), and Green Property Management System (GPMS).



(Source: Researchers' own, 2021)

Figure 1. System Use in CRESM

One of the prominent systems mentioned by multiple participants is the BMS. P2:Q7, P13:Q3, P8:Q6, P7:Q8, P9:Q4, P4:Q5, and P12:Q3 all referred to the utilization of BMS in their respective organizations. BMS is a comprehensive system designed to control various aspects of building operations, such as fire systems, lifts, air conditioning, air handling units, and water management. This system is particularly valued for its ability to monitor and control mechanical areas, air conditioning, and electrical components, as highlighted by P4. It plays a crucial role in optimizing the operation and performance of building systems, resulting in improved efficiency, reduced energy consumption, and lower operating costs (Yin, 2010). Another system that emerged from the study is BIM, which was mentioned by P6:Q2. BIM serves as a digital representation of a facility, providing valuable information for managing and assessing sustainable buildings. It integrates indicators related to energy management, indoor quality, and other elements of sustainability performance measurement. BIM will not only support the BMS but also can be used to analyse building performance (Yin, 2010).

WMS and EMS were also identified as integral components of sustainable building operation. P2:Q10 emphasized the importance of WMS in daily water measurement, while P2:Q9 highlighted the role of EMS in daily energy measurement. These systems play a crucial role in identifying abnormal activities and deviations from expected consumption levels, allowing for prompt action to be taken. Energy management during building operation could improve green building performance (Aghili & Amirkhani, 2021). Further, water management and energy management have been found by Fauzi et al. (2023) as key elements in CRESM.

Furthermore, in alignment with the GBI criteria, participants acknowledged the significance of incorporating systems that comply with sustainable practices. P13:Q4 specifically mentioned the alignment of energy management systems with GBI criteria as similar as found by Adnan et al (2017) GBI criteria are the main indicator to incorporate when managing green building. Then, the GPMS was mentioned by P2:Q8. GPMS is a relatively new system adopted by property management companies to integrate various aspects of building maintenance, administration, management, and financial processes. It facilitates efficient communication and streamlines operations within the management team (Razali et al. (2015).

Other system adopted is work management system (P8:Q8) which is utilized to assign work tasks to responsible individuals, including third parties such as clients, contractors, suppliers, and tenants. This system promotes efficient work practices as it is closely monitored by top management, enabling them to determine the person in charge and responsible for any issue related to the assigned tasks. Another system in place is the parking booking system (P8:Q7), which facilitates the reservation of parking spaces by visitors prior to their arrival at the building. This system provides the location details of the designated parking spaces, ensuring convenience and efficient parking arrangements.

Table 2. Summary of CRESM Approach and Their Indicators

Theme	Approach	Example
Type of Management	In-house management	Fully in-house
	Outsourced management	Fully outsourced
	Combination	Combination of in-house and outsourced management In-house - monitor, outsourced - managed
Indicator	Green Property Management (GPM)	Included of: Work management System Parking booking system Rental collection system Message delivery system
	Green Lease Practice (GLP)	Provide house rules Provide tenant guide
	Building Management System (BMS)	Water management system Energy management system
	Building Information Modelling (BIM)	Integrates energy management, indoor quality, and other green elements
	Sustainable Performance Measurement System (SPMS) Performance Measurement System (PMS)	Post evaluation Provide SOP to all equipment PPM schedule
	Green Building Index Criteria (GBI)	Used criteria as guide

(Source: Researchers' Own, 2021)

Last but not least, a rental collection system (P6:D8:Q9) is implemented to monitor rental payments. Tenants receive notifications regarding payment deadlines, and upon completing the payment, they receive a digital receipt that can be saved and printed. In case of delayed payments, automated reminders can be sent to tenants. This system streamlines the rental payment process and ensures prompt and accurate payment management. Corporations, companies, and organizations have the flexibility to adopt various approaches and systems to effectively manage sustainable office buildings. These approaches can be categorized based on the type of management and the indicators and systems used. For a summary of the CRESM practices identified in this study, please refer to Table 2.

CONCLUSION

The diverse approaches adopted by the participants draw attention to the varying preferences and strategies employed by corporations in managing their sustainable real estate. While some corporations opt for a combination of in-house and outsourced CRESM, others prefer a fully outsourced approach. The decision for a corporation to choose a particular approach likely depends on several factors, such as resource availability, expertise, and the specific goals and requirements of the corporation. Furthermore, most corporations prefer to outsource their real estate management functions rather than handling them internally. This outsourcing trend may be driven by factors such as specialized expertise, cost efficiency, and the desire to focus on core business operations. Finally, the presence of external management entities, such as PM companies and FM companies, allows corporations to leverage the knowledge and resources of industry professionals in effectively managing their properties.

Incorporating indicators such as preventive management schedules, house rules, standard operating procedures, and post-evaluation in CRESM enables effective management, maintenance, and continuous improvement of sustainable buildings. These indicators serve as valuable tools for ensuring adherence to sustainability standards and achieving optimal building performance. This study also revealed multiple systems employed by corporations to ensure the efficient and controlled operation of sustainable buildings. These include the Building Management System (BMS), Building Information Modelling (BIM), Water Management Systems (WMS), Energy Management Systems (EMS), and Green Property Management System (GPMS). The adoption of these systems reflects the commitment of organizations to adhere to sustainable practices and optimize building.

ACKNOWLEDGMENTS

Special appreciation to Real Estate Management Program, Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA Perak Branch, Seri Iskandar Campus, 32610, Seri Iskandar Perak, Malaysia, Pembiayaan Yuran Prosiding Berindeks (PYPB), Tabung Dana Kecemerlangan Pendidikan (DKP), Universiti Teknologi MARA (UiTM), Malaysia for funding this article.

REFERENCES

Abdullah, S., Razak, A. A., Hanafi, M. H., & Salleh, M. N. (2011). Managing government property assets: the main issues from the Malaysian perspective. Journal of Techno-Social, 3(1).

Adnan, Y. M., Aman, N. U., Razali, M. N., & Daud, M. N. (2017). The implementation of green lease practices for office buildings in Kuala Lumpur, Malaysia. Property Management. 35(3). https://doi.org/10.1108/PM-12-2015-0067

Aghili, N., & Amirkhani, M. (2021). SEM-PLS approach to green building. Encyclopedia, 1(2), 472-481.

Ali, Z.; McGreal, S; Adair, A and Webb, J.R. (2008), Corporate Real Estate Strategy: A Conceptual Overview, Journal of Real Estate Literature, 16 (1), s1-22.

Aliagha, G. U., Hashim, M., Sanni, A. O., & Ali, K. N. (2013). Review of green building demand factors for Malaysia. Journal of Energy Technologies and Policy, 3(11), 471-478, http://www.iiste.org/Journals/index.php/JETP/article/view/8596

Arditi, D., & Nawakorawit, M. (1999). Issues in building maintenance: property managers' perspective. Journal of Architectural Engineering, 5(4), 117-132.

Collins, D., Haugen, T., Lindkvist, C., & Aamodt, C. (2019). Bridging the gap between sustainable FM and sustainable buildings an exploratory study of six public buildings in Norway. Facilities. https://doi.org/10.1108/F-01-2018-0007

Demirdoven, J. (2015, April). An interdisciplinary approach to integrate BIM in the construction management and engineering curriculum. In Proceedings of 9th BIM Academic Symposium and Job Task Analysis Review, Washington, DC (pp. 112-119).

Edwards V.& Ellison L.(2004), Corporate Property Management: Aligning Real Estate With Business Strategy. Blackwell Science Limited.Fauzi, N.S., Kamarudin,N., Moh Ali, S.N., Salleh, N.A., & Johari, N. (2015). Outsourcing property management perspective: universities in the District of Perak Tengah. Proceedings of Postgraduate Conference on Global Green Issues (Go Green), 7-8 October 2015

Fauzi, N. S. (2021). Corporate real estate sustainable management (CRESM) model for office buildings (Doctoral dissertation, Universiti Teknologi MARA).

Fauzi, N. S., Ali, S. N. M., Arshad, H., & Fachrudin, K. A. (2023). Key Elements of Corporate Real Estate Sustainable Management for Office Buildings. Environment-Behaviour Proceedings Journal, 8(23), 207-214.

Gim, J., & Jang, S. S. (2020). Lodging REITs and third-party operators: Do more operators enhance the performance of REITs?. Tourism Management, 79, 104092.

Izyumov, M. D. (2023). ESG in corporate real estate management: global trends and Russian experience. In E3S Web of Conferences (Vol. 403, p. 01012). EDP Sciences.

Kaur, T., & Solomon, P. (2022). A study on automated property management in commercial real estate: a case of India. Property Management, 40(2), 247-264.

Kumar, K. (2013). Sustainability performance measurement: an investigation into corporate best practices (Doctoral dissertation, PhD Thesis). National Institute of Development Administration).

Lowe, C., & Ponce, A. (2014). UNEP-FI / SBCI ' S Financial & Sustainability Metrics Report: An international review of sustainable building performance indicators & benchmarks. http://www.unepfi.org/fileadmin/documents/metrics_report_01.pdf

Lu, Y., Chang, R., Chong, D., & Ngiam, M. L. J. (2020). Transition towards green facility management: bridging the knowledge gaps of facilities managers. Journal of Green Building, 13(3), 122–144.

Lützkendorf, T., & Lorenz, D. (2014). Sustainability Metrics Translation and Impact on property Investment and Management. In UNEP FI PROPERTY WORKING GROUP REPORT.

Manning, C., Rodriguez, M., & Roulac, S. (1997). Which corporate real estate management functions should be outsourced?. Journal of real estate research, 14(3), 259-274.

Medel-gonzález, F., García-ávila, L. F., Antonio, V., & Salomon, P. (2016). Sustainability performance measurement with Analytic Network Process and balanced scorecard : Cuban practical case. Production, 26(3), 527–539.

Ohueri, C. C., Enegbuma, W. I., & Kenley, R. (2018). Energy efficiency practices for Malaysian green office building occupants. Built Environment Project and Asset Management, 8(2), 134–146. https://doi.org/10.1108/BEPAM-10-2017-0091

Oladokun, T.T. and Aluko, B. T. (2015). Corporate Real Estate Strategies: The Nigerian Experience. Journal of Corporate Real Estate. 17 (4), 244 -259

Olawumi, T. O., & Chan, D. W. M. (2019). An empirical survey of the perceived benefits of executing BIM and sustainability practices in the built environment. Contstruction Innovation, 10 (May).

Razali, M. N., Kamarudin, N. R., & Othman, S. H. (2015). Green property management for commercial buildings Green property management for commercial buildings. WIT Conference on Sustainable Development and Planning, 19-21 June 2015, Istanbul, Turkey, June. https://doi.org/10.2495/SD150121

Støre-Valen, M. (2019). Digitization of FM: Experiences from Norwegian property managers. In European Facilities Management Conference 2019.

Xu, J., Lu, W., & Li, L. H. (2019). Cognitive facilities management: Definition and architecture. In International Conference on Smart Infrastructure and Construction 2019 (ICSIC) Driving data-informed decision-making (pp. 115-122). ICE Publishing.

Yin, H. (2010). Building management system to support building renovation. Department of Civil and Environmental Engineering, UCC, Snapshots of Doctoral Research, University College Cork. Yin H.

Ziemba, E., Śmietana, K., Ramian, T., & Kania, K. (2015). The Concept of a Sustainable Approach to Corporate Real Estate Management. Real Estate Management and Valuation, 23(4), 85–94. https://doi.org/10.1515/remav-2015-0039

Zilber, T. B., & Meyer, R. E. (2022). Positioning and fit in designing and executing qualitative research. The Journal of Applied Behavioral Science, 58(3), 377-392.

EXPLORING CONCEPTUAL MODEL ON THE KEY CRITERIA AND COMPONENTS OF GREEN BUILDING CONSTRUCTION MATERIALS FOR HOTEL OPERATIONAL SUSTAINABILITY

Nur Adlina Ismail[1], Natasha Khalil[1]*, Suwaibatul Islamiah Abdullah Sani[1], Noor Akmar Shah Nordin[2] and Husrul Nizam Husin[1]
[1]College of Built Environment, Universiti Teknologi MARA Perak Branch, Seri Iskandar Campus, 32610 Perak Malaysia
[2]Deutsche Gesellschaft Fuer Internationale Zusammenarbeit (GIZ) GmbH, Block B5, Precinct 162502 Putrajaya, Malaysia

**Corresponding Email: natas582@uitm.edu.my*

Abstract
The core business of hotels lies on the efficient services and operations, therefore, the principles of green and sustainability must be prioritized. The viability of the hotel sector is crucial for upholding the sustainability principles; thus, a careful selection of green building materials is urgently needed for upscaling the consumption of hotel construction and sustainable hotel operations. However, the list of green materials for hotel buildings are still lacking and not widely recognized by manufacturers. Even though materials and resources are one of the green rating tools criteria, however it is not prioritised as the major contribution on the rating score and have the lowest credited points. This study is aimed to establish a conceptual model of key criteria of green building materials that relates to the hotel's operational sustainability. A qualitative approach utilised integrative review technique and 31 articles from January 2012 to December 2023 has been considered for literature synthesis. The findings finalised that there are 11 criteria of green building materials consists of Manufacturers' Identification, Materials Declaration, Life Cycle Assessment, Indoor Air Quality Performance, Toxic Disposable, Design Adaptability, Regional Materials, Durability, Reusable Design, Renewable Resources and Water Efficiency. It was deductively clustered into five key criteria; Manufacturers Criteria, Health Criteria, Consumption Criteria, Design Components Criteria and Resource Management Criteria. This finding explores the entailing review on the criteria for choosing building materials and justify how it impacted the hotel's operational sustainability.

Keywords: *Green Building Materials; Materials Criteria: Sustainable Operations; Hotels Operational Sustainability; Conceptual Model*

INTRODUCTION

Green strategies on the buildings are extremely needed to minimize environmental impact such as greenhouse gas reduction (Sicignano et al., 2019). To implement green strategies for buildings, green building rating tools were established to achieve the aims towards minimizing environmental harm from building design and operations. As described by Haddad (2019), green building rating tools are designed to promote sustainable and environmentally responsible practices in the construction and operation of buildings. The rating tools provide a framework and guidelines for reducing resource consumption, minimizing waste generation, and lowering greenhouse gas emissions. Among crucial aspect addressed by green building rating tools is the use of sustainable materials and resources which encourage the selection of environmentally friendly materials, such as recycled content, rapidly renewable resources, and low volatile organic compound (VOC) products. By prioritizing sustainable sourcing and reducing waste, these tools support the transition towards a circular economy and minimize the environmental impact of construction activities. In local green building rating systems, such as Green Building Index (GBI), Malaysian Carbon Reduction and Environmental Sustainability Tools (MyCREST), GreenRE, Melaka Green Seal, and Penarafan Hijau JKR (PhJKR), also includes the use of sustainable materials.

PRIMARY THEME OF SUSTAINABILITY	MALAYSIAN GREEN BUILDING RATING TOOL				
	GBI	GreenRE	MyCREST	Melaka Green Seal	PHJKR
Project Planning & Management	–	–	✔	✔	–
Site Planning & Management	✔	✔	✔	✔	✔
Transportation	✔	✔	✔	✔	✔
Water efficiency	✔	✔	✔	✔	✔
Energy efficiency	✔	✔	✔	✔	✔
Materials & resources	✔	✔	✔	✔	✔
Waste	✔	✔	✔	–	✔
IEQ	✔	✔	✔	✔	✔
Innovation	✔	✔	✔	–	✔

(Source: Foo & Fuad, 2018)

Figure 1. The Relevant Aspects of Sustainability are Covered by Malaysian Green Building Rating Tools

Figure 1 depicts the relative importance of various sustainability themes among Malaysians for these green building assessment systems (Foo & Fuad, 2018). *Materials and Resources* is one of the specified criteria that focuses on sustainable materials. These green rating schemes applied to various project type and building's category, including non-residential projects, new residential, township projects, and highway projects. However, it can be seen that much of green strategies are majorly applied to offices and residential properties, but green initiatives in hotel industry in still in infancy stage (Ad, 2017). A summary of project's applicability in green building ratings by Foo & Fuad (2018) showed that majority of the schemes are more focusing to the commercial buildings rather than the hotel's category building.

Hotels are significant for tourism industry, and it constitute one of pillars in the tourism sector. The hotel industry is highly unique among other commercial buildings (Bohdanowicz, 2006). Like other structures, hotels are constructed and operated in a way that has an adverse effect on the environment. For example, hotels use a lot of energy, water, cleaning products, and wastewater generators. The core business of hotels lies on the efficient services and operations, therefore, the principles of green and sustainability must be prioritized. The viability of the hotel sector, one of the largest components of the tourism sector, is crucial for upholding the sustainability principles (Khalil et al., 2022). It incorporates elements of environmental, economic, and social sustainability (see Figure 2). Tourism Malaysia statistics in 2020 shows that hotel guests climbed by less than 35% during the same period to 82.44 million in 2018, while the number of hotel rooms expanded by almost 80% from 168,840 in 2009 to 308, 210 in 2018. These numbers show that the hotel sector, which has for a long time ignored a number of issues of environmental compatibility in design, as well as responsible resource management and business operations, has an urgent need for more environmentally sound practices and products. The demand for clean areas, nature and intact areas for tourism sector is growing, hence the hotel industry is showing increasing interest in sustainable development (Jovanovic, 2019).

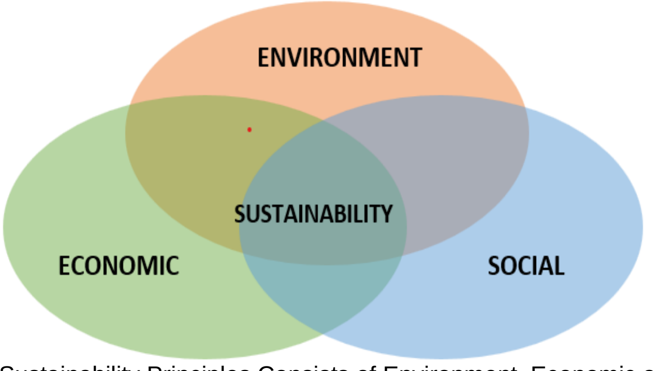


Figure 2. Sustainability Principles Consists of Environment, Economic and Social

It is imperative that suitability of materials for hotel industry will help to reduce the environmental impact that has indicated as one of the criteria to be awarded as green hotels in green rating schemes. Hence, one of the strategies that can help to foster the applicability of sustainability materials for hotels is through green procurement adoption. The National Sustainable Consumption and Production Blueprint (SCP-GGP), which is a government policy, and the Economic Planning Unit's adoption of green procurement execution are both in sync with one other. Additionally, the established guideline of Government Green Procurement (GGP) published by Ministry of Environment and Water (KASA) make this point very clear. The GGP guideline outlines 40 sustainable products and services, including for hotels services and maintenance management (Malaysian Green Technology and Climate Change Centre, 2020). However, the specific criteria for hotel services in the GGP guideline only focuses to the waste management criteria such as zero of single-use plastics. There are no specific criteria focusing on the usage of green and sustainable materials for hotels. Another e-market promotion of sustainable materials introduced to the Malaysian context is through MyHIJAU Mark directory (MGTC, 2020). The Government of Malaysia has authorised MyHIJAU Mark, Malaysia's official green recognition programme, which aims to promote certified goods and services that adhere to national and international environmental criteria under a single mark. The MyHIJAU directory lists the eco-label products according to the various categories. However, the list of materials for hotel buildings are still lacking and not widely recognized by manufacturers.

According to Ministry of Tourism, Art and Culture (MOTAC), there are 4788 registered hotels in Malaysia ranging from 1 to 5 stars rating. Despite the numbers, only one hotel is recognized as green hotel by MOTAC and as to date, there are only 17 green rated hotels awarded by ASEAN Green Hotel. This illustrates that despite its benefits, the hotel industry is still slow to implement green solutions, highlighting the pressing need for more environmentally friendly practises in this industry. According to Yee et al. (2020), one of the issues discourage the stakeholders to step into green is the financial aspect. Implementing sustainable materials as green strategies in a construction project requires high initial costs. Stakeholders are worried about profitability more than environment (Ametepey et al., 2015). One of the issues stated by (Kamaruzzaman et al., 2016) is buildings materials that produce air pollutants such as paint that contain volatile organic compounds (VOC) and materials that contain formaldehyde can cause indoor air dwellings to occupants. These harmful compounds that could have both short- and long-term effects on one's health. Sneezing, eye discomfort, throat irritation, and skin allergies are examples of short-term effects. Long-term effects include asthma, cancer, infertility, and a host of other conditions. As results, it gives impact to hotel’s customer as most of them spend their time indoor. In addition, although customers are the focus of the hotel industry, employees who operate the hotels spend the majority of their working hours in the hotel's building (Bangwal et al., 2022). All of these negative impacts from harmful pollutants may have a long-term effect on them. (Andersen et al., 2009) also shows that the building with poor indoor air quality consumes more energy results giving high operating cost.

OVERVIEW OF BUILDING MATERIALS IMPACT TO THE HOTEL SUSTAINABLE OPERATIONS AND PERFORMANCE IMPACT

The core business of hotels lies on the hotel buildings design and its service operation. As the hotels are more concentrating on aesthetics values as one aspect of perceived experiential value, hence, a careful selection of materials is urgently needed for hotel sectors. Choosing building materials is crucial to sustain the business and operational management of hotels. Thus, the growth of the green hotel industry has increased demand for sustainable building materials usage. Performance impact of sustainable hotels operations is therefore aligned to environmental performance, economic performance and social performance (Sonmez & Tavsan, 2018; Khalil et al., 2022; Artuger, 2020).

Environmental Performance

When evaluating products and materials, it is crucial to check for third-party confirmation of sustainability, safety, and quality claims in addition to the manufacturer's own claims. When it comes to sustainable materials, improving indoor environmental quality, human health, and wellness, as well as preserving energy, water, raw materials, biodiversity, and land, are all essential components of environmental sustainability (Jadallah, 2018). Opting for eco-friendly and sustainable building materials, such as recycled content materials or renewable materials, aligns with the hotel's commitment to green practices and environmental responsibility. Khalil et al. (2022) added that sustainable practices in hotels can enhance the hotel's reputation, attract environmentally conscious guests, and contribute to the overall sustainability goals of the hotel industry. Choosing sustainable materials for hotels helps boost their environmental performance by reducing resource consumption, lowering carbon emissions, minimizing waste, improving indoor air quality, conserving natural resources, enhancing brand image, and ensuring compliance with green building certifications (Lee & Zainordin, 2019). As stressed by Artuger (2020), it is an essential step in aligning hotel operations with sustainable practices and mitigating the environmental impact of the hospitality industry.

Economic Performance

Economic elements of sustainability related to economic benefits such as cost reduction, increased revenue, and economic growth. Selecting durable building materials, such as high-quality flooring, finishes, and fixtures, can minimize the need for frequent repairs and replacements. This reduces maintenance costs and downtime, ensuring smooth hotel operations and minimizing disruptions for guests. Given enough information about the advantages of sustainable design, consumers are more likely to pay more when doing so will ultimately result in them saving money by using less energy, such as electricity and water (Chan et al., 2017). However, people continue to be unaware of the advantages of choosing sustainable materials, and they hesitate to spend more on them. Using hotel owners as an example, Legrand et al. (2013) assert that when they are operating on a tight budget, they prioritise energy conservation. This fulfills their needs while saving money by utilising technology like solar-powered space water heating and wind-powered energy production. According to Mate (2009), cost is not a deterrent for designers who actively practise sustainable design, but it is viewed as a substantial deterrent by designers who do not practise sustainable design or who only do so when necessary. Bergman (2011) stated that keeping a building healthier can have advantages including minimising medical expenditures and staff attrition, which will boost productivity. Samari et al. (2013) claim that the only factor contributing to clients' and designers' perceptions of sustainable shows how designing sustainably would improve the user's health and productivity materials as expensive is a lack of knowledge in these fields. Sichali & Banda (2017) highlighted that it can lower the building's operating and maintenance costs. If sustainable materials prevent harm to the environment and inhabitants, the additional cost is insignificant.

Social Performance

An approach to social sustainability emphasizes the relationship between people, the environment, and strategies. If the goal is to encourage sustainable growth in a society, social norms, interactions, and limits must be taken into consideration (Ayalp, 2013). Building materials play a crucial role in defining the hotel's overall ambiance and aesthetic appeal. Selecting visually appealing and high-quality materials can enhance the guest experience, create a memorable atmosphere, and positively impact guest satisfaction and loyalty. Social sustainability concepts include equitable opportunity, community, and standard of living. However, money, people, and the environment are what Manchanda & Steemers (2009) characterize as the three perspectives of sustainability. People, they assert, comprise the social component, which also includes the users' comfort, happiness, and well-being. Sustainability is hindered by fundamental design principles, which forbid the indiscriminate use of natural resources. Designers must consider the societal norm when determining how to evaluate both need and wealth. Setting a reasonable and credible definition of need is the responsibility as a designer (Ayalp, 2013). The majority of study on how workplaces affect health and welfare has focused on elements like thermal comfort, lighting, acoustics, and indoor air quality, with far less attention paid to the actual materials utilised. By choosing materials with no or low VOCs, the indoor environment air quality may be enhanced and made healthier for occupants (Speigel & Meadows, 2012).

Based on the above elements of sustainability in the hotel operations, it is clearly unveiled that operation management for hotels is crucial to achieve the sustainable performance of hotels. Careful consideration of these factors during material selection can optimize hotel operations, enhance guest satisfaction, and contribute to the hotel's long-term success. It is vital to explore an extensive review in determining the criteria of green building materials for the sustainable hotels’ operation. Criteria refers to a set of specific requirements or standards that guide the selection and evaluation of materials used in design and construction projects. According to Achintha (2016), the criteria serve as benchmarks or guidelines to assess the suitability and performance of building materials based on various factors, such as sustainability, quality, safety, and functionality. Building materials criteria encompass a wide range of considerations and can vary depending on the context, project goals, and applicable regulations or certification programs (Asdrubali et al., 2012).

METHODOLOGY

This study primarily aims to identify the criteria of green building materials that can have impact towards the hotel's operation. From the necessity of materials criteria, it helps to further develop conceptual of green building materials criteria to the sustainable hotel operations and performance impact. Within this purpose, a review of relevant literature was performed using integrative review technique, adapted from Oermann and Knafl (2021). The search strings of literature are extracted from reputable databases; Scopus, Web of Science and Emerald which limits publications from January 2012 to December 2023. From the databases, the initial search string was done using the keywords such as "*sustainable materials*", "*green building materials*" and "*green materials criteria*". A total of 88 articles were attained as an initial retrieved articles from the searching databases. Next, a detailed screening using inclusion criteria is used to finalize the relevant articles for review analysis and synthesis. The literature content is deductively screened and categorized into these three themes of practices; i) environmental performance, ii) economic performance and iii) social performance. A final of 31 articles is included for the data analysis and synthesis after excluding the irrelevant criteria on the scope of study. Bibliographic analysis is used to present the literature findings and supported with an establishment of initial conceptual model by the end of the finding discussion.

ANALYSIS OF FINDINGS

In this study, the devotion of material's criteria towards the hotel's operational sustainability are different from the materials' criteria in the established in green rating certification. Even though in the green rating certification has mentioned the detail criteria for materials (in example: reused materials, sustainable resources, waste management and green products), however those criteria are setting up for the hotels to achieve green rating during design and construction. It is not clearly seen whether the criteria have any effect to the hotel operations. Building materials can be used strategically to reflect the hotel's brand image and differentiate it from competitors. Unique or innovative materials can contribute to a distinct architectural style or design theme, making the hotel stand out in a crowded market and attracting guests seeking a specific experience (Artuger, 2020). Based on the integrative review on the criteria of green building materials, it was found that there are 11 criteria of green building materials consists of *Manufacturers' Identification, Materials Declaration, Life Cycle Assessment, Indoor Air Quality Performance, Toxic Disposable, Design Adaptability, Regional Materials, Durability, Reusable Design, Renewable Resources* and *Water Efficiency*. These criteria were compiled from 31 sources and research, as per summary shown in Table 1.

Table 1. Summary of Bibliographic Analysis of Components in Green Building Materials

Source(s)	Components of Green Building Materials										
	Manufacturer's Identification	Materials Declaration	Life Cycle Assessment	IAQ Performance	Toxic Disposable	Design Adaptability	Regional Materials	Durability	Reusable Design	Renewable Resources	Water Efficiency
Abdul Rahman (2016)	/	/				/	/				
Asdrubali et al. (2012)			/								
Aslani et al. (2019)									/	/	
Atan (2015)		/									
Ceshin & Gaziulusoy (2016)			/								
Cuviella-Suarez et al. (2019)				/							/
Defterios & Toh (2019)					/						
Dong & Hua (2018)								/			
Gabarda-Mallorqui (2017)				/					/		/
Garetti & Taisch (2012)	/		/								
Godavitarne (2017)					/						
Hanafi et al. (2015)	/	/					/		/	/	
Jadallah (2018)								/	/	/	
Koshnava et al. (2020)				/							
Kono et al. (2018)							/				
Llop & Ponce (2014)	/								/		
Machado et al. (2020)		/									
Mohamed (2018)									/		
Nehr et al. (2017)				/							
Rashdan & Ashour (2017)	/	/	/		/	/				/	/
Rosen & Kishawy (2012)	/										
Ruuskan &Hakinen (2014)	/				/				/		
Sabnis & Pranesh (2017)	/						/				
Samari et al. (2013)			/					/			
Sameh (2014)							/				
Stafford (2015)				/							
Stelmack et al. (2015)		/									
Syed et al. (2014)	/									/	
Van Tran et al. (2020)				/							
Zega et al. (2020)			/					/			
Zhu et al. (2016)						/				/	

Based on these eleven criteria, it was deductively clustered into five (5) key criteria; namely, Manufacturers Criteria, Health Criteria, Consumption Criteria, Design Components Criteria and Resource Management Criteria. If green building materials are adopted in green hotels that focuses to the operational sustainability, these are the criteria that needs to be considered for the materials selection. The entails description of these five key criteria is shown in Table 2.

Table 2. Key Criteria of Green Building Materials and Its Description

	Key Criteria of Green Building Materials	Description	The Components of Criteria	Source(s)
1.	Manufacturers Criteria	Refers to a person or business that transforms raw materials into finished items using various tools, equipment, and techniques before selling the products to consumers	Manufacturers' Identification Materials Declaration Life Cycle Assessment	Abdul Rahman (2016); Asdrubali et al. (2012); Atan (2015); Ceshin & Gaziulusoy (2016); Garetti & Taisch (2012); Hanafi et al. (2015); Llop & Ponce (2014); Machado et al. (2020); Rashdan & Ashour (2017); Rosen & Kishawy (2012), Ruuskan &Hakinen (2014); Sabnis & Pranesh (2017); Stelmack et al. (2015)
2.	Health Criteria	Refers to level of pollution which, in the case of noncarcinogens, prevents adverse health effects in humans	Indoor Air Quality (IAQ) Performance Toxic Disposable	Cuviella-Suarez et al. (2019); Defterios & Toh (2019); Gabarda-Mallorqui (2017); Godavitarne (2017); Koshnava et al. (2020); Nehr et al. (2017); Rashdan & Ashour (2017); Stafford (2015)
3.	Consumption Criteria	Refers to responsible consumption that buyers or as citizen consumers must make their choice taking into account environmental impacts at all stages of the product life cycle	Design Adaptability Regional Materials	Abdul Rahman (2016); Hanafi et al. (2015); Kono et al. (2018); Rashdan & Ashour (2017); Sabnis & Pranesh (2017); Sameh (2014); Zhu et al. (2016)
4.	Design Components Criteria	Refers to the process of creating or developing a product or material	Durability Reusable Design	Aslani et al. (2019); Dong & Hua (2018); Hanafi et al. (2015); Jadallah (2018); Llop & Ponce (2014); Mohamed (2018); Samari et al. (2013); Zega et al. (2020)
5.	Resource Management Criteria	Refers to process of allocating resources to achieve the greatest organizational value	Renewable Resources Water Efficiency	Aslani et al. (2019); Cuviella-Suarez et al. (2019); Gabarda-Mallorqui (2017); Hanafi et al. (2015); Rashdan & Ashour (2017); Syed et al. (2014); Zhu et al. (2016)

DISCUSSION OF FINDINGS

Manufacturers Criteria

A manufacturer is a person or business that transforms raw materials into finished items using various tools, equipment, and techniques before selling the products to consumers, wholesalers, distributors, retailers, or other manufacturers for the production of more complex goods (Corporate Finance Institution, 2020). Garetti & Taisch (2012) stated that creating a new material will consume a great number of resources and waste. This demonstrates the importance of manufacturers in selecting resources for product manufacturing. In a nutshell, manufacturers' criteria could be employed to select a sustainable building material for green hotel projects. The discussion of its components in this criterion are as follows:

Sustainable Manufacturer's Identification

Manufacturing industries which are a largely based industry already started to contribute towards environment by implementing sustainable manufacturing (Garetti & Taisch, 2012). Sustainable manufacturing (SM), often known as green manufacturing, is a production strategy that minimises waste and has little impact on the environment (Rosen & Kishawy, 2012). These goals will mostly be achieved by putting strategies into practise that have an impact on operational principles, product design, and process design. Machado et al. (2020)'s define sustainable manufacturing as a system that integrates product and process design issues with manufacturing, planning, and control issues in order to identify, quantify, assess, and manage the flow of environmental waste with the ultimate goal of reducing the environmental impact to that of the Earth's self-recovery capability while also attempting to maximise resource efficiency supports this. Thus, selecting manufacturers and suppliers that prioritize sustainability and environmental principle is a necessity for this criterion. (Rashdan & Ashour, 2017) stated that for this purpose, designers such as architects and interior designers are the responsible parties to review the manufacturers company policies and operations that declare their products and materials as environmentally friendly. Their effort on health and environment consciousness should be evaluated too.

Materials Declarations

Declarations and certifications are certified statement that one has fulfilled the requirements of and may practice in a field. Thus, to assess the sustainability credentials of materials as sustainable materials, materials declarations and certifications are important. This is to make sure they are within either international or national standards and met benchmarks for criteria of sustainable materials. Bacon (2011) added that by using a set of criteria to assess a material's quality, safety, value, and impact on one's health, benchmarks for sustainable standards may be established. These standards are used to evaluate the environmental and health claims made by sustainable materials based on how they affect people and the environment (Rashdan & Ashour, 2017). Stelmack et al. (2014) stated that a sustainable materials certification verifies that a material complies with specific sustainability requirements. Designers should evaluate materials certifications issued by regulatory bodies (Boks & Mcaloone, 2009). Numerous certification bodies, such as Eco Labelling Scheme, Carbon Footprint Labelling Scheme, Energy Efficiency Rating & Labelling Scheme, Water Efficient Product Labelling Scheme, and Malaysian Timber Certification Scheme, are working to promote and put sustainable precautionary principles into practise through extensive product databases (Malaysian Green Technology Corporation & Kementerian Tenaga, 2018). According to Atan (2015), the Government of Malaysia's official green recognition programme in Malaysia is called MyHIJAU. MyHIJAU brings concept in uniting all green certifications under a single mark that cover all types of products, materials and services A good or service will be provided that complies with regional and global environmental standards will be given the MyHIJAU mark (Abdul Rahman, 2016). The prerequisite for MyHIJAU's certification of green materials is that they must already be in compliance with performance standards or have green label certification that meets the minimum requirements recognised by GreenTech Malaysia, such as the SIRIM Eco Labeling Scheme and SIRIM Carbon Footprint Labeling.

Life Cycle Assessment

Life cycle assessment (LCA) assesses every aspect of a product's life cycle, including the gathering and extraction of raw materials, the production process, installation, transit, use, and post-use or end-of-life (Mah & Al-Hussein, 2008). Kang & Guerin, (2009) claims that designers should take into account this standard, which choose materials that have a minimum impact on the environment over their whole life cycle. To fully grasp a material's impacts from cradle to grave, manufacturers must evaluate its impacts and components (Bakker et al., 2010). Thus, LCA aims to assess a wide range of effects, such as environmental toxins that threaten ecosystems, resource depletion, freshwater stewardship, ecosystem degradation, habitat loss, social responsibility, and toxic compounds that are harmful to human health (Ceschin & Gaziulusoy, 2016). Manufacturers must be transparent of their products on people and planet. Designers should use materials that have been compared and certified by a certification body according to comparable criteria in order to achieve this criterion. Decisions on choosing materials into green hotels can be supported by third-part certifications. Additionally, LCA is the most effective method for determining a product's actual environmental effects (Asdrubali et al., 2012). Consideration must be given to material extraction, production, transport, building, operation, and administration, as well as deconstruction and disposal, recycling and reuse.

Health Criteria

Green products can be defined as those that have a lower negative environmental and health impact than their substitutes (Khoshnava et al., 2020). Thus, type of materials to be used in green hotels should be selected based on the health criteria. Occupants' health or more specifically clients are one of priority for hotels management to be taken care. As described in the analysis of findings, the components under these criteria are IAQ performance and toxic disposable. The followings provide the discussion on its justification:

Indoor Air Quality (IAQ) Performance

IAQ can be produced by emission from building materials inside of houses or structures (Van Tran et al., 2020). Additionally, the U.S. EPA estimates that some pollutants, such as volatile organic compounds (VOCs), have concentrations that are frequently two to five times higher indoors than outdoors and may even be as much as 100 times greater. These pollutants can be caused by building materials and furnishings, such as worn-out asbestos-containing insulation, newly installed flooring, upholstery or carpet, and cabinetry or furniture made of certain pressed wood products. Therefore, indoor air quality performance must be considered as a criterion in selecting materials for green hotel projects. Nehr et al. (2017) state that the IAQ evaluation with the building materials, which considers microbiological pollutants, chemicals, allergens, fibres, and any mass or energy stressor that may have an impact on occupant health, should be taken into consideration by designer. Assessment tools for IAQ can be employed by designers in design and construction phase. To encourage compliance in designated workplaces, the Department of Occupational, Safety and Health developed the Industry Code of Practice on Indoor Air Quality 2010 in 2010.

Toxic Disposable

Hotels should ensure the building's interior promote health and safety for building occupants. In addition, the hotel core business is solely concerned with the provision of guest accommodation and related services. Mate (2006) supported by stating the materials and products that designers specify must thus be properly investigated, and they must inform their clients of any possible long-term health hazards. Designers can also analyse materials in feasibility study to substitute the materials with safer alternative. They can reduce the danger of ECCs by scrutinising health claims made in marketing materials. They should carefully review the information on materials like paints, adhesives and sealants, waterproofing, fabrics, furnishings, insulation, drywall, and substrates to ensure that everything has been taken into account to provide the best interior environment (Marchand & Walker, 2008). Furthermore, toxic gas emissions released during production and usage should be considered too (Kanth et al., 2011). Production of building materials involved raw materials extraction which can give impact to the environment. Utilizing raw materials from natural sources that are less likely to produce chemicals or volatile organic compounds (VOCs) during manufacture or disposal can help to lessen the impact (Alfsen & Greaker, 2007). Thus, criteria of chemical emissions and toxic disposable of a materials should be taken into account to select material used in green hotel projects.

Consumption Criteria

Consumption criteria is known as the factors and considerations related to the consumption or use of materials during the construction, operation, and maintenance of a building or structure (Kono et al., 2018). These criteria focus on optimizing material usage, reducing waste, and promoting efficiency in the overall consumption of building materials. As described in the analysis of findings, the components under these criteria are Design Adaptability and Regional Materials. The followings provide the discussion on its justification:

Design Adaptability

A design's adaptability is an indicator of how well it manages change. While a completely dynamic design seamlessly manages any change, a static design is incapable of handling change (Gu et al., 2004). Thus, design adaptability could be one of the criteria of sustainable materials for green hotel projects. In order to meet this criterion, Kang & Guerin (2009) recommended that designers investigate their capacity to design places that satisfy clients' needs while requiring the least amount of space and resources. Utilizing multipurpose furniture and depending on smart technologies that offer flexibility through smart materials like lighting that can be utilised for various purposes are two ways to achieve design adaptability for green hotels (Winchip, 2011). By using a material's advantages for many purposes, interior designers can use fewer materials overall. Hardwood, for instance, can be used in a variety of construction-related components, including decks, flooring, panelling, and luxury furniture. In addition, hardwood is used to create wooden window fixture, panels, cupboards, and doorframes.

Regional Materials

Consumption of materials from regional materials can be considered as one of criteria for materials and resources in green building index assessment tools. The building materials are regarded as regional materials if they are produced and extracted locally, promoting the use of local resources and minimising the environmental effects of transportation. For more than 20% of the total material value, the building materials must be collected, harvested, and manufactured within 500 kilometres of the project location. Thus, Kono et al. (2018) suggested design approaches that enable the use of local goods and materials should be advocated by the green hotel designers. This method will decrease the significant environmental impact of the energy required to transport commodities across long distances.

(Sabnis & Pranesh, 2017). This is supported by Sameh (2014) stating that this approach can be alternative to support local economy.

Design Components Criteria

The criteria of design components refer to the specific factors or requirements that are considered during the design phase of a building or structure (Samari et al., 2013; ASlani et al., 2019). These criteria help guide the selection and specification of building materials based on their performance and suitability for the intended application. As described in the analysis of findings, the components under this criteria are Durability and Reusable Design components. The followings provide the discussion on its justification:

Durability

Durability can be defined as ability to exist for a long time without significant deterioration in quality or value. It should be one of criteria for sustainable materials which is friendly for environment. Materials that durable will have longer life cycles and need to be cared and replaced less frequently. Designers should therefore advocate for long-lasting, low-maintenance materials in their green hotel projects. Materials that meet this criterion may be more expensive, (Samari et al., 2013) refutes that upfront cost for these materials is high but they can be a saving in overall cost. For example, concrete. Concrete is an extremely durable building material that, in some situations, can last for hundreds of years (Zega et al., 2020).

Reusable Design Components

Reusing construction materials can lower waste production and demand for new materials. By doing this, the environmental harm caused by the extraction and exploitation of virgin resources is lessened. Thus, Gabarda-Mallorqui (2017) recommend that once a material served its purpose, designers should clarify whether it can be recycled or reused. Designers should encourage the usage of reused or refurbished furniture whenever possible to extend the life of the item (Aslani et al., 2019). Construction methods that minimize waste materials should be introduced. Similarly, designers can incorporate a reuse and recycling system to optimise the effectiveness of water management in buildings by minimizing water use and recycling wastewater (Llop & Ponce, 2014).

Resource Management Criteria

Lastly, the fifth criteria of green building materials that relates to the sustainable operations is resource management criteria. In the context of building materials, resource management criteria refer to the factors and considerations related to the efficient and responsible use of resources throughout the lifecycle of a building or structure (Syeda et al., 2014; Gabarda-Mallorquí et al., 2017). These criteria focus on conserving resources and promoting sustainability in the selection, use, and disposal of building materials. As revealed in the analysis of findings, the components under this criteria are Renewable Resources and Water Efficiency. The followings provide the discussion on its justification:

Renewable Resources

A resource that can be replenished is referred to as being renewable and having an unending supply (Zhu et al., 2016). The renewable resources usage for raw materials usually from biomass. It needs less energy to produce and are less harmful to the environment. They should be biodegradable, cultivated without pesticides, not degrade soils or taint streams, and harvested with the least amount of machinery possible. Their harvest rotations typically less than 10 years. For instance, (Syeda et al., 2014) suggested that bamboo can be used raw materials for flooring. Therefore, usage of renewable resources must be considered as one of criteria of sustainable materials for green hotel projects which can positively reduce the environmental impacts.

Water Efficiency

Other than electricity, hotel industry need water to function. It is necessary for both fundamental human requirements and leisure activities like golf and skiing, as well as a social asset that might attract tourists (Gabarda-Mallorquí et al., 2017). Hall & Murphy (2010) added water availability is an important factor to ensure the profitability of the tourism industry in the Mediterranean basin which is the top tourist destination in the world. Therefore, availability of water resources should be used efficiently by hotel management. Water efficiency could be achieved by usage of low flow sanitary equipment such as smart faucets and water-efficient sinks (Cuviella-Suárez et al., 2019). (Rashdan & Ashour, 2017) suggested that plumbing systems that facilitate the use of graywater for irrigation and toilet flushing can be recommended by designers of green hotel projects. Thus, this criterion is important in considering sustainable materials to be used in the projects to ensure the conservation of resources.

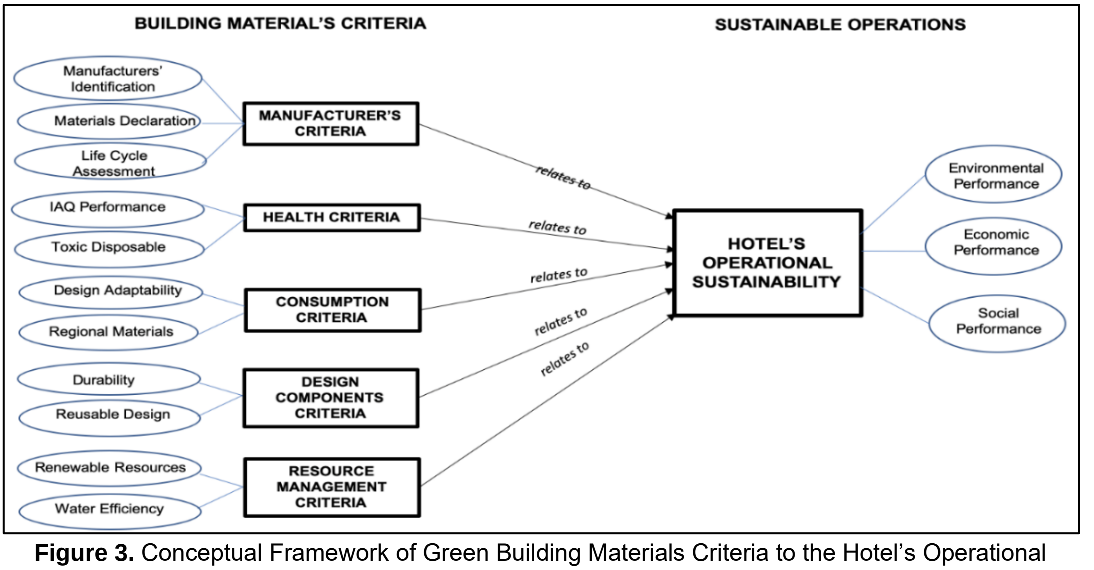


Figure 3. Conceptual Framework of Green Building Materials Criteria to the Hotel's Operational Sustainability

Based on the literature synthesis and discussion, the initial criteria of building materials for hotel's operational sustainability are further developed into a conceptual framework for this research. Figure 3 shows the conceptual framework that consists of criteria of building materials and its relation to the sustainable performance in hotel operations.

As highlighted by Khalil et al. (2022), effective hotel operations will ensure long-term sustainability in business and earn profits and development over a period. This will reflect the performance measurement and performance impact of the hotel industry. By considering these aspects and incorporating sustainable building materials into their design and construction processes, hotels can achieve higher levels of sustainability, reduce operational costs, enhance guest experience, and demonstrate their commitment to environmental responsibility. Ultimately, the careful selection of building materials is a key component of successful hotel sustainable operations. The conceptual framework in Figure 3 is drawn to the direction of current needs and selection of green building materials, particularly for hotel operational sustainability. Further studies into have yet to address the untested hypothesis between the both variables, building materials criteria and hotel operational sustainability, as confirmative relations.

CONCLUSION

In summary, this study addresses the imperative need for a systematic approach to selecting green building materials in the realm of hotel operational sustainability. Given the central role of the hospitality industry in delivering efficient services and operations, prioritizing green and sustainable practices is paramount. Our examination of key criteria and components of green building materials has unveiled an inclusive set of 11 criteria: Manufacturers' Identification, Materials Declaration, Life Cycle Assessment, Indoor Air Quality Performance, Toxic Disposable, Design Adaptability, Regional Materials, Durability, Reusable Design, Renewable Resources, and Water Efficiency. The literature synthesis and establishment of a conceptual model underscore the intricate considerations involved in green building material choices. This model, categorized into Manufacturers Criteria, Health Criteria, Consumption Criteria, Design Components Criteria, and Resource Management Criteria, provides a structured framework for decision-making in material selection for hotel construction and operation. As hotels aim to bolster their commitment to sustainable operations, the proposed conceptual model stands as a valuable guide for decision-makers, architects, and stakeholders engaged in hotel construction and management. Integrating these key criteria into decision-making processes will significantly contribute to the broader goal of scaling up sustainable practices in the hotel industry. To conclude, this study's findings enrich the ongoing discourse on sustainable practices in the hotel sector, laying the groundwork for future research and practical implementation. The integration of green building materials is not merely an option but a strategic imperative for the endurance and adaptability of hotels in an evolving landscape of environmental awareness and operational sustainability.

ACKNOWLEDGEMENT

This research is partly sponsored under the consultation project funded Malaysian Green Technology and Climate Change Corporation (MGTC) and GIZ. The authors would like to express gratitude appreciation to Universiti Teknologi MARA (UiTM) for providing access to the subscribed online library databases, which were instrumental in accessing the literature for this study.

REFERENCES

Abdul Rahman, H. (2016). Green Consumerism. *The Myth of Green Marketing*, *2*(December), 88–123. https://doi.org/10.3138/9781442657427-006

Achintha, M. (2016). Sustainability of glass in construction. In *Sustainability of Construction Materials* (pp. 79–104). Elsevier. https://doi.org/10.1016/b978-0-08-100370-1.00005-6

Ad, A. (2017). Green Hotels and Sustainable Hotel Operations in India. *International Journal of Management and Social Sciences Research*, *6*(2), 13–16.

Alfsen, K. H., & Greaker, M. (2007). From natural resources and environmental accounting to construction of indicators for sustainable development. *Ecological Economics*, *61*(4), 600–610. https://doi.org/10.1016/j.ecolecon.2006.06.017

Ametepey, O., Aigbavboa, C., & Ansah, K. (2015). Barriers to Successful Implementation of Sustainable Construction in the Ghanaian Construction Industry. *Procedia Manufacturing*, *3*(January 2016), 1682–1689. https://doi.org/10.1016/j.promfg.2015.07.988

Andersen, R. V., Toftum, J., Andersen, K. K., & Olesen, B. W. (2009). Survey of occupant behaviour and control of indoor environment in Danish dwellings. *Energy and Buildings*, *41*(1), 11–16. https://doi.org/10.1016/j.enbuild.2008.07.004

Artuger, S. (2020), The effect of servicescape in hotels on customer satisfaction: evidence from resort hotels, Turizam, Vol. 24 No. 3, pp. 113-124.

Asdrubali, F., Schiavoni, S., & Horoshenkov, K. V. (2012). A Review of Sustainable Materials for Acoustic Applications. *Journal of Building Acoustics*, *19*(4), 283–312.

Aslani, A., Bakhtiar, A., & Akbarzadeh, M. H. (2019). Energy-efficiency technologies in the building envelope: Life cycle and adaptation assessment. *Journal of Building Engineering*, *21*, 55–63. https://doi.org/10.1016/j.jobe.2018.09.014

Atan, Abd. M. (2015). MyHIJAU Programme & Green Technology Financing Scheme. In *Seminar Perundangan Penggunaan Tenaga Elektrik Secara Cekap Shah* (Issue May).

Ayalp, N. (2013). Multidimensional Approach to Sustainable Interior Design Practice Multidimensional Approach to Sustainable Interior Design Practice. *International Journal of Energy and Environment*, *7*(4), 143–151.

Bangwal, D., Suyal, J., & Kumar, R. (2022). Hotel building design, occupants' health and performance in response to COVID 19. *International Journal of Hospitality Management*, *103*(103212). https://doi.org/10.1016/j.ijhm.2022.103212.

Bergman, D. (2011). *Sustainable Design: A Critical Guide*. Pearson Books

Bohdanowicz, P. (2006). *Responsible resource management in hotels – attitudes , indicators , tools and strategies*. Royal Institute of Technology, Stockholm.

Ceschin, F., & Gaziulusoy, I. (2016). Evolution of design for sustainability: From product design to design for system innovations and transitions. *Design Studies*, *47*, 118–163. https://doi.org/10.1016/j.destud.2016.09.002

Chan, A. P. C., Darko, A., & Ameyaw, E. E. (2017). Strategies for promoting green building technologies adoption in the construction industry-An international study. *Sustainability (Switzerland)*, *9*(6), 1–18. https://doi.org/10.3390/su9060969

Corporate Finance Institution. (2020). *Manufacturer - Definition, History of Manufacturing, Types*. CFI Team. https://corporatefinanceinstitute.com/resources/knowledge/other/manufacturer/

Cuviella-Suárez, C., Colmenar-Santos, A., Borge-Diez, D., & López-Rey, Á. (2019). Heat recovery in sanitary-ware industry applied to water and energy saving by multi-effect distillation. *Journal of Cleaner Production, 213,* 1322–1336. https://doi.org/10.1016/j.jclepro.2018.12.269

Defterios, J., & Toh, M. (2019). *Malaysia is fighting the climate crisis with better buildings*. CNN Business. https://edition.cnn.com/2019/08/12/business/malaysia-climate-change-green-buildings/index.html

Dong, F., & Hua, Y. (2018). Are Chinese residents willing to recycle express packaging waste? Evidence from a Bayesian regularized neural network model. *Sustainability (Switzerland)*, *10*(11). https://doi.org/10.3390/su10114152

Foo, C. H., & Fuad, F. B. A. (2018). An Overview of Green Building Rating Tools in Malaysia. *OUTLOOK: Building & Investment*, 34–37.

Gabarda-Mallorquí, A., Garcia, X., & Ribas, A. (2017). Mass tourism and water efficiency in the hotel industry: A case study. *International Journal of Hospitality Management*, *61*, 82–93. https://doi.org/10.1016/j.ijhm.2016.11.006

Garetti, M., & Taisch, M. (2012). Sustainable manufacturing: Trends and research challenges. *Production Planning and Control*, *23*(2–3), 83–104. https://doi.org/10.1080/09537287.2011.591619

Godavitarne, C., Robertson, A., Peters, J., & Rogers, B. (2017). Biodegradable materials. *Orthopaedics and Trauma*, *31*(5), 316–320. https://doi.org/10.1016/j.mporth.2017.07.011

Haddad, Z. (2019). The Green Case For Business Building: A Review of the Costs and Benefits for Developers, Investors and Occupants. EE World Energy Engineering Congress 2019

Hanafi, M. H., Razak, A. A., Abdullah, S., Ismail, R., & Nawi, M. N. M. (2015). Contributing factors of steel formwork usage in malaysian construction industry: Housing scheme. *Advances in Environmental Biology*, *9*(3), 130–132.

Jadallah, R. (2018). *An exploration into how design can better align the attributes of luxury and sustainability for "high-end" hotel guest rooms* (Issue September). De Monfort University.

Jovanovic, S. (2019) *Economics of Sustainable Development*, *3*(January-June 2019), 1–7.

Kamaruzzaman, S. N., Ashiqin, N., Zawawi, A. E., & Riley, M. (2016). Critical Aspects of the Inclusive Environmental for the Well-being of Building Occupant-A Review. *MATEC Web of Conferences*, *66*(0011). https://doi.org/10.1051/00114

Kang, M., & Guerin, D. A. (2009). The characteristics of interior designers who practice environmentally sustainable interior design. *Environment and Behavior*, *41*(2), 170–184. https://doi.org/10.1177/0013916508317333

Kanth, R. K., Liljeberg, P., Tenhunen, H., Wan, Q., Amin, Y., Shao, B., Chen, Q., Zheng, L., & Kumar, H. (2011). Evaluating sustainability, environmental assessment and toxic emissions during manufacturing process of RFID based systems. *Proceedings - IEEE 9th International Conference on Dependable, Autonomic and Secure Computing, DASC 2011*, 1066–1071. https://doi.org/10.1109/DASC.2011.175

Khalil, N., Che Abdullah, S.N., Haron, S.N. and Hamid, M.Y. (2022). A review of green practices and initiatives from stakeholder's perspectives towards sustainable hotel operations and performance impact. Journal of Facilities Management, 1472-5967 DOI 10.1108/JFM-03-2022-0025

Khoshnava, S. M., Rostami, R., Zin, R. M., Štreimikienė, D., Mardani, A., & Ismail, M. (2020). The role of green building materials in reducing environmental and human health impacts. *International Journal of Environmental Research and Public Health*, *17*(7). https://doi.org/10.3390/ijerph17072589

Kono, J., Ostermeyer, Y., & Wallbaum, H. (2018). Investigation of regional conditions and sustainability indicators for sustainable product development of building materials. *Journal of Cleaner Production*, *196*, 1356–1364.

Lee, W. W., & Zainordin, N. (2019). An Identification of Building Maintenance Criteria Toward Green Building Residential Project. *Malaysian Construction Research Journal (MCRJ), 7(2), 95-103.*

Llop, M., & Ponce, X. (2014). *Identifying the Role of Final Consumption in Structural Path Analysis: An Application to Water Uses*.

Machado, C. G., Winroth, M. P., & Ribeiro da Silva, E. H. D. (2020). Sustainable manufacturing in Industry 4.0: an emerging research agenda. *International Journal of Production Research*, *58*(5), 1462–1484. https://doi.org/10.1080/00207543.2019.1652777

Mah, D., & Al-Hussein, M. (2008). An Integrated Evaluation Framework For Sustainable Residential Construction. *The International Journal of Interdisciplinary Social Sciences*, *3*(6), 129–136. https://doi.org/https://doi.org/10.18848/1833-1882/CGP/v03i06/52633

Malaysia Green Technology and Climate Change Centre. (2020). *Garis Panduan Perolehan Hijau Kerajaan 3.0*. https://www.myhijau.my/wp-content/uploads/2021/01/GGP-Guidelines-3.0.pdf

Manchanda, S., & Steemers, K. (2009). Sustainability & Satisfaction: Findings from field studies of office buildings in the UK and India. *Conference on Passive and Low Energy Architecture*.

Mate, K. (2009). *Attitudes versus Actions : Are interior designers genuinely embracing sustainable design through material selection ? In Proceedings of the Fifth International Conference of the Association of Architecture Schools in Australasia (AASA), Wellington, New Zealand, 4–5 September 2009*

Mate, K. J. (2006). Champions, Conformists, and Challengers : Attitudes of Interior Designers as Expressions of Sustainability. *Design Research Society International Conference*, *2002*, 1–8.

Mohamed, O. (2018). Durability and compressive strength of high cement replacement ratio self-consolidating concrete. *Buildings*, *8*(11). https://doi.org/10.3390/buildings8110153

Nehr, S., Hösen, E., & Tanabe, S. ichi. (2017). Emerging developments in the standardized chemical characterization of indoor air quality. *Environment International*, *98*, 233–237. https://doi.org/10.1016/j.envint.2016.09.020

Oermann, M.H. & Knafl, K.A. (2021) Strategies for completing a successful integrative review. Nurse Author & Editor, 31, 65-68

Rashdan, W., & Ashour, A. F. (2017). Criteria for sustainable interior design solutions. *WIT Transactions on Ecology and the Environment, 223*, 311–322. https://doi.org/10.2495/SC170271

Rosen, M. A., & Kishawy, H. A. (2012). Sustainable manufacturing and design: Concepts, practices and needs. In *Sustainability* (Vol. 4, Issue 2, pp. 154–174). MDPI. https://doi.org/10.3390/su4020154

Ruuska, A., & Häkkinen, T. (2014). Material efficiency of building construction. *Buildings*, *4*(3), 266–294. https://doi.org/10.3390/buildings4030266

Sabnis, A., & Pranesh, M. R. (2017). Sustainability evaluation of buildings in pre-use phase using figure of merit as a new tool. *Energy and Buildings*, *145*, 121–129. https://doi.org/10.1016/j.enbuild.2017.02.063

Samari, M., Godrati, N., Esmaeilifar, R., Olfat, P., & Shafiei, M. W. M. (2013). The investigation of the barriers in developing green building in Malaysia. *Modern Applied Science*, *7*(2), 1–10. https://doi.org/10.5539/mas.v7n2p1

Sameh, S. H. (2014). Promoting Earth Architecture As A Sustainable Construction Technique in Egypt. *Journal of Cleaner Production*, *65*, 362–373. https://doi.org/10.1016/j.jclepro.2013.08.046

Sichali, M. M., & Banda, L. J. (2017). Awareness, Attitudes and Perception of Green Building Practices and Principles in the Zambian Construction Industry. *International Journal of Construction Engineering and Management*, *6*(5), 215–220.

Sicignano, E., Ruocco, G., & Melella, R. (2019). Mitigation Strategies for Reduction of Embodied Energy and Carbon, in the *Construction Systems of Contemporary Quality Architecture*. *Sustainability*. https://doi.org/10.3390/SU11143806.

Sonmez, E., & Tavsan, F. (2018). Relating material selection and sustainability in design. *Open House International*, *43*(2), 28–32. https://doi.org/10.1108/ohi-02-2018-b0005

Speigel, R., & Meadows, D. (2012). *Green Building Materials: A Guide to Product Selection and Specification*.

Stafford, T. M. (2015). Indoor air quality and academic performance. *Journal of Environmental Economics and Management*, *70*(1996), 34–50. https://doi.org/10.1016/j.jeem.2014.11.002

Stelmack, A., Foster, K., & Hindman, D. (2014a). *Sustainable Residential Interiors*. John Wiley & Sons.

Syeda, A., Shrujal, B., & Kumar, J. (2014). A Case Study on Bamboo as Green Building Material. *International Journal of Engineering and Advanced Technology (IJEAT)*, *2*, 2249–8958.

Van Tran, V., Park, D., & Lee, Y. C. (2020). Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality. *International Journal of Environmental Research and Public Health*, *17*(8). https://doi.org/10.3390/ijerph17082927

Winchip, S. M. (2011). *Sustainable Design For Interior Environments* (Second Edition). Fairchild.

Yee, H. C., Ismail, R., & Jing, K. T. (2020). The Barriers of Implementing Green Building in Penang Construction Industry. *World*, *12*, 1–10.

Zega, C. J., Santillán, L. R., Sosa, M. E., & Villagrán Zaccardi, Y. A. (2020). Durable Performance of Recycled Aggregate Concrete in Aggressive Environments. *Journal of Materials in Civil Engineering*, *32*(7), 1–10. https://doi.org/10.1061/(asce)mt.1943-5533.0003253

Zhu, Y., Romain, C., & Williams, C. K. (2016). Sustainable polymers from renewable resources. *Nature*, *540*(7633), 354–362. https://doi.org/10.1038/nature21001

ANALYSIS OF MERCURY (Hg) HEAVY METAL IN RIVERS ARTISANAL GOLD MINING KALIREJO AREA, KOKAP DISTRICT, KULON PROGO REGENCY SPECIAL REGION OF YOGYAKARTA

Shilvyanora Aprilia Rande*, A. A Inung Arie Adnyano and Hendro Purnomo
Master of Mining Engineering (MME) program, Yogyakarta National Institute of Technology (ITNY), Indonesia

Corresponding Author: shylvyanora@itny.ac.id

Abstract
Gold mining projects contribute to the demand for construction materials as mines are developed, and associated infrastructure is built. Apart from that, gold mining activities able to increase income and improve the community's welfare. However, Mercury (Hg) in processing gold (pyrometallurgy) can pollute the environment and is dangerous if dissolved. This study is intended to determine the condition of surface water against the content of dissolved Hg in the Plampang River flow. Three river water and three river sediment samples were used in the study, which was carried out using the purposive sampling approach. The water quality standard is based on Government Regulation 82 of 2001 for Hg: 1 ug/l or 0.001 ppm. Sample 1 (Hg = 0.01817 ppm), Sample 2 (Hg = 0.00092 ppm), and Sample 3 (Hg = 0.00113 ppm) were the absorbed Hg samples in water. The quality standard for mercury (Hg) in river sediments is 0.2 ppm (mg/kg), according to US EPA (1997). In river sediments, samples of mercury (Hg) had 1 Hg = 0.07971 ppm, 2 Hg = 0.04569 ppm, and 3 Hg = 0.11641 ppm. The mercury levels of three sediment samples satisfy the US EPA's 1997 threshold. Only one of the three locations, point 1, with a value of 0.018 ppm, has a mercury level in the water that exceeds the criterion. According to the findings of the analysis of the mercury content in sediment and water samples, water sample 1, which is close to community gold mining, has a high concentration of mercury. This indicates that the mercury content in people's gold mining is eroded and revealed into river bodies, not because the mercury is contaminated during the gold processing process through pyrometallurgy or amalgamation.

Keywords: *Gold Mining; Mercury (Hg) Heavy Metal; Environmental pollution; Infrastructure; River*

INTRODUCTION AND ISSUES TOWARDS THE RESEARCH

The relation between construction and gold mining activities lies in the demand for construction materials, infrastructure development, and the economic impact of gold mining in regions where it occurs (Aksa et al., 2022). Gold mining operations often require significant infrastructure, such as roads, bridges, and power supply, to access remote areas where deposits are located. Construction activities are essential for building and maintaining the necessary infrastructure to support mining operations. Hence, particularly for this research, it addresses the gold mining activities in the dome of the Kulon Progo Mountains. The dome's short axis (± 20 km) points in the direction of West-West-East Southeast, while the long axis (± 32 km) points in the direction of South-West-North Northeast. The Jonggrangan plateau, with an elevation of 859 meters above sea level, is the highest point on the dome (Purworejo et al., 2013). Following Gunung Kidul Regency, Kulon Progo has significant reserves of mining resources. The extraction of minerals, such as gold, has boosted local GDP and created jobs in the area. How mining materials are managed, particularly in community mining, is still highly worrying. Most community mining operations neglect environmental management during their active and idle periods. This can lead to altered landforms and possibly detrimental effects on the environment, including the mass movement of rocks and soil, pollution of the surrounding water and soil, and changes in the surrounding environment surrounding the mining area. The study is being conducted in Kalirejo Village, Kokap District, Kulon Progo Regency. The research area spans around 100 hectares, and inside that area is a gold mining site that is part of the People's Mining Area. Following Gunungkidul Regency, Kulon Progo has significant reserves of mining resources. The mining and processing minerals, such as gold, has boosted local GDP and created jobs in the area. How mining materials are managed, particularly in community mining, is still highly worrying. As supported by Darris Alwan (2021), when it comes to landform changes and potential adverse environmental effects like mass movements of soil and rocks and soil and water pollution, especially in the surrounding area, most community mining businesses pay little attention to environmental management throughout their active years and after they close.

Mercury contamination is mainly caused by traditional gold mining. It was found that there are sixty thousand small-scale miners work at Indonesia's 713 gold mines, dispersed throughout Java, Sumatra, Kalimantan, and Sulawesi. The community's mining operations are typified by straightforward, reasonably priced exploration and exploitation methods. The locals typically employ basic conventional instruments like hammers, crowbars, and hoes for mining and excavating operations. Additionally, leftover tailings from a fully-fledged pond and spills during transit lead to mercury pollution from gold mining.

According to Kitong et al. (2013), rocks can naturally contain heavy metals such as mercury sulfide (HgS) or mercury (cinnabar). As mercury is often found together with other metal sulfide deposits, such as Au, Ag, Sb, As, Cu, Pb, and Zn, mercury and some other heavy metals are usually found in relatively high concentrations at vein-type gold mineralisation sites (Sismanto et al., 2007). The amalgamation procedure is used at gold extraction sites to process gold directly using mercury. Because mercury is readily available and has not received much attention from the authorities, miners have long used it (Kitong et al., 2013). The mercury-containing tailings resulting from the treatment of mercury using the amalgamation method are put into holding ponds around the treatment site after the amalgamation process is complete, left untreated. The tailings contain between 800 to 6900 parts per million of mercury. The tailings ponds are full, but the gold mining process continues (Aksa et al., 2022). As a result, some of the tailings eventually spilt into the Plampang River and contaminated the water with mercury. The amalgamation method is no longer used but has been replaced by the pyrometallurgical process in the current gold treatment process. Therefore, it is necessary to re-evaluate the mercury content in the river flow to determine whether it exceeds the permissible limit.

Humans risk becoming infected with mercury when they consume contaminated food, such as fish, shells, and shrimp from a polluted river. As mentioned by Aksa et al. (2022), Aquatic biota tissues contain highly concentrated Me-Hg, a mercury compound produced via biomagnification caused by interactions between trophic levels in the food chain. The geochemical cycle that exists determines the amount of mercury that has accumulated in the aquatic fauna. The community that uses the river waters may have health issues due to the trash produced by mining operations polluting the rivers. Once a heavy metal enters the water, it will contaminate it if its concentration exceeds the quality limit. Furthermore, it will settle in sediments with a thousand-year residence period. This study aimed to analyse the content of heavy metal mercury (Hg) in water and riverbed sediments around artisanal gold mining in the study area.

Based on the background above, the problem is that gold processing uses amalgamation methods that can cause environmental pollution. Currently, gold processing has switched to using pyrometallurgical methods in Sangon Village, so research is needed to check whether pyrometallurgical processes have the potential to have an impact on the environment around the mine or not, especially on the river around the mine.

LITERATURE REVIEW: OVERVIEW OF GOLD MINING ACTIVITIES

Traditional gold mining contributes significantly to mercury contamination (Dian Wahyuningtyas Puspitaningrum, 2013). The amalgamation of mercury has been employed in numerous conventional gold mines throughout Indonesia. Gold is a chemical element in the periodic table with the symbol Au (Latin: 'aurum') and atomic number 79. A transition metal (trivalent and univalent) that is mushy, shiny, yellow and heavy. It melts in liquid form at a temperature of about 1000 degrees centigrade. It is soft and malleable, its hardness ranges from 2.5–3 (Mohs scale), and its specific gravity depends on the type and content of other metals that combine (Dian et al., 2013). Gold minerals are also associated with oxidised sulfide deposits. Gold-bearing minerals consist of native gold, electrum, gold telluride, and some gold alloys and compounds with sulfur, antimony and selenium (Kitong et al., 2013). Electrum is another type of real gold; only its silver content is >20%.

Mercury is a metal element that is liquid at the temperature of money. It is rarely found without being bound to other elements. Hefty metal, silvery-white, poor heat introduction compared to other metals, and ordinary electrical introduction. This element easily forms alloys with other metals such as gold, silver, and tin (also called amalgams). Its ease of mixing with gold is used to extract gold from its ores (Mohsin, 2006). Mercury, written with the chemical symbol (Hg) or hydrargyrum, which means "liquid silver" (liquid silver), is a hefty metal that is liquid at room temperature, silvery-white, and has the following properties (Pallar, 1994 in Sismanto et al., 2007):

1. Liquid at room temperature. It is not highly volatile (gas/vapour pressure is 0.0018 mm Hg at 25°C).
2. There is a complete expansion at a temperature of 396°C.
3. It is the most volatile metal.
4. An excellent metal for conducting electricity.
5. It can dissolve various metals to form alloys, also called amalgams.
6. A highly toxic element for animals and humans.

Another essential property of mercury is its ability to dissolve other metals and form alloys known as amalgams. Gold and silver are metals that can be dissolved with mercury, so mercury is used to bind gold in the process of processing sulfide ores containing gold through amalgamation. Mercury–gold amalgamation is done by heating it so that the mercury evaporates, leaving behind the gold metal and its mixture. Mercury is rarely found as a pure metal (native mercury) in nature (Sismanto et al., 2007).

In artisanal gold mining activities, one of the processes to obtain gold is the amalgamation process, a mixture process between gold and mercury (Hg). The amalgamation technique involves mixing rocks containing gold and mercury metals using logs. In this activity, water flow is needed to separate fine rock and amalgam (a mixture of mercury and gold), which is flowed into tailings ponds. Generally, mercury enters river waters as elemental Hg (HgO) with high density. This mercury will sink to the bottom of the water or accumulate in the sediment at a depth of 5-15 cm below the surface of the sediment. The elemental mercury can be turned into organic mercury by bacterial activity, namely into methyl mercury (CH_3Hg), which has toxic properties, extreme binding power and high solubility, especially in the body of aquatic animals such as fish (Kusuma, R.C. et al., 2017).

Gold Processing by Amalgamation Method

Handcuffing precious metals on the inside of added ore to allocate mercury (Hg) in the kobokan is called the benchmark of amalgamation. Amalgam is the most inexpensive and straightforward technique of stirring precious metals.

The drum is used where smelting occurs, and the ore particle size is reduced from coarse (1 cm) to fine (80-200 mesh) by crushing. Rails/rails. With the help of windmills or generators, the drums are rotated following the flow of river water. Miners remove and grind soil and rocks containing gold into finer/smaller sizes (Sosial, Dampak et al., 2023). Put clean dirt in a bucket and add water (1:1) and mercury. The amount of mercury-added depends on the gold content of the ore (Sosial, Dampak et al., 2023). Miners add mercury to bind more gold. Also, the barrel is sealed and runs for less than 6 hours. After iteration, filtration separates the gold mixture from rock, water, and residual mercury. Large amounts of mercury are released into the environment during filtration, thus polluting the environment. The resulting gold amalgam is heated/burned to separate mercury from gold (Aksa et al., 2022).

Pyrometallurgy is a branch of extractive metallurgy that involves thermal methods of extracting metals from their ores. Pyrometallurgy can also be referred to as carbon technology because of the extensive use of carbon as a fuel and reducing agent. Pyrometallurgy is the most crucial division of extractive metallurgy, as it is involved in the refining of most metals (Purworejo, 2013). The stages of the metal extraction process by pyrometallurgical method are as follows:

1. Drying eliminates most of the free water contained in the ore.
2. Calcination-reduction, i.e. elimination of remaining free water and elimination of crystalline water, preheating of ores and reduction of most metallic elements and control of iron reduction.
3. Electric furnace smelting reduces the remaining metal and separates the main product from its by-product.
4. Refining eliminates unwanted minor elements from the main product to meet market needs.

IMPACT TOWARDS ENVIRONMENTAL

Gold ore mining located in Sangon Kulon Progo Hamlet, Yogyakarta, is carried out by small-scale gold miners or traditional gold miners by residents. Gold ore processing in Sangon Hamlet still uses amalgamation technology, where mercury (Hg) is used as a medium to bind gold. Processing with mercury has been carried out since 1990 until now; in Sangon Hamlet, two mining pits are still active. After the amalgamation process, the waste (tailings) containing mercury is discharged into a holding pond near the mining site without further treatment; even If the waste storage pond is complete, the gold mining process continues. This causes some waste to flow into the Cedar River, which results in mercury pollution in these waters (Daris Alwan, 2021).

Based on Kitong et al. (2012), although gold mining activities positively impact the economy, such as increasing employment and community income, they are also followed by negative impacts. These negative impacts include (a) a decrease in farmers' income around the mining site due to a decrease in soil quality, (b) an increase in the price of essential commodities due to an increase in demand and a decrease in land productivity, and (c) the presence of mercury content in vegetables and rice grown around the mining site. In addition, the river water began to be polluted. River sediments in Sangon, Kulon Progo, contain mercury (Sosial et al., 2023).

Heavy metal pollution in the environment is a common problem in different regions. Most heavy metals will accumulate in soil and aquatic environments, and the side effects will last long. These heavy metals, such as mercury (Hg), Cadmium (Cd), Zinc (Zn), and Lead (Pb), have highly toxic properties and are harmful to the environment (Li et al., 2017). Many contaminants are often observed in the environment, including metal contaminants such as copper, cadmium, zinc, and mercury; this study will discuss heavy metal concentrations of mercury present in river sediments. Mercury contamination in sediment rivers occurs due to natural processes (weathering of mineralised rocks), gold processing processes (amalgamation), and Industrial processes that use mercury-containing raw materials. To find the source, mercury contamination must be considered carefully because river sediments have no standard mercury levels of quality. Mercury (Hg) is a chemical element classified as a dangerous and toxic heavy metal that benefits humans and other living things (Sosial et al., 2023).

MATERIALS AND METHODS

The method used in this study is the survey method as adopted from (Khozin, 2013). Determining sampling points is done using the purposive sampling method, which looks at specific considerations (sampling points are selected from upstream, middle and downstream locations). Sampling of river water itself using the random sampling method. River water sampling 3 points and three river sediment samples (point 1 after artisanal gold mining, point 2 after pyrometallurgical gold processing and point 3 near the former gold processing site by amalgamation). After the sample is taken, it is taken to the laboratory for analysis. This study's samples were water and river sediments around the PETI activity. They continued with analysis in the laboratory to measure the levels of accumulated heavy metal content (Hg) and analyse pH with AAS (Atomic et al.).

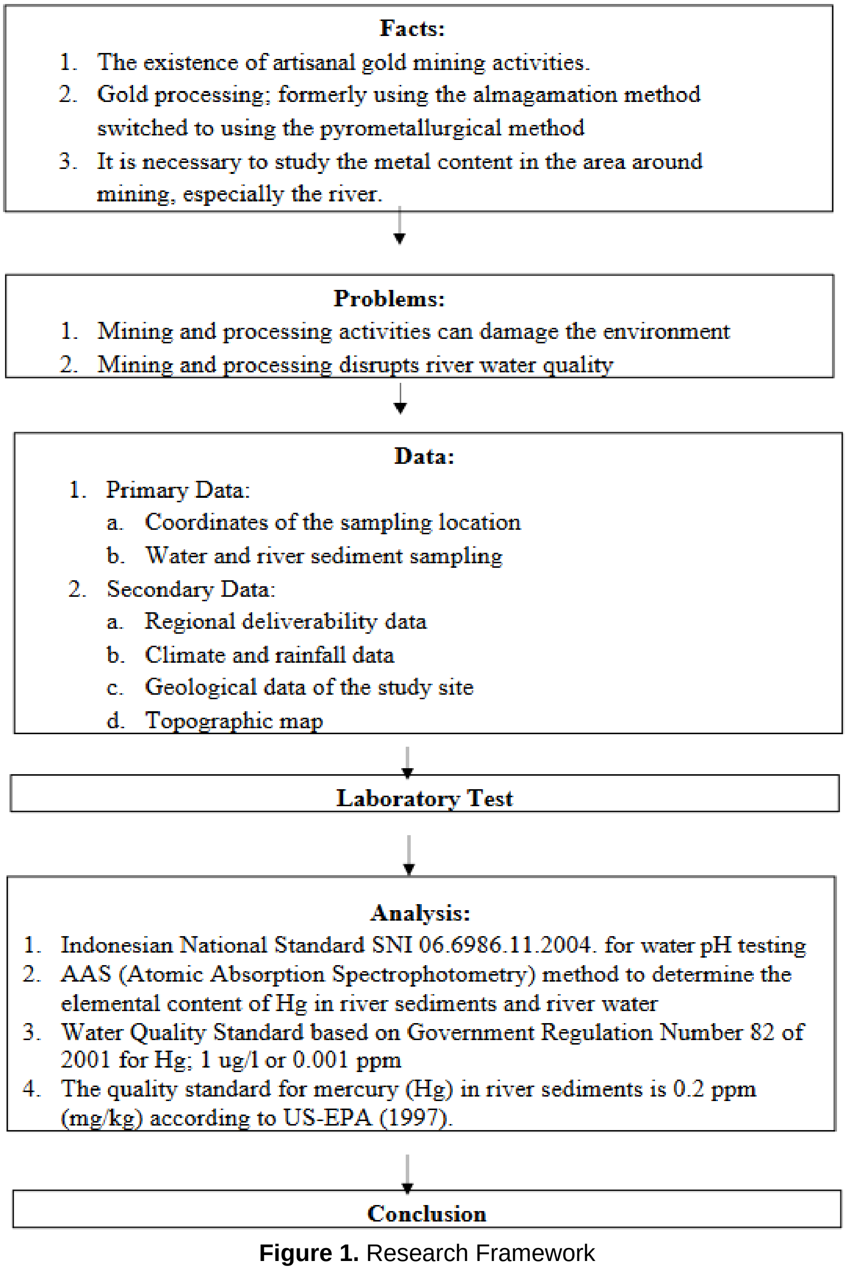


Figure 1. Research Framework

Sampling Location

Water and sediment sampling locations are located at 3 points on the Plampang River, Sangon Hamlet. Here are the coordinates of the sampling location.

Table 1. Coordinate Sampling Location

NO	X	Y	Z	Information
1	0398251	0397470	0397184	Near the gold mining site
2	9136206	9134573	9134275	Near pyrometallurgical gold processing sites
3	347	121	110	Near the former processing of amalgamated gold

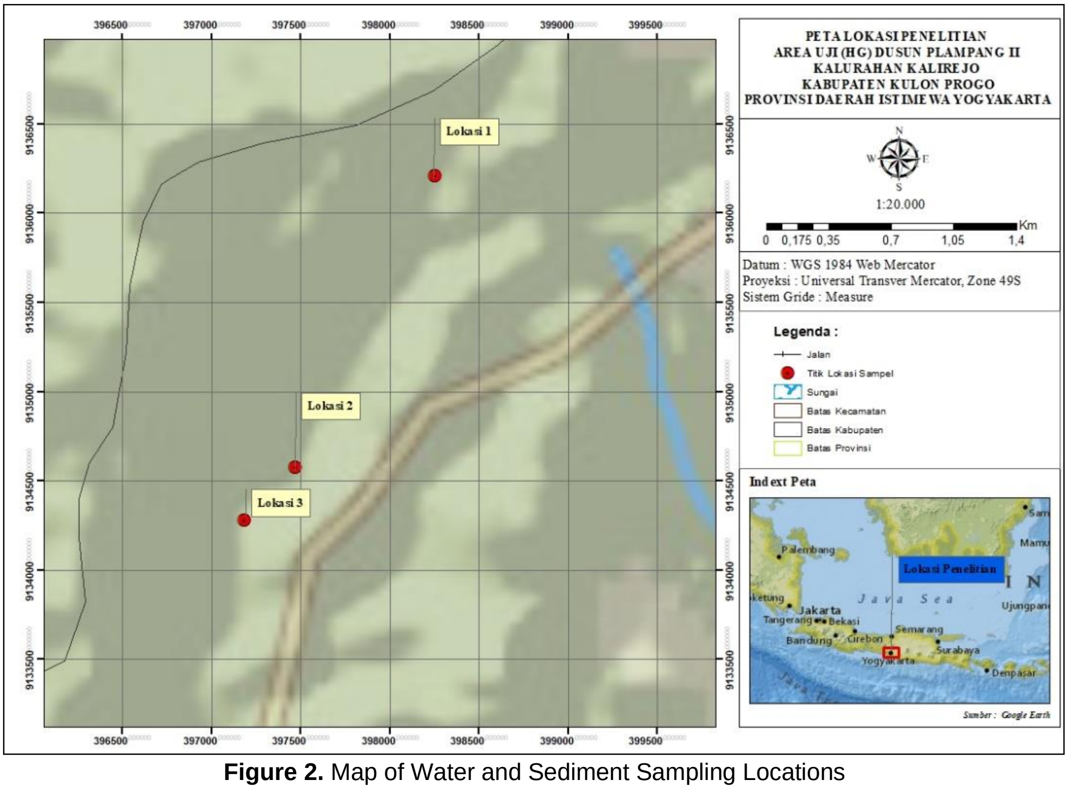


Figure 2. Map of Water and Sediment Sampling Locations

Figure 3. Sediment Samples

Figure 4. Water Samples

RESULTS AND DISCUSSION

pH Test Results on Water Samples

From the results of testing water samples, it was found that the pH of the water at the sampling location was classified as safe for the environment, namely water pH > 8.

Table 2. Water pH Test Results

NO	SAMPLE	pH
1	Water sample 1	8,4
2	Water sample 2	8,56
3	Water sample 3	8,34

Hg Content Test Results on Water Samples

Based on PP No. 82 of 2001 Water Quality Standard standards based on PP No. 82 of 2001 for Hg; 1 ug/l or 0.001 ppm. The following are the results of the Hg content test on water samples in the Plampang River;

Table 3. Hg Content Test Results on Water Samples

NO	Air	Unit	Quality Standards	Conversion	
1	18,17	ug/l	1 ug/l	0,01817	ppm
2	0,92	ug/l	1 ug/l	0,00092	ppm
3	1,13	ug/l	1 ug/l	0,00113	ppm

The results of laboratory tests and analysis with AAS (Atomic Absorption Spectrophotometry) obtained samples 1; 0.01817 ppm, sample 2; 0.00092 ppm and sample 3; 1.13 ppm. From these results, sample 1 is above the threshold of water quality standards, while sample 2 is below the water quality standard and sample 3 is in accordance with the threshold.

Hg Content Test Results in Sediment Samples

Based on mercury (Hg) quality standards in river sediments of 0.2 ppm (mg / kg) referring to US-EPA (1997), the test results of Sangon River sediment samples are below the quality standard limit. The following are the results of the Hg content test on sediment samples in the Plampang River;

Table 4. Hg Content Test Results on Sediment Samples

NO	Soil	Unit	Conversion	
1	79,71	ug/kg	0,07971	ppm
2	45,69	ug/kg	0,04569	ppm
3	116,41	ug/kg	0,11641	ppm

3 river sediment collection sites are not polluted because the Hg content in the river is below the < quality standard of 0.2 ppm. Associated with the geological conditions of the research area, where in the study area there is an alteration zone (Nugraha, 2015), and in general the constituent rocks are diorite intrusion, andesite lava and volcanic breccia. In altered volcanic rocks, heavy metals can be present naturally, such as sulfide metal deposits,

so that in gold mineralization areas there is an increase in heavy metal content (Herman, 2006).

Based on the theory of magma differentiation process, the element Mercury can be formed at the epithermal stage. Epithermal stages are formed near the earth's surface to a depth of 1500 m, temperatures 500^0C–200^0C, associated with shallow intrusive rocks, precious metals that can precipitate at this stage Pb, Zn, Au, Ag, Hg, Sb, Cu, Se, Bi and U, minerals that precipitate are Au-native, Ag, Cu, Bi, Pyrite, Marcassite, Sphalerite, Galena, Chalcopyrite, Sinabar, Stibnit, Realgar, Orpiment and Argentite, the impurity minerals are Chert, Chalcedony, Chlorite, Epidote, Carbonate, Flourite, Barite, Adularia, Serisite, Dickite, Rodocrosite and Zeolite (Sumarjono, 2020). From the results of the analysis of Hg content in water samples and sediment samples, water sample 1 which is located near community gold mining has a high Hg content, meaning that the Hg content in community gold mining is revealed and eroded into the river body not because it is polluted from the gold processing process either by amalgamation or pyrometallurgy.

CONCLUSION

Based on the results of research on heavy metal content in rivers caused by gold processing using pyrometallurgical methods has no impact on the environment. It is known from laboratory tests at 3 sampling locations obtained; For water pH at 3 locations, the test value > pH 7 meets the quality standard pp no 82 of 2001and for Hg levels in sediment 3 sediment samples have met US-EPA 1997 standards. For Hg levels in water in 3 locations, only 1 location has a value more than the parameter, namely the location of point 1 whose value is 0.018 ppm. This is because the location of the first point is located near the traditional gold mining site not near the gold processing site. From the results of the analysis of Hg content in water samples and sediment samples, water sample 1 which is located near community gold mining has a high Hg content, meaning that the Hg content in community gold mining is revealed and eroded into the river body not because it is polluted from the gold processing process either by amalgamation or pyrometallurgy.

REFERENCES

Aksa, Mardiyanti A. et al. (2022). Hazards of Mercury Pollution at Traditional Gold Mining Locations in Kalirejo Village-Yogyakarta Special Region. 1(1): 69–73. https://ftuncen.com/index.php/JWIKAL69.

Daris Alwan, Muhammad (2021). Analysis Of Hg Concentration In River Sediments At A Traditional Gold Mine Site, Kulon Progo, Yogyakarta submitted to the Islamic University of Indonesia to meet the requirements for obtaining a Bachelor (S1) degree in Environmental Engineering." : 1–66.

Dian Wahyuningtyas Puspitaningrum (2013). Extraction Of Gold From Rocks Using Cyanidation And Amalgamation Methods With The Addition Of Cassava Trees. *Angewandte Chemie International Edition, 6(11), 951–952.* (Mi): 5–24.

Faithful (2005).Mercury Spread Due To Gold Mining Business In Sangon Area, Kulon Progo Regency, D.I. Yogyakarta." *Colloquium of Field Results.*: 1–17.

Khozin, Abror. (2013). User Perceptions of Librarians' Performance in Circulation Services in the Regional Library of Sragen Regency. *Management*: 30–39. http://eprints.undip.ac.id/40779/3/BAB_III.pdf.

Kitong, Melin T., Jemmy Abidjulu, and Harry S. Koleangan. (2012). "Analysis of mercury (Hg) and arsenic (As) in Ranoyapo River sediments, Amurang District, North Sulawesi." *Colloquium of Field Results*.1 (1): 16.

Kusuma, R.C., Wawan Budianta, and Arifudin. (2017). Study of heavy metal content at a traditional gold mining site in Sangon Village, Kokap District, Kulon Progo Regency. *Proceedings of the XII National Seminar "Industrial and Information Technology Engineering"*: 322–27.

Purworejo (2013). Kulonprogo Regency, Karangsambung Information Center, and Earth, .8: 75–86.

Santoso, Dian Hudawan, and Muammar Gomareuzzaman (2018). "Technical Feasibility Of Gold Mining In Community Mining Area Case Study: Kalirejo Village, Kokap District, Kulon Progo Regency." *Journal of Science Tech* 4(1): 19–28.

Santoso, Dian Hudawan, and Muammar Gomareuzzaman (2018). Kelayakan Teknis Penambangan Emas Pada Wilayah Pertambangan Rakyat Studi Kasus: Desa Kalirejo, Kecamatan Kokap, Kabupaten Kulon Progo, Jurnal Ilmiah Ilmu Pengetahuan dan Teknologi, pp. 19–28.

Sismanto et al. (2007). Remediasi Elektrokinetik Menggunakan Elektroda 2-D Hexagonal Pada Tanah Limbah Pertambangan Emas Yang Mengandung Tembaga (Cu) Dan Merkuri (Hg) Di Kokap Kulonprogo Yogyakarta, retrieved from: https://dokumen.tips/documents/remediasi-elektrokinetik.html?page=1.

Sosial, Dampak et al. (2023). Social , Economic , And Environmental Impacts Of Small-Scale Gold. 3(1): 1–9.

Sumarjono, Erry. (2020). Mercury in Gold Ore in Sangon II Hamlet, Kalirejo, Kulonprogo Kokap, Mercury in Gold Ore in Sangon II Kalirejo Hamlet, Kulonprogo Kokap, Special Region of Yogyakarta. *Journal of the National Institute of Technology Yogyakarta* 2019(March): 91–97.

BIOPHILIC DESIGN TO ENHANCE THE HEALING ENVIRONMENT IN MALAYSIAN PRIVATE HOSPITALS: EXPERTS' PERSPECTIVES

Nurul Zalifah Zakaria, Suriati Ahmad* and Atikah Fukaihah Amir
Department of Built Studies and Technology, College of Built Environment, Universiti Teknologi MARA (UiTM) Perak Branch, Seri Iskandar Campus, 32610 Seri Iskandar, Perak, Malaysia

*Corresponding Email: *suria564@uitm.edu.my*

Abstract
Malaysia is making many efforts to integrate nature into hospital building design to enhance the healing environment. This aligns with the Malaysian Sustainable Development Goal (Goal 3), which is to focus on good health and well-being, ensure everyone lives a healthy life, and encourages well-being at all ages. Therefore, the biophilic design concept successfully implemented in international hospital buildings to incorporate nature could be used for Malaysian hospital buildings. This study aims to establish the biophilic design elements checklist for Malaysian private hospitals through experts' perspectives. Therefore, five experts who were involved in designing green hospitals in Malaysia had been selected for semi-structured interviews to obtain valid and reliable data. The experts were architects of the Green Building Index (GBI) green-rated hospitals in Malaysia. The data were analysed by using content analysis. From the analysis, twelve biophilic design elements had been agreed upon by the experts to be integrated into private hospitals in Malaysia. Establishing a biophilic design elements checklist for Malaysian private hospitals could encourage more green hospital development.

Keywords: *Nature; Biophilic design; Hospital; Field experts; Design Checklist*

INTRODUCTION

Natural interactions provide many advantages to physical health, psychological well-being, and cognitive performance. People are encouraged to spend at least 120 minutes with nature every week to increase their health and well-being (White et al., 2019). Even though the world is growing with a greater focus on technology development, the human and nature connection still needs to be emphasised. Therefore, E.O. Wilson (1984) introduced the biophilic design concept that had to be utilised by many designers in their projects to bring humans closer to nature.

Biophilic design is a concept that strengthens the human and nature connection through direct nature, indirect nature, and space conditions (Nkubiyaho, 2020). It improves productivity, give positive impacts on people's stress levels, and speeds up the recovery time from pain. Human contact with nature and the quality of this relationship is beneficial to humans' emotions, culture, health and thought (Totaforti, 2018). According to scholars and experts, the utilisation of biophilic design may have an impact on the human mind and body-depending on the way it is applied and the results that follow.

Research by Ulrich in 1980 has discovered the patients' recovery and relationship with nature where the biophilic design has proven to be beneficial for the healing process and hospital environments (El Messeidy, 2019). The application of biophilic design is a method of healing for humans since it improves the healing environment in hospitals. The hospital space design with consideration of the biophilic design concept is needed within the hospital building's internal compound and spaces. The utilisation of biophilic design in hospital space design is important to connect nature with occupants which may result in positive impacts on them (Totaforti, 2018).

PROBLEM STATEMENT

Today's hospital design focuses on technology and mechanical development which causes hospital design to ignore the demand relationship between humans and nature. The development of modern hospital construction that focuses on the built environment has taken away the healing benefits of human healthcare (Lydia, 2019). The concept of biophilic design has been successfully implemented in international hospital buildings including the Ostra Hospital in Sweden (El Messeidy, 2019) and Singapore's Khoo Teck Puat Hospital (KTPH) (Cheok & Chan, 2017). However, the study related to biophilic design implementation in Malaysia has only covered shophouses based on the study done by Bahauddin et al. (2021; 2019) and office buildings (Ibrahim et al., 2021) (Hui & Bahauddin, 2019). Particularly, there are no biophilic hospitals found or being built in Malaysia. Hence, this has significantly evidenced the lack of study on the biophilic design that focuses on Malaysian hospitals, thus placing a notable gap (knowledge and practise) that is able to offer from this research.

Malaysia and 192 world leaders adopt the 2030 Agenda for Sustainable Development (2030 Agenda). With more than 200 indicators, 17 Goals and 169 Targets, the SDGs encourage action over the following fifteen years in areas of vital importance to the environment and mankind. One of the SDGs goals (Goal 3) is to focus on good health and well-being by ensuring everyone lives a healthy life and encouraging well-being at all ages. Apart from that, the SDGs (Goal 11) emphasise sustainable cities and communities. It is a worldwide commitment to more sustainable, resilient, and inclusive development. In accordance with the 2030 Agenda, Malaysia implements the Twelfth Malaysia Plan and Shared Prosperity Vision 2030 with the goal to create an inclusive, prosperous, and sustainable Malaysia. This highlights the significance of this research to further improve the current hospital design – in line with the national agenda to provide a better quality of life.

In particular, the post-Covid-19 pandemic around the world has resulted in numerous health issues and complications. Patients admitted and staying in hospital require a longer duration due to quarantine and treatment, thus giving them a limited time to spend outdoors. Besides that, the workload of healthcare workers increased, and they are working overtime and being in the hospital building longer. This affects both workers' and patients' physical health and mostly mental health (Muller et al., 2020). This significantly explains that more studies on biophilic design approaches are needed to enhance the hospital healing environment.

LITERATURE REVIEW

The Evolution of Biophilic Design

Biophilic design is an approach to connect its occupant with nature (Ryan et al., 2014). The term biophilic is originally from biophilia, which means the passionate life's love and everything alive such as plants, people, social groups, and ideas. Erich Fromm (1973), a psychoanalyst who studied about unconscious mind, introduced the term biophilia in his book titled *The Anatomy of Human Destructiveness*. He stresses on the biophilia concept while elaborating differences between 11 human beings and other natures (Moghaddami, 2019). According to the Dictionary of Environment and Ecology Fifth Edition in 2004, ‘bio’ means living organisms while ‘philia’ is referring to attraction towards something. Overall, biophilia means the innate feeling of human beings to connect with nature and living organisms (Sayuti, 2016).

Biophilia has many meanings based on researchers and their areas of study. Edward O. Wilson, cited in Krcmarova (2009), defines biophilia as a natural tendency to concentrate on life and other life processes as well as describing the relationship with nature not only in the physiological aspect but also contains the genetic basis of the meaning. He established a hypothesis about biophilia in 1984 through his book titled *Biophilia* and popularised that response. The hypothesis elaborates on the concept of humans need to relate to nature and some biotic forms because of individual fulfilment and evolution to survive. Moghaddami (2019) accentuated that the ideas on biophilia through his observations, journeys, and personal experience he had in the natural environment caught wider attention.

In-depth research and studies on biophilia have led to the evolution of biophilic design. The biophilic design concept was expanded into the field of architecture at the beginning of the 21st century (Zhong et al., 2021). It has taken on meaning as an expression of the inherent human need to integrate with nature in the design of the built environment (Kellert, 2008). It is an attempt to translate the understanding of the relationship between humans, natural systems and processes into the building. Kellert et al. (2011) did mention that the positive effects of the natural systems, processes and constructed landscapes built into our buildings remain essential to human well-being and performance in their book titled *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*.

The Significant Elements, Attributes and Patterns of Biophilic Design

Kellert & Calabrese (2015) established the biophilic design elements framework in three categories which are the direct experience of nature, the indirect experience of nature and the experience of space and place. Table 1 below shows the twenty-four attributes listed to be potentially applied to the building design.

Table 1. Experiences and Attributes of Biophilic Design by Kellert & Calabrese (2015)

Direct Experience of Nature	Indirect Experience of Nature	Experience of Space and Place
Light	Images of nature	Prospect and refuge
Air	Natural materials	Organized complexity
Water	Natural colours	Integration of parts to wholes
Plants	Stimulating natural light and air	Transitional spaces
Animals	Naturalistic shapes and forms	Mobility and wayfinding
Weather	Evoking nature	Cultural and ecological attachment to place
Natural landscape and ecosystem	Information richness	
Fire	Age, change and the patina of time	
	Natural geometrics	
	Biomimicry	

(Source: Kellert & Calabrese, 2015)

There is also a biophilic design framework introduced by Browning et al. in 2014 through a book titled *14 Patterns of Biophilic Design: Improving Health and Wellbeing in the Built Environment*. The idea of listing the design patterns is supported and published in *Terrapin Bright Green LLC*. It is to arrange a systematic biophilic design agreement among urban designers and architects (Moghaddami, 2019). Table 2 below shows the biophilic design elements that are divided into three categories which are natural in the space, nature analogues and nature of the space. The framework consists of fourteen biophilic design patterns that can be implemented into the buildings' design.

Table 2. Biophilic Design Patterns

Nature in Space	Natural Analogues	Nature of The Space
Visual connection with nature	Biomorphic forms and patterns	Prospect
Non-visual connection with nature	Material connection with nature	Refuge
Non-rhythmic sensory stimuli	Complexity and order	Mystery
Thermal and airflow variability		Risk/peril
Presence of water		
Dynamic and diffuse light		
Connection with natural system		

(Source: Browning et al., 2014)

Green Building Index (GBI)

Green Building Index (GBI) is the Malaysian green rating tool system introduced in 2009. It is the first rating tool system that is recognised to encourage more use of green architectural concepts in Malaysia. The GBI green-rated buildings are known for incorporating environmentally-friendly design and sustainable criteria to decrease the negative impacts and ensure the new buildings being built remain relevant in the future (Kamil et al., 2018). GBI was highlighted by Usman & Abdullah (2018) to have more advantages, more parameters and a better range of rating grades than other green rating tools in Malaysia – namely GreenRE, PH JKR and Green PASS, which are in the last level of development or newly launched. Building design needs to meet the requirements of the GBI rating tool system and received an award that is platinum, gold, silver or certified. Out of five hundred GBI projects in Malaysia, there are six GBI hospitals building projects as illustrated in Table 3 below.

Table 3. Green Building Index (GBI) Hospitals in Malaysia

No	Name	Location	GBI Rating	Validity	Hospital Category
1	1 Blok Bangunan Tambahan 15 Tingkat Hospital Pakar Ampang Puteri 	Selangor	Certified	25th January 2013 – 24th January 2016	Private
2	Bandar Dato' Onn Specialist Johor Hospital 	Johor	Silver	6th July 2018 – 5th July 2021	Private

No	Name	Location	GBI Rating	Validity	Hospital Category
3	Gleneagles Hospital 	Kuala Lumpur	Gold	3rd September 2015 – 2nd September 2018	Private
4	Hospital Pakar Kanak-Kanak Universiti Kebangsaan Malaysia 	Kuala Lumpur	Certified	10th May 2019 – 9th May 2022	Government
5	KPJ Damansara 2 Specialist Hospital 	Selangor	Certified	10th May 2019 – 9th May 2022	Private
6	Pantai Hospital Laguna Merbok 	Kedah	Silver	24th June 2021 – 23rd June 2024	Private

(Source: https://www.greenbuildingindex.org/how-gbi-works/gbi-certified-buildings/)

METHODOLOGY

A qualitative method was used for this study and a semi-structured interview was conducted to collect data. It was to collect information related to the green elements applied in Malaysian Green Building Index (GBI) green-rated hospitals and the expert's perspective on biophilic design elements for private hospital buildings. A semi-structured interview is an open framework that enables focused, conversational and two-way communication between the researcher and interviewee (Halil, 2013). According to Rabionet (2011), the semi-structured interview was a powerful and flexible medium to collect data by accumulating the thirty interviewees' experiences and expertise. Thus, the data obtained from the interview were reliable and valid.

The semi-structured interview questions were prepared by referring to the systematic and comprehensive literature review before the interviews were conducted. This study has undertaken the UiTM human research ethic exercise, with approval granted in November 2022. A set of questions with three parts which were knowledge about biophilic design, biophilic design elements, as well as challenges and improvements for this study and seven questions were established. The experts were asked with open-ended questions in Part A and Part C. However, in Part B, the experts were asked with close-ended questions with agree and disagree answers' option. Part B requires them to choose one answer and give an explanation of the choice made.

Firstly, in Part A, the focus is drawn to the hospital concept and understanding related to biophilic design. For Part B, questions were designed to obtain feedback from the interviewees related to biophilic design elements guided by Kellert & Calabrese (2015) and Browning et al. (2014). Since there is no Malaysian government policy related to biophilic design, the international biophilic design elements were used as references to build the interview questions. The biophilic elements from Kellert & Calabrese (2015) and Browning et al. (2014) are valid and reliable because there are many hospitals abroad such as Khoo Teck Puat Hospital and Ostra Hospital that have successfully integrated the concept of biophilic design in reference to their studies. Part C questions were focused on the challenges of incorporating nature into the hospital, suggestions for improvement and their perceptions towards the effectiveness of biophilic design.

The range of interviewees recommended for this data collection method is between five to twenty-five (Townsend, 2013). Considering this recommendation and the limited number of GBI hospitals, therefore five experts were selected for semi-structured interviews based on the above recommendation. The experts were architects involved in designing the GBI green hospitals in Malaysia since Malaysia had no expertise in biophilic hospitals. According to Hamid et al. (2014), GBI is one of the Malaysian rating systems that the professional associations established, and only GBI has reached maturity at this time as it continues to manufacture various tools compared to other green rating tools in Malaysia. They are the experts who have mastered the green elements design in hospitals specifically GBI design, since they have led the construction of the green-rated hospital in Malaysia. This panel of experts is identified based on the architectural firms involved in constructing each green hospital.

RESULTS AND DISCUSSION

This study was using the content analysis method to analyse the data obtained. This method was chosen because it was a well-known and most often used method to analyse interview transcripts (Zhang & Wildermuth, 2009). It is a method to identify the data collection patterns gained from interviews, books, films, social media and much more. The advantages of using content analysis is it has high validity since the data were related to the interviewee's experience. This has made data patterns easy to see and summarise. No computer programmes were used to analyse the data because the number of interviewees was only five.

This data analysis method was using a summative distinct approach. It involves identifying the significant keywords by counting occurrences across the sources and reading them over to provide a conclusion. In the summative distinct approach, the analysis is used to investigate and explore a topic without inferring meaning (Hsieh & Shannon, 2005). This method was used to report on the most highlighted, significant keywords and elements for each question. Counting the frequency of keywords that appear in the transcripts' data allows validate findings and makes judgements regarding how important the data and findings are made (Miles & Huberman, 1994). Hence, using content analysis with a summative approach is beneficial to explore the relevant aspects and provide simple insight into the usage of certain words for better understanding.

The semi-structured interview data were analysed by content analysis with a summative approach where the significant keywords were identified. The higher the frequency of the keywords means the more important it was in the topic. The significant keywords of Part A: Knowledge About Biophilic Design was shown in Table 4. This section highlighted the main concept of hospital building utilised by designers, the sources for designers to improve knowledge regarding biophilic design and understanding of biophilic design.

Table 4. Significant Keywords of Part A

No.	Questions	Significant Keywords
1	The main concept of hospital building	• Apply green concept that comply with all government policies • Hospital must have a user-friendly design • Focused on the function of the hospital
2	Biophilic design knowledge	• 4 out of 5 experts have heard about biophilic design • Sources of biophilic design knowledge are from reading and experts
3	Understanding of biophilic design	• It is a concept of incorporating natural element into building design • A concept used to increase connectivity with nature

From the analysis, it was discovered that Malaysia is nearing the biophilic design concept without notice. The expert's idea of integrating nature, focusing on the function of the hospital and ensuring a user-friendly hospital design into their GBI hospitals was slightly found in the biophilic design concept. However, biophilic design elements were insufficient and still needed to enhance the healing environment in hospitals because GBI hospital design is energy-centred and not a human-centred hospital that focuses on healing.

Biophilic design is not a new concept and has been widely used by architects and designers abroad. From the semi-structured interviews, the experts' specific understanding of biophilic design was still shallow although they have expertise in green design for hospital buildings. Most experts rate their knowledge related to biophilic design range from twenty-five percent to fifty percent indicating the understanding on biophilic design concept is lacking. Awareness of the use of biophilic design should be emphasized and spread among experts and designers to build more biophilic hospitals in Malaysia. Sources of knowledge that are only from reading and experts can also be diversified.

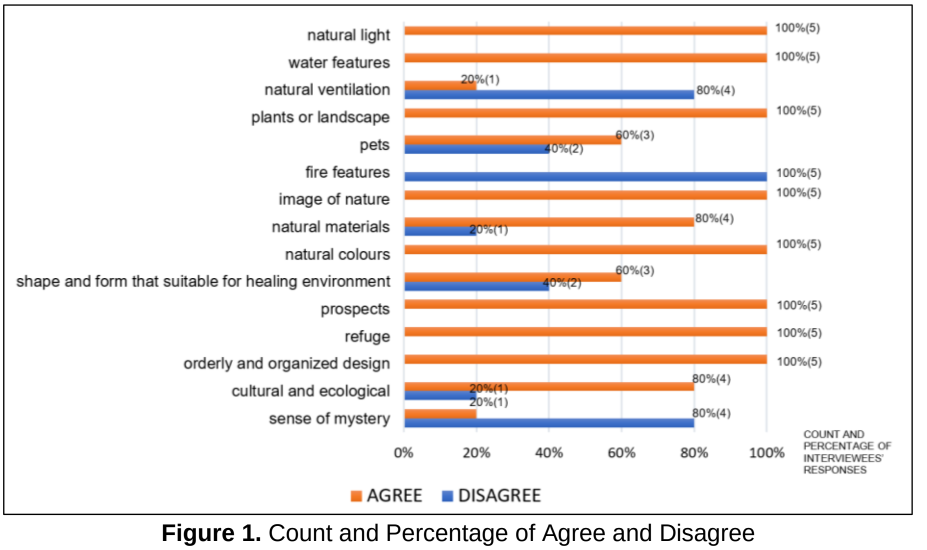
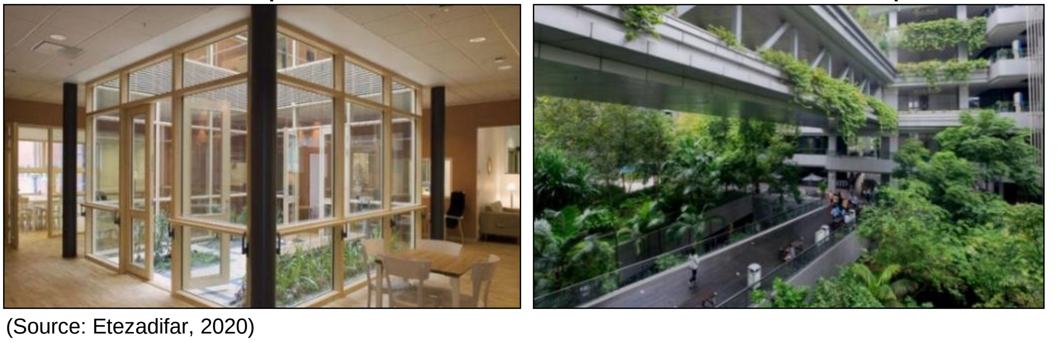


Figure 1. Count and Percentage of Agree and Disagree

For Part B: Biophilic Design Elements, Figure 1 above shows the count and percentage of interviewees' responses for each of the biophilic design elements' application to hospital building design. Since there are five interviewees in total for this data collection then one count refers to 20%; 20%(1), 40%(2), 60%(3), 80%(4), 100%(5). Biophilic element that gets 100% means five out of five interviewees have the same answer. Both count and percentage were used in this study to evaluate the interviewees' answers easily.

The 100% agreeable elements by the experts are natural lighting, water features, plants or landscape design, the image of nature, natural colours, consideration of prospects and refuge and lastly orderly and organised hospital design. These biophilic design elements are essential elements that must be present in the development of green hospitals to enhance the healing environment. There was no figure presented during the interview session. However, Figure 2 below shows the example of hospital design incorporating biophilic design elements mentioned by the experts during the interview session. The successful hospitals such as Ostra Hospital and Khoo Teck Puat Hospital had been mentioned by the experts as examples of the maximal use of natural light and plants in hospital design. Meanwhile, the element that was disagreed with by all interviewees is fire features. This is because the element is not suitable for Malaysian weather, climate and temperature. Malaysia is a hot, humid country.

Ostra Hospital **Khoo Teck Puat Hospital**

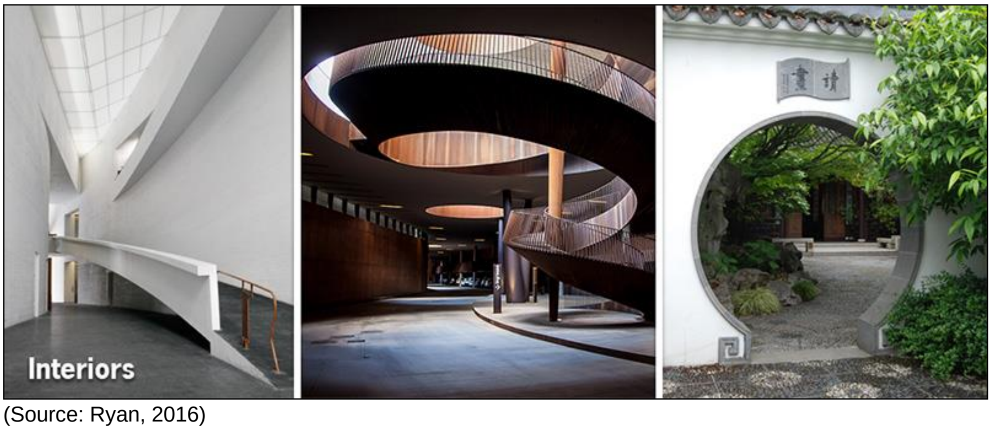


(Source: Etezadifar, 2020)

Figure 2. Biophilic Hospitals

Besides that, the biophilic design elements with the highest percentage of agreement are incorporating pets' areas (60%), natural materials (80%), shapes and forms that are suitable for healing environments (60%) as well as cultural and ecological aspects (80%). The percentage of experts who agree that this element should be used in the design is higher than those who disagree because of its advantages and benefits to hospital occupants. The experts acknowledge that the biophilic design elements have a positive impact on physical and mental health such as releasing stress and speeding up healing.

Natural ventilation and a sense of mystery are mostly not agreed to be applied to Malaysian private hospital design. Four out of five experts prefer full air-conditioned hospital design due to comfort for patients and health reasons - such as preventing polluted air from entering, avoiding uncomfortable sweating, and allergy. As for the sense of mystery, the experts disagree with this biophilic design element. Curved hallways, dimly-lighted area and partially-obscured artwork as shown in Figure 3 had been mentioned by the experts as designs to be avoided in hospitals. Figure 3 was not presented during the presentation but it was taken from the *14 Patters of Biophilic Design* book to illustrate the example of design with mystery biophilic elements mentioned by the experts. A hospital design needs to be straightforward, easily visible and clear.



(Source: Ryan, 2016)

Figure 3. Design in Mystery Elements of Biophilic Design

The significant keywords of Part C: Challenges and Improvements are shown in Table 5 below. The challenge of incorporating nature in hospital design can help designers in thinking of solutions to design a successful biophilic hospital. Designers cannot overlook the needs of The Ministry of Health (MOH), firefighting requirements and more. To help with technical aspects and authority requirements, other bodies such as *Cawangan Kawalan Amalan Perubatan Swasta* (CKAPS) will help and check the hospital design plan. Cost and maintenance can be overcome in ways such as the selection of materials for the building, the type of plants chosen for the landscape, the way the pipes are installed and even the way the wires are installed for electricity.

Table 5. Significant Keywords of Part C

No	Questions	Significant Keywords
1	Challenges in incorporating biophilic design	• Fulfilled local **authorities' requirements** • Comply and do not disregard on **technical** aspect of hospital building • Consideration on **cost** in designing • Ensure the hospital design has an easy and regular **maintenance**
2	Improvements that can be made	• Designers should study on the **element suitability** for hospital building
3	Effectiveness of biophilic design	• A hospital **cannot 100% depends** on natural element to create healing environment but should also has mechanical system

Designers also need to study the suitability of the biophilic elements before applying them to the hospital design even though the requirements and checklists have been provided. For example, the concept of open space to utilise natural ventilation is suitable for rural areas but not for urban areas with unhealthy and polluted air. According to experts, nature through biophilic design cannot be one hundred percent helpful in healing and hospital design needs to be balanced with mechanical systems. Medical machineries such as ventilators, ultrasound and blood analysers are still needed in the treatment of diseases even when patients are exposed to nature. Nature can mostly help mental health by reducing stress and creating positive emotions.

CONCLUSION AND RECOMMENDATION

The study findings have discovered that there is a total of twelve biophilic design elements which are the most justifiable for Malaysian private hospitals. Natural light, water features, plants or landscape, pets' area, image of nature, natural materials, natural or soft colours, shape and form, prospects, refuge, complex and orderly design as well as culture and ecology can be found as the suitable biophilic design elements to be applied in hospital design and validated by the experts. From the semi-structured interview and data analysis, it can be summarised that not all biophilic design elements listed by Kellert & Calabrese (2015) and Browning et al. (2014) are suitable for Malaysian private hospital contexts. Table 6 below illustrate the biophilic design checklist for Malaysian private hospitals that can significantly guide the designers to develop and build a Malaysian biophilic hospital.

Table 6. Biophilic Design Checklist for Malaysian Private Hospitals

Checklist
☐ Allowing the natural light to enter the building
☐ Allowing the presence of water features outdoors
☐ Planting plants or landscape design outdoors
☐ Incorporating pets' area for certain type of pets
☐ Giving an image of nature through photos, murals, etc.
☐ Use natural materials not for structure but for aesthetic purpose
☐ Use natural, soft or pastel colours and avoid contrasting and vibrating colours
☐ Shape and form suitable for healing environment o Building design with basic geometrics and shapes for easy equipment arrangement and wayfinding o Fulfilled authorities'' requirements
☐ Consideration of prospects where the design has a long-term benefit
☐ Consideration of refuge where the design of the building provides a sense of safety and security
☐ The building has a complex and orderly design that does not make people confused and chaotic
☐ Conservation and preservation of the site's culture and ecology such as local flora and fauna, history and meteorological conditions to preserve both the natural and built environment

As a consequence, further study on biophilic design for Malaysian hospitals is needed to develop biophilic design hospitals in Malaysia since the advantages have been highlighted. This adds a new idea to the field of hospital design that enables the healing environment in hospitals to be enhanced. In conclusion, this paper evidence that the reliability and practicality in applying biophilic design are no more in doubt and lead towards achieving the Malaysian Sustainable Development Goal Agenda 2030, the Twelfth Malaysia Plans and Shared Prosperity Vision 2030 to provide a better quality of life.

REFERENCES

Bahauddin, A., Ong, J. and Prihatmanti, R. (2019) The Biomorphic and Biophilic Design Approaches in Rebuilding Place of Heritage Shophouses. *The European Proceedings of Multidisciplinary Sciences EpMS,* 280-290.

Bahauddin, A., Prihantmanti, R., and Ong, J. (2021) Biophilic Design Patterns and Local Knowledge of Plants Application in Baba-Nyonya Heritage Shophouses' Courtyard. *ARTEKS : Jurnal Teknik Arsitektur,* 6(2):305–314.

Browning, W., Ryan, C., and Clancy, J. (2014) 14 Patterns of Biophilic Design: Improving Health & Well-being in the Built Environment. New York. Terrapin Bright Green LLC, 61 pp.

Cheok, C., and Chan, K. L. (2017) Khoo Teck Puat Hospital. *In Mental Health of A Nation*, 114–119.

El Messeidy, R. (2019) Application of Biophilic Patterns in Health Care Environments to Enhance Healing. *Engineering Research Journal 163*, 87-99.

Etezadifar, S. S. (2020) *The Role of Biophilia in Hospital Humanization: The Case Study of San Luigi Gonzaga University Hospital.* Master Thesis, Politecnico Di Torino. 141 pp.

Halil, F. M. (2013). *The Implementation of Strategic Partnering in Industrialised Building System.* Ph.D. Thesis, Universiti Teknologi MARA. 279 pp.

Hamid, Z. A., Noor, M. S. M., Foo, C. H. and Roslan, A. F. (2014) Towards A National Green Building Rating System for Malaysia. *Malaysian Construction Research Journal*, 14(1):1-16.

Heish, H. F. and Shannon, S. E. (2005) Three Approaches to Qualitative Content Analysis. *Qualitative Health Research*, 15(9):1277-1258.

Hui, J. O. M., and Bahauddin, A. (2019). Biophilic Design in Heritage Indoor Co-Working Space in George Town, Penang, Malaysia. *Malaysian Journal of Sustainable Environment*, 6(2):642–650.

Ibrahim, I., Khairuddin, R., Abdullah, A., Amin, I. M., and Wahid, J. (2021). Analysis of Biophilic Design in Communal Space of an Office Building. Case study: Pertubuhan Arkitek Malaysia (PAM) Centre. *Proceedings of 8th International Conference on Advanced Materials Engineering & Technology* (ICAMET 2020), 1-8.

Kamil, M., Deepak, T. J., and Shanti, M. (2018). Review of Green Building Index GBI in Malaysia. *International Journal of Trend in Scientific Research and Development.* 18-22.

Kellert, S. R. Heerwagen, J. and Mador, M. (2011). Dimensions, Elements, and Attributes of Biophilic Design. Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life. John Wiley & Sons Inc, 19 pp.

Krcmarova, J. (2009) Wilson's Concept of Biophilia and The Environmental Movement in the USA. *Internet Journal of Historical Geography and Environmental History*, 6(1-2):4-17.

Lydia, S. (2019) *Biophilic Interior Design Concept for Outpatient Clinic for Hospital Kuala Lumpur*. Universiti Teknologi MARA. 14 pp.

Miles, M. B., and Huberman, A. M. (1994). Qualitative Data Analysis Second Edition. America: SAGE Publications, 354 pp.

Moghaddami, H. J. (2019). *Re-Thinking Biophilic Design Patterns in Preschool Environments for Children.* Master Thesis, The Graduate School of Natural and Applied Sciences of Middle East Technical University, 138 pp.

Muller, A. E., Hafstad, E. V., Himmels, J. P. W., Smedslund, G., Flottorp, S., Stensland, S., Stroobants, S., Van de Velde, S., and Vist, G. E. (2020). The Mental Health Impact of The Covid-19 Pandemic on Healthcare Workers, and Interventions to Help Them: A Rapid Systematic Review. *In Psychiatry Research* 293, 1-11.

Nkubiyaho, B. (2020). The Concept of Biophilic City and Biophilic Design. *Reseachgate*, 1-32.

Rabionet, S. E. (2011). How I Learned to Design and Conduct Semi-Structured Interviews: An Ongoing and Continuous Journey. *The Qualitative Report*, 16(2):563-566.

Ryan, C. (2016). 14 Patterns of Biophilic Design: Mystery. *Human Spaces*, 1-8.

Ryan, C. O., Browning, W. D., Clancy, J. O., Andrews, S. L., and Kallianpurkar, N. B. (2014). Biophilic Design Patterns: Emerging Nature-Based Parameters for Health and Well-Being in the Built Environment. *International Journal of Architectural Research: ArchNet-IJAR*, 8(2):1-62.

Sayuti, N. A. A.. (2016) *Biophilic Design? A Study of Emotions, Influences, and Perceptions of Furniture Design Incorporating Living Organisms*. Ph.D. Thesis, University of Canberra. 107 pp.

Totaforti, S. (2018). Applying The Benefits of Biophilic Theory to Hospital Design. *City, Territory and Architecture*, 5(1):1–9.

Townsend, K. (2013) Saturation And Run Off: How Many Interviews Are Required In Qualitative Research?. *ANZAM 2013*, 1-17.

Ulrich, R. S. (1993). Biophilia, Biophobia, and Natural Landscapes. The Biophilia Hypothesis. America: Island Press, 483 pp.

Usman, A. M. and Abdullah, K. (2018). Comparative Study on the Malaysian Sustainable Building Rating System. *International Journal of Integrated Engineering: Special Issue 2018: Center for Graduate Studies*, 10 (3):69-77.

White, M. P., Alcock, I., Grellier, J., Wheeler, B. W., Hartig, T., Warber, S. L., Bone, A., Depledge, M. H., and Fleming, L. E. (2019). Spending At Least 120 Minutes A Week in Nature is Associated with Good Health and Wellbeing. *Scientific Reports*, 9(1):1–11.

Wilson, E. O. (1984). Biophilia, The Human Bond with Other Species. America: Harvard University Press, 158 pp.

Zhang, Y. & Wildermuth, B. M. (2009). Qualitative Analysis of Content. ResearchGate, 1-12.

Zhong, W., Schröder, T., & Bekkering, J. (2021). Biophilic Design in Architecture and Its Contributions to Health, Well-Being, and Sustainability: A Critical Review. *Frontiers of Architectural Research*, 11(1):1-28.

PRIORITISATION OF INDICATORS FOR ASSESSING THE OPERATIONAL PERFORMANCE OF PUBLIC PRIVATE PARTNERSHIP (PPP) PROJECTS USING AHP MULTI-CRITERIA DECISION-MAKING METHODS

Nor Suzila Lop[1*], Kharizam Ismail[1], Haryati Mohd Isa[1], Natasha Khalil[1] and Ellyyanti Tahir[2]
[1]Department of Quantity Surveying, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Perak Branch, Seri Iskandar Campus, Seri Iskandar, 32610 Perak, Malaysia
[2]School of Quantity Surveying, Jalan. R. Mangun Mula Raya No. 2, Jakarta Timur, Indonesia

**Corresponding Email: norsu993@uitm.edu.my*

Abstract
Public Private Partnership (PPP) procurement has been used worldwide as a mechanism for the public sector to procure public facilities and services. Therefore, the quality performance of public facilities and services provided by concessionaire will be evaluated based on Key Performance Indicators (KPIs) as stipulated in the contract. This KPIs is used for determining the level of performance against the agreed level of standards as expected by the government. However, most of the PPP projects are currently facing difficulties in meeting the government's standards. It is due to several issues for instance lack of methods for measuring the KPIs, the lack of KPIs implementation, project performance not reflecting the actual performance on-site, and inconsistent of works performance. These shortcomings have led to the difficulty in determining the performance level of the PPP projects. Thus, objective of this paper is to determine the relative importance weight for KPIs in measuring the operational performance of PPP projects. This research adopted the quantitative approach using questionnaires that consisted of the Analytical Hierarchy Process (AHP). Out of the 23 experts, 19 experts expressed their willingness to participate in the survey. Thus, the response rate for the survey was deemed acceptable, (i.e. 82.6%). The data are then analysed by using The Expert Choice 11 software for multi-criteria decision making. The results of AHP have successfully assigned weights and prioritized KPIs, with seven dimensions and 36 sub-dimensions of KPIs by listing the most critical KPIs according to weights. Hence, the establishment of the weighted KPIs was successfully employed as an aid of improving current method of assessing operational performance of PPP projects.

Keywords: *Analytical Hierarchy Process (AHP); Key Performance Indicators; Operational Performance; Public Private Partnership (PPP)*

INTRODUCTION

The PPP procurement approach has been adopted extensively in construction projects globally to achieve value for money (VFM). As mentioned by Almarri & Boussabaine (2017), the main driver behind the paradigm of PPP procurement is achieving VFM by providing all the necessary service provisions at an optimal cost and to the output specified standards. Furthermore, VFM in the PPP context is often used to express satisfaction on the cost of good quality service by achieving good performance (Ismail, 2009). Although the importance of achieving good performance is often emphasised in implementing this procurement approach, there are still numerous PPP projects that demonstrate poor performance levels especially in social infrastructure projects (Liu et al., 2016, Lop et al., 2020). Besides this, Hashim et al. (2017) reported that most PPP projects face difficulties in meeting client expectations known as government. Hence, these issues have raised questions concerning the rationale of adopting the PPP approach in Malaysia, where VFM is a part of the goal to achieve success (UKAS, 2009).

Currently, the implementation of PPP's, especially for PPP schemes in Malaysia, has entered into more than fifth year of the operational and maintenance (O&M) phase and many researchers had argued on the issues and challenges that will be faced by the stakeholders in this phase (Lop et al., 2020; Hashim et al., 2017; Khaderi & Aziz, 2010). Among these include insufficient PPP implementation guidelines, difficulties in managing key performance indicators (KPIs), maintenance approach, service delivery failure, asset risk, and life cycle issues, and challenges in PFI management (Hashim et al., 2017). He further added that these issues would indirectly contribute to project implementation failure. This is also supported by Hashim et al. (2018) in a study stating that defects occurring in PPP projects had significantly affected project performance and disrupted project operations during the O&M phase. Lop et al. (2020) revealed that four major issues were discovered in the implementation of PPP project, namely lack of skills and knowledge on PPP, lack of procedures and its implementation, challenges in PPP management, and conflicts on documentation. All the issues highlighted will significantly affect the operational performance of PPP projects and simultaneously lead to project failure.

In Malaysia, one of the problems faced by PPP stakeholders is managing KPIs effectively (Lop et al., 2020; Hashim et al., 2017). In the PPP approach, KPIs is used to ensure that project performance is achieved at a certain level in line with agreed quality standards. Thus, KPIs are a useful mechanism in assessing the performance of a PPP project operation. The agreed level of performance helps determine the payments or deductions from the public sector to the private sector. Therefore, if the quality of service does not meet the minimum standards and requirements as stipulated in the output specification, a payment deduction or other penalties can be triggered in the form of a performance failure payment deduction (Yescombe, 2007). Javed et al. (2013) revealed that there were numerous complex KPIs specified in the PPP contract, resulting in the difficulties in monitoring, measuring, and implementation by end users. This finding is further supported by an interview conducted by Javed et al. (2013) on the challenges faced by Australian PPP projects. Therefore, actions need to be taken to ensure that all the problems can be overcome without affecting the operational performance. Therefore, assigning the weight and prioritisation of Key Performance Indicators (KPI) is important in ensuring the operational performance of PPP project can be measured more accurately.

CONCEPTS OF KEY PERFORMANCE INDICATORS

NAO (2003d) has acknowledged that most of the PPP contracts in the UK utilise KPIs as a benchmarking tool to evaluate FM contractors' regarding service delivery. This is similar to Holman (2009) suggesting that KPIs include benchmarks, targets, milestones, dates, numbers, percentages, variances, distribution, rates, time, cost, indexes, ratios, survey data and reports that are used to evaluate phenomenon. These evaluations typically compare actual to estimated performance regarding effectiveness, efficiency and quality. Hence, to measure the performance of PPP projects, appropriate KPIs need to focus on and measure the impact.

In other words, KPIs are more specific milestones or components of performance measures that serve as precursors to indicate progress towards the eventual achievement of the desired performance measures (Garvin et al., 2011). In this sense, KPIs should be specific rather than general, measurable against objectives and capable of being achieved. KPIs must also be relevant to the services provided, and the scoring mechanism must be capable of calculating monthly unitary payment (Oyedele, 2013). Accordingly, KPIs are the core elements and viewed as an effective method able to help PPPs in assessing the project performance and deliver VFM (Yuan et al., 2012).

The importance of KPIs in PPPs is the ability to assess the work performance against the standards as agreed by the public and private sectors. However, there remains a firm debate among researchers with regards to the significance of KPIs. There are several factors concerning the importance of implementing KPIs in PPP projects. The importance of using KPIs as a measurement tool is in the ability of the KPIs to benchmark the performance of a project against other comparable industries or projects where the lessons learned from others can be used to make targeted improvements (Ismail, 2009). Whereas, according to Reh (2018b); Ismail and Yusuf (2009a); and Smith (2001), benchmarking can be described as the process of comparing an organisation's operations or processes against other organisations within the same industry or other related organisations. The concept involves measuring the actual performance of certain aspects related to activities and comparing these against others referred to as best practice examples in a specific sector (Haponava & Al-Jibouri, 2012). Consequently, benchmarking has become an important component in many organisations and industries (i.e. construction) for continuous improvement and quality initiatives. Moreover, benchmarking encourages industry practitioners to collaborate in sharing best practices and ideas while avoiding the burden of having too many KPIs (Ismail & Yusuf, 2009a).

Nevertheless, KPIs are also important to highlight organisational and project related weaknesses through performing a project assessment using KPIs. For instance, an organisation without an effective strategy, supported by KPI's to measure project performance, may experience significant defects or poor service delivery (Lop et al., 2017b). Inevitably, if these weaknesses or failures are not addressed, poor performance and low satisfaction level may result. Thus, KPIs are crucial to assist organisations and projects to continuously improve in order for the organisation and projects to be successful. Moreover, the implementation of KPIs will undoubtedly benefit multiple stakeholders.

Importantly, as a useful tool to help improve performance, KPIs can help to monitor and evaluate performance, particularly in PPP projects. According to Liu et al. (2014b), monitoring and evaluating the performance of PPP projects are the core activities of contract and project management, which are considered important in most countries as part of their PPP policy regime. Therefore, KPIs are not only used in scoring the performance level but are also for monitoring the activities and outcomes in PPP projects (Yuan et al., 2009). This is also supported by Mladenovic et al. (2013); Cox et al. (2003) and Kagioglou et al. (2001) stating that KPIs are recognised as one of the popular tools used to measure the performance of PPP projects. Likewise, PPP project performance needs to be measured continuously to ensure that the concessionaire complies and meets established standards. Principally, performance will be measured when the project enters the O&M phase of the PPP project. According to the study by Akbiyikli (2013), during the O&M phase, service delivery is frequently measured to determine its compliance with the output specification(s) and payment deductions for performance failure according to the payment mechanism.

Even though several studies investigating KPIs have been conducted with the aim to improve performance, the use of KPIs is continuously debated (Ismail, 2012; Khaderi & Aziz, 2010). For instance, numerous challenges have been highlighted from a global perspective during the implementation of PPPs as reported by Lawther and Martin (2014); Javed et al. (2013); Toor and Ogunlana (2010). Most of the researchers' stated that KPIs lack clarity, difficult to understand, too complicated and some are too general and may lead to project failure and poor projects performance. Hence, this illustrates that there is a need to establish effective KPIs for measuring and monitoring the performance of PPP projects in order to achieve the project's goals and demonstrate VFM. According to Locke and Latham (2006), goals are related to the impact and in that goal has set the key standard to achieve satisfaction with performance. He also added that the level of satisfaction can be created by measuring the discrepancies between goals and performance levels.

KEY PERFORMANCE INDICATORS FOR SPECIFIC PPP O&M PHASE

One of the major tasks in designing a Performance Measurement System (PMS) is the selection of KPIs as they are at the heart of a PMS, enabling performance-based management decisions to be effectively made concerning strategies and activities (Neely et al., 2005). Moreover, selected KPIs represent the most fundamental and important dimensions for tracking future progress and to assess the current baseline performance of the process (Carlucci, 2010). She also stated that the KPIs reflect "how good" a system is, as an objectively measurable term.

Table 1 presents the summary of KPIs for specific O&M phase by previous researchers. From the review of literature, there are 13 indicators identified under five (5) elements of KPIs that have been implement for measuring the performance of PPP projects during O&M phase. During the O&M phase, health, safety and environment, facility management, and good governance are very important since this phase involves end users and the condition of the buildings (Liu et al., 2015; Ogunsanmi 2013; Yuan et al., 2008). These indicators are grouped under one single KPI namely; process. The process indicators help to monitor whether the process is delivering value as intended, which will assist the end users in tracking the capabilities of the process (i.e., strength and weakness) in providing value to the stakeholders (Yuan et al., 2008).

Table 1. Summary of KPIs for Specific O&M Phase

Item	Key Performance Indicators		Authors
	Dimensions	Sub-dimensions	
1	Process	1. Health, Safety and Environment 2. Facility Management 3. Good Governance	Liu et al. (2015); Ogunsanmi (2013); Yuan et al. (2008)
2	Innovations & Learning	1. Training & Learning System 2. Technology Transfer 3. Investment in Research & Development	Liu et al. (2015); Ogunsanmi (2013); Yuan et al. (2008)
3	Strategies	1. Value for Money (VFM)	Liu et al. (2015)
4	Stakeholder's Satisfaction	1. Public Clients Satisfaction 2. Concessionaire Satisfaction 3. End user's Satisfaction 4. Project Team Satisfaction	Liu et al. (2015); Ogunsanmi (2013); Yuan et al. (2008)
5	Stakeholder's Contribution	1. Concessionaire Performance 2. User Willingness to the infrastructure use	Liu et al. (2015)

The second KPI is regarding innovation & learning which are both important factors to influence the performance of PPP projects (Akbiyikli et al., 2012). The PPP project is in effect, a long-term process with significant risks, competition, and uncertainty, and requires the private and public sectors to acquire advanced knowledge and experience along with relevant information. Whereas innovation is the method of applying new knowledge and techniques in strategic planning, process design, creative financial applications, resource allocation and management to improve performance (Yuan et al., 2008). Knowledge or technology transfer could also be an effective mechanism for mitigating risks associated with PPP projects which is a key issue in the increasing complexity of the PPP operating environment (Mustapa & Carrillo, 2008; Carrillo et al., 2006). Moreover, sufficient investment on research, an excellent learning organisation and a suitable training mechanism can help to increase the ability to improve performance through gaining new knowledge (Liu et al., 2015; Ogunsanmi, 2013; Yuan et al., 2008).

According to Liu et al. (2015), VFM related to PPP projects needs to be assessed by examining organisational strategies in managing projects. These indicators focus on what long term and short-term strategies are required to ensure the needs and wants of targeted PPP stakeholders are achieved. Stakeholder apposition has been reported as the main reason why PPP projects fail (Yuan et al., 2008). Therefore, capturing and addressing the input of stakeholders is important for the success of PPP projects which include public client’s satisfaction, concessionaire’s satisfaction, end user’s satisfaction and the project team’s satisfaction (Liu et al., 2015; Ogunsanmi 2013; Yuan et al., 2008). These indicators are selected given they also help to measure the performance of PPP projects and are grouped under one single KPIs namely; stakeholder’s satisfaction.

The final KPIs for the O&M phase are in relation to the stakeholder’s contribution. The indicators are grouped under the following KPIs: concessionaire performance and user’s willingness to use the infrastructure (Liu et al., 2015). These indicators are also related to the roles and responsibilities of stakeholders in PPP projects. However, these five (5) KPIs just mentioned from the previous studies are insufficient in representing the KPIs for measuring the performance for the entire O&M phase of the project. During the O&M phase, maintaining the government asset is very crucial as it involved soft facilities management (FM) services (e.g. cleaning, catering, security, etc) and hard FM services (e.g., building maintenance, groundwork, landscaping, etc). Therefore, there is a need to explore and determine more appropriate KPIs that suit for the O&M phase of the PPP projects.

All these identified KPIs by previous researchers has been organised and characterised through the empirical study for public infrastructure projects (Liu et al., 2015; Ogunsanmi, 2013; Yuan et al., 2008). Even though, all these KPI models discussed among the previous researchers have been built specifically to assess the overall performance of PPP projects however these KPIs has been segregated according to the appropriate phases in project implementation.

INITIAL DEVELOPMENT OF DIMENSIONS AND SUB-DIMENSIONS OF KPIs FOR O&M PHASE

The implementation of PFI projects in all campuses (the six case studies) was based on the KPIs developed and agreed by all three parties; i.e. UiTM, MOHE and the concessionaire. Contractually, there are six (6) dimensions and 37 sub-dimensions of the KPIs specified in the Building Maintenance Manual (BMM) under the Concessionaire Agreement (CA). All KPIs need to comply and be achieved by the concessionaire throughout the implementation of the project. However, most of the participants mentioned that they needed to comply with all agreed KPIs in performing the maintenance works and in delivering good quality services and facilities to the public sector. Even though the KPIs were contractually agreed between the parties, the interview participants argued about the effectiveness and appropriateness of the current KPIs during the O&M phase. This argument was founded on the participant's experiences throughout the implementation of the operational PFI projects. Most of the issues and arguments mentioned were concerning the appropriateness of the KPIs in the O&M phase, overlapping and redundant KPIs, and the lack of KPIs in measuring project performance during PFI implementation.

Table 2. Initial Construct of 7 Dimensions and 36 Sub-Dimensions of KPIs

No.	Key Performance Indicators (KPIs)		
	Dimensions	Sub-Dimensions	
1.	Operational Element	1.1	Action time
		1.2	Pending Work Instruction
		1.3	Maintenance Index
		1.4	Facilities Condition Index
		1.5	Condition Auditing
		1.6	Health, Safety and Environment
		1.7	Innovation & Learning
		1.8	End User's Satisfaction
2.	Mechanical	2.1	Availability Major Service
		2.2	HVAC Element
		2.3	Sewerage Treatment Plant
		2.4	Water Reticulation
		2.5	Lift Element
		2.6	Fire Fighting
		2.7	Building Management System
		2.8	Energy Management
		2.9	Planned Preventive Maintenance for Mechanical
		2.10	Compliance to statutory requirements
		2.11	Customer rating feedback for mechanical
3.	Electrical	3.1	Power Factor
		3.2	3 Phase Load & Balancing
		3.3	Lighting
		3.4	Utilities
		3.5	Customer rating feedback for electrical
4.	Telecommunication	4.1	Response time for PABX breakdown
		4.2	Action time for PABX breakdown
		4.3	Customer rating feedback for telecommunication
5.	Civil, Structural & Architectural	5.1	Low risk safety hazards for civil, structural & architectural
		5.2	Request for unscheduled maintenance for civil, structural & architectural
		5.3	Planned Preventive Maintenance for civil, structural & architectural
6.	Landscape & Ground	6.1	Low risk safety hazards for landscape & ground
		6.2	Request for unscheduled maintenance for landscape & ground
		6.3	Planned Preventive Maintenance for landscape & ground
7.	Pest Control & Wildlife Control	7.1	Low risk safety hazards for Pest Control & Wildlife Control
		7.2	Request for unscheduled maintenance for Pest Control & Wildlife Control
		7.3	Planned Preventive Maintenance for Pest Control & Wildlife Control

The initial construct of dimensions and sub-dimensions of KPIs for O&M phase was confirm through qualitative approach via a semi-structured interview technique. 32 participants among PPP stakeholders (i.e., public sectors and private sectors) within 6 case studies were involved in the interview. The purpose of conducting interviews was to investigate KPI implementation by determining the appropriate KPIs for use as a measuring tool in PPP projects. Therefore, their input had been needed in order to determine the appropriates KPIs for assessing operational performance of PPP projects. The issues of six (6) dimensions and 37 sub-dimensions of the KPIs as stipulated in the contract in six (6) case studies was discussed during the interview. Although the current KPIs are considered complete, there remain some areas that need to be further refined to ensure that the KPIs are comprehensive and act as a useful tool in measuring the operational performance of PPP projects. Thus, the findings of the interview contribute towards identifying appropriate KPIs for the O&M phase of PPP projects as illustrated in Table 2. There are 36 sub-dimensions classified under seven (7) dimensions of improved KPIs resulted from the interviews. This will be developed further according to the priority based on the relative importance and assigned weights for each listed dimensions and sub-dimension (i.e., the main survey) using the AHP method as a decision-making approach.

RESEARCH METHODOLOGY

Before conducting quantitative research, qualitative research approach has been conducted in order to gathered data on the appropriate KPIs through the case studies via semi-structured interviews. The selection of cases studies was based on the list of projects established by the Public Private Partnership Unit (UKAS) of the Prime Minister's Department of Malaysia. Six (6) UiTM PFI campuses under phase 1 were chosen as the research case studies.

In order to prioritise the KPIs, this research adopted the quantitative approach using questionnaires that consisted of the Analytical Hierarchy Process (AHP). The final list of the KPIs (i.e., 7 Dimensions and 36 sub-dimension) was incorporated into the questionnaire as survey questions. The purpose of the survey was to determine the relative importance weight for each KPIs in measuring the performance. For this research, the AHP method developed by Prof. Dr Thomas L. Saaty in 1977 was adopted to gain the expert's judgement for the decision-making approach in prioritisation and assigning a weight for the KPIs. The rationale behind adopting the AHP method in this research was that it could assist in the decision-making process especially in measuring PPP project performance that requires decision makers to determine the operational performance level of a project. The use of AHP was also deemed appropriate because it can determine the priority of KPIs according to the assigned weight. Besides, the AHP method can assist decision makers in comparing the relative importance of KPIs systematically and quantitatively.

Application of Analytical Hierarchy Process (AHP)

The AHP is a theory of measurement through pairwise comparisons and relies on the judgement of experts to derive priority scales (Esmatullah et al., 2016; Doloi et al., 2010; Saaty, 2008, 1990). This approach required experts to compare and rate the relative importance of each KPI by considering its impact on the project's operations. This AHP technique also dealt with a multi-criteria decision-making (MCDM) process where it involved the expert's judgment through rating the importance of the KPIs. Regarding this process, with this, Khalil et al. (2016); and Sabaei et al. (2015); recommended using the Analytic Hierarchy Process (AHP) developed by Prof. Thomas L. Saaty in 1977. It is supported by Sabei et al. (2015) that AHP is the most suitable method amongst other types of MCDM methods as AHP can provide decision makers with a robust solution. Furthermore, Saaty (1980) stated that the AHP allowed experts to rate the KPI weightings with greater consistency through pairwise comparisons. The rating process is vital in assigning weighting and prioritise the KPIs. Therefore, it requires knowledge from experts who understand and experience in managing PPP projects during the O&M phase. In addition, it also should involve in assessing the operational project's performance. The involvement of experts is important to ensure that the rating process is valid and reliable. To complete and answer the research question more precisely, hence, the AHP method was adopted in this research.

Administration of the Questionnaire (AHP Method)

In the context of the research, the researcher decided to employ a questionnaire using the AHP method as the main instrument for the main data collection process based on the findings from the semi-structured interviews. A set of questionnaires were provided earlier to the respondents via email and followed by a telephone conversation with the respondent. This was to confirm receipt of the questionnaire, their consent and setting an appointment date to perform the research. This method is unlike the usual questionnaire distribution method, where respondents can answer the questionnaire without any explanation given by the researcher. Similarly, the confirmation of the invitation and the date of the appointment were vital to assist the respondents in deciding on this AHP approach. In total, 19 respondents agreed to participate in the survey.

According to Saaty and Ozdemir (2014), there are no pre-set rules for determining the size of experts sampling for the AHP method as it relies on the purpose of the survey, the nature of the problem, the availability of experts and the diversity of the targeted population (Khalil et al., 2016). Purposive sampling was adopted which 23 experts was shortlisted. However, only 19 experts were agreed to participate and selected based on the following pre-determined criteria:

a) Designated in the position of manager/top level in the division and also a professional practitioner.
b) Possessing knowledge in PPPs particularly concerning the implementation of KPIs.
c) More than 3 years' experience dealing with PPP projects concerning operational performance assessments.
d) Ten years minimum experience in a managerial capacity dealing with issues related to project management; currently or previously.

In applying the AHP method, consistency in judgment is a significant concern. In this research, the data collected from the questionnaires were processed to structure the corresponding pairwise comparison judgment matrices (PCJM), in order to establish the normalised weights. Each of these matrices was then converted into the largest eigenvalue problem and was solved to determine the normalised and unique priority weights for each criterion. The computer package, The Expert Choice 11, was then used to analyse the data and present the results for the AHP survey. The output quality of the AHP was strictly related to the consistency of the pairwise comparison judgement given by the panel of experts. Saaty (2008), suggested a simple procedure for checking consistency, called the consistency ratio (CR). If the CR value is larger than 0.10, it implies that there is a 10% chance that the elements have not been properly compared (Saaty, 2008). In this case, the decision maker (panel experts) must review the comparisons made. If the CR equals 0, the judgments are perfectly consistent. Therefore, to control the results, the CR must be less than 0.10 ($CR < 0.1$) in order to prove the comparisons are acceptable and all of the judgements are consistent.

RESULT AND DISCUSSIONS

Employing the AHP method, the data were analysed using computer software (Expert Choice 11) where the weightings indicated by the respondents for the dimensions and sub-dimensions were extracted from the pairwise comparison of the relative importance. The numerical pairwise comparisons of all dimensions were obtained by combining the judgements of the 19 experts.

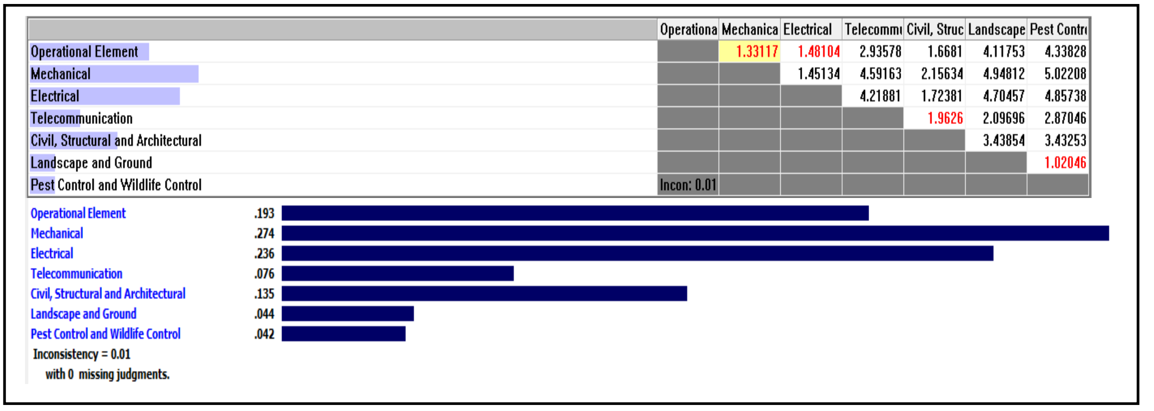
In this rating process, there were seven (7) dimensions for the pairwise comparison; operational element; mechanical; electrical; telecommunication; civil, structural and architectural; landscape and ground and pest control and wildlife control. Subsequently, the pairwise importance of each sub-dimension was made within the same areas. For instance, there were eight (8) sub-dimensions for the operational element, 11 sub-dimensions for mechanical, five (5) sub-dimensions for electrical, three (3) sub-dimensions for telecommunication, three (3) sub-dimensions for civil, structural and architectural, three (3) sub-dimensions for landscape and ground and three (3) sub-dimensions for pest control and wildlife control. All pairwise importance from each sub-dimension was undertaken within the specified dimensions.

Step 1: Structuring the Problem

The first step of performing the AHP analysis was to design the decision hierarchy. This is also called decision modelling, which consists of building a hierarchy to analyse the decision. At this stage, the relevant dimensions and sub-dimensions of operational performance were based on seven (7) dimensions, and 36 sub-dimensions considered in the development of the AHP hierarchy. This step was crucial to ensure all appropriate dimensions and sub-dimensions were considered for the judgement.

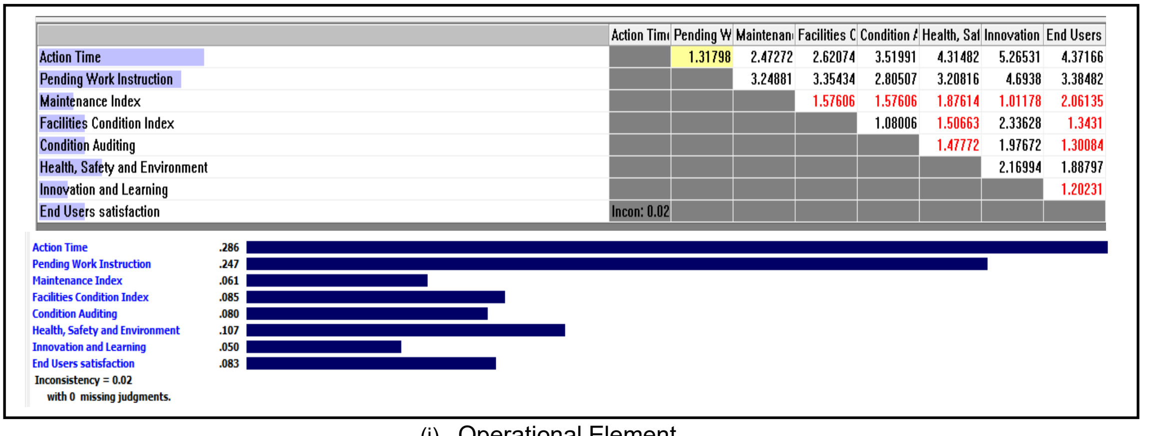
Step 2: Pairwise Comparison Judgement Matrix (PCJM)

The next step was to perform a pairwise comparison of the dimensions and sub-dimensions followed by calculating the relative weights. This step required the panel experts to judge the relative importance of each KPI (dimensions and sub-dimensions) by assessing their impact on the project operations and contribution towards the achievement of the overall goal. The data collected from the questionnaires were processed in order to structure the corresponding pairwise comparison judgment matrices (PCJM) to establish the normalised weights. Once the judgements were finalised regarding the comparisons, each of the matrices was then converted into the largest eigenvalue problem, solved to determine the normalised and unique priority weights for each KPI. Figure 1 and 2 display the results of the PCJM of the operational performance for the main dimensions and sub-dimensions according to the assigned weightage.



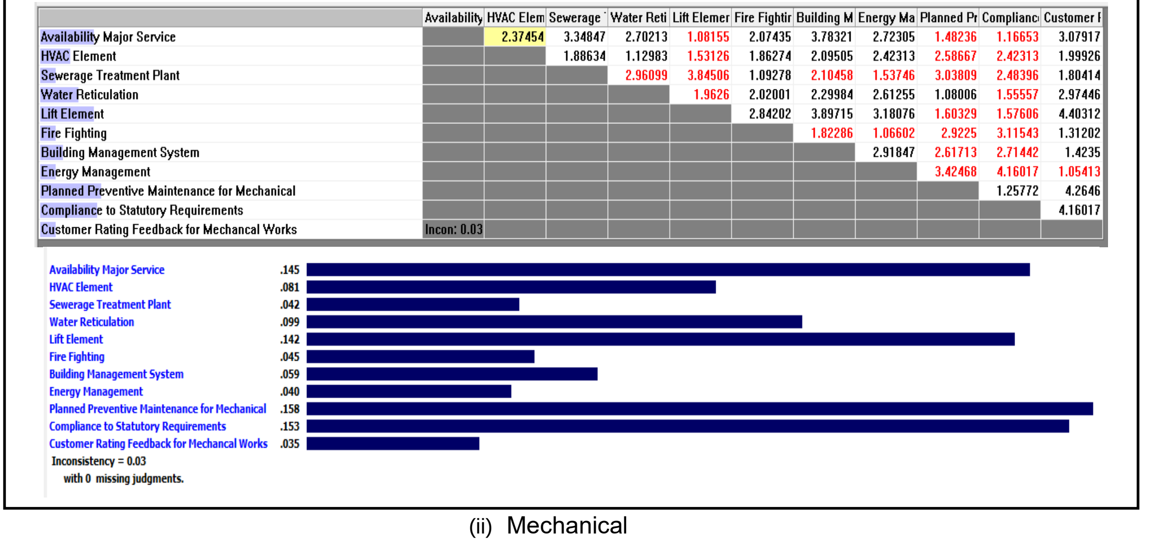
	Operationa	Mechanica	Electrical	Telecomm	Civil, Struc	Landscape	Pest Contr
Operational Element		1.33117	1.48104	2.93578	1.6681	4.11753	4.33828
Mechanical			1.45134	4.59163	2.15634	4.94812	5.02208
Electrical				4.21881	1.72381	4.70457	4.85738
Telecommunication					1.9626	2.09696	2.87046
Civil, Structural and Architectural						3.43854	3.43253
Landscape and Ground							1.02046
Pest Control and Wildlife Control	Incon: 0.01						

Figure 1. Pairwise Comparison Judgement Matrices (PCJM) – Main Dimensions



	Action Tim	Pending W	Maintenan	Facilities C	Condition A	Health, Sal	Innovation	End Users
Action Time		1.31798	2.47272	2.62074	3.51991	4.31482	5.26531	4.37166
Pending Work Instruction			3.24881	3.35434	2.80507	3.20816	4.6938	3.38482
Maintenance Index				1.57606	1.57606	1.87614	1.01178	2.06135
Facilities Condition Index					1.08006	1.50663	2.33628	1.3431
Condition Auditing						1.47772	1.97672	1.30084
Health, Safety and Environment							2.16994	1.88797
Innovation and Learning								1.20231
End Users satisfaction	Incon: 0.02							

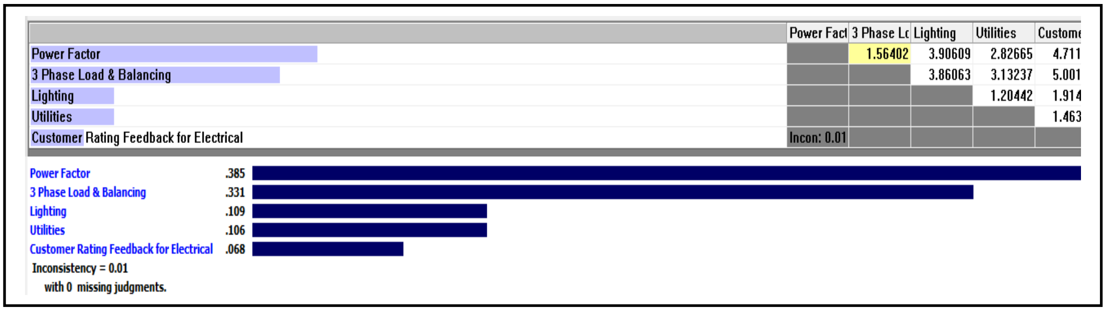
(i) Operational Element



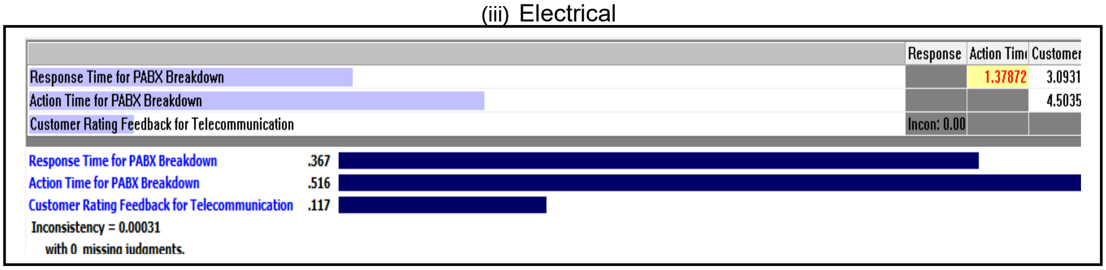
	Availability	HVAC Elem	Sewerage	Water Reti	Lift Elemer	Fire Fightir	Building M	Energy Ma	Planned Pr	Complianc	Customer F
Availability Major Service		2.37454	3.34847	2.70213	1.08155	2.07435	3.78321	2.72305	1.48236	1.16653	3.07917
HVAC Element			1.88634	1.12983	1.53126	1.86274	2.09505	2.42313	2.58667	2.42313	1.99926
Sewerage Treatment Plant				2.96099	3.84506	1.09278	2.10458	1.53746	3.03809	2.48396	1.80414
Water Reticulation					1.9626	2.02001	2.29984	2.61255	1.08006	1.55557	2.97446
Lift Element						2.84202	3.89715	3.18076	1.60329	1.57606	4.40312
Fire Fighting							1.82286	1.06602	2.9225	3.11543	1.31202
Building Management System								2.91847	2.61713	2.71442	1.4235
Energy Management									3.42468	4.16017	1.05413
Planned Preventive Maintenance for Mechanical										1.25772	4.2646
Compliance to Statutory Requirements											4.16017
Customer Rating Feedback for Mechancal Works	Incon: 0.03										

(ii) Mechanical

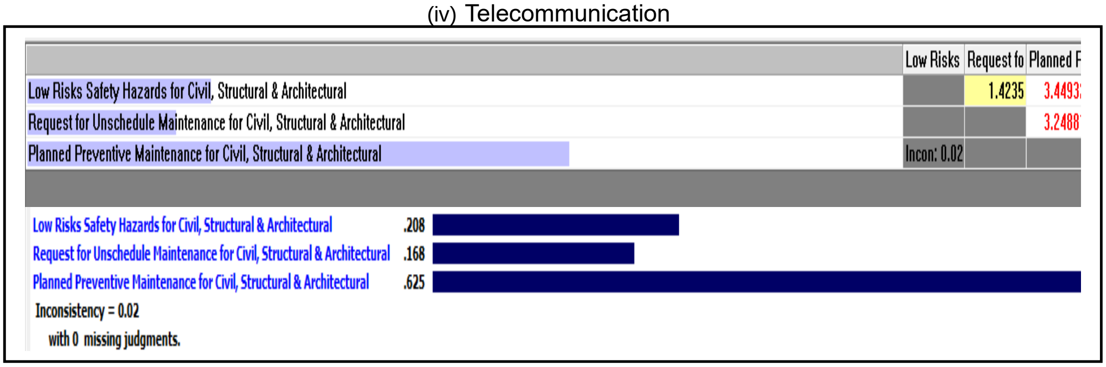
Figure 2. Pairwise Comparison Judgement Matrices (PCJM) - Sub-Dimensions (i) and (ii)



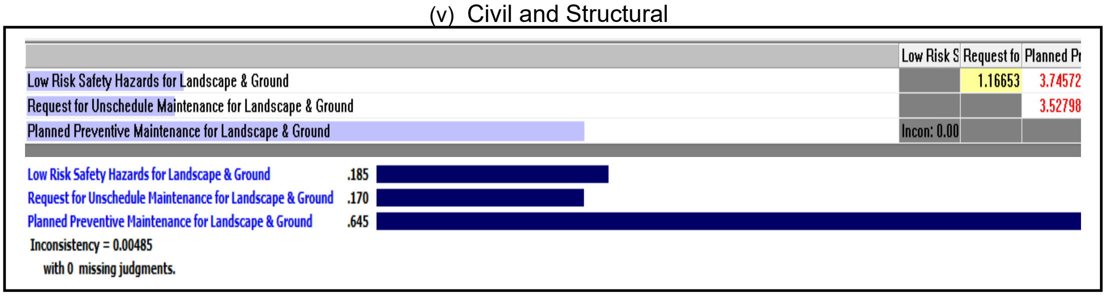
(iii) Electrical



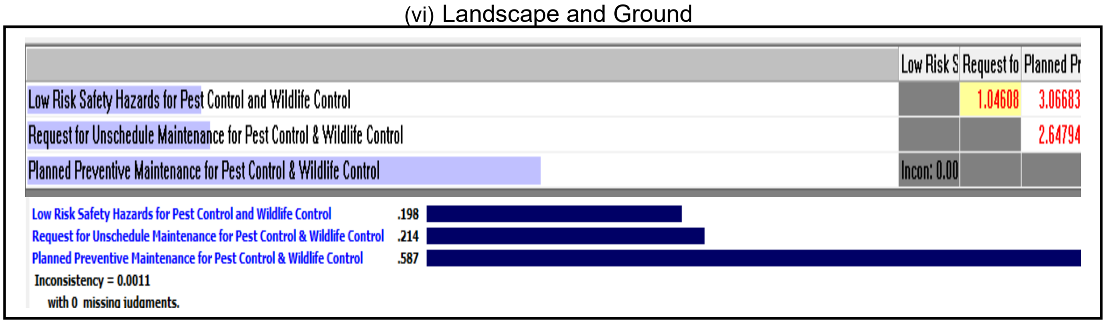
(iv) Telecommunication



(v) Civil and Structural



(vi) Landscape and Ground



(vii) Pest Control and Wildlife Control

Figure 2. Continued - (iii), (iv), (v), (vi) and (vii)

Based on the results presented in Figure 1 and 2, the 36 sub-dimensions were keyed-in in the AHP software (The Expert Choice 11) according to their category (based on the 7 dimensions). In AHP, weights were determined to perform a pairwise comparison between each pair of dimensions and sub-dimensions. Further, each comparison was converted to numerical values.

As shown in Figure 1 and 2, the weightage was assigned based on the priority values. The results show that the assigned weight for the *operational element* is 0.193, *mechanical* is 0.274, *electrical* is 0.236, 0.076 for *telecommunication*, 0.135 for *civil, structural and architectural*, *landscape and ground* is 0.044 and *pest control and wildlife control* is 0.042. The results were then prioritised according to their assigned weight.

Similarly, as presented in Figure 1 and 2, the priority values for each sub-dimension are determined within separate main dimensions. The results show that the most important sub-dimensions within the **operational element** are *action time* (0.286) which shows the highest weight amongst others followed by *pending work instruction* (0.247), and *health, safety and environment* (0.107). As can be seen in the figure, the weighted assigned for other sub-dimensions such as for *facilities condition index* is at 0.085, *condition auditing* is at 0.080, 0.083 for *end users' satisfaction* and 0.061 for *maintenance index*. However, *innovation and learning* have the lowest weight assigned at 0.050. Even though the results of innovation and learning is lower compared to other sub-dimensions, it doesn't mean that this sub-dimension is not important, but it indicates a lower impact on the project's operations. Accordingly, the findings indicate that it is important for FM contractors to manage the complaints of end users as a failure to manage these complaints will undoubtedly impact project operations and performance. This is in line with Hashim et al. (2011) stating that it is important to manage the end user's complaints reported by the users by completing works according to the action time as listed in the work order.

As for the **mechanical** category, the sub-dimensions valued as the most important are *planned preventive maintenance for mechanical* (0.158), *compliance to statutory requirements* (0.153), *availability major service* (0.145) and *lift element* (0.142). Besides, the weight assigned for other sub-dimensions is at the middle range such as for the *water reticulation* element at 0.099, the *HVAC* element at 0.081, 0.059 for the *building management system*, 0.045 for *fire-fighting,* 0.042 for the *sewerage treatment plant* and 0.040 for *energy management*. Meanwhile, the *customer rating feedback for mechanical* (0.035) had a low weightage of relative important assigned amongst all sub-dimensions within the mechanical dimension. Accordingly, the findings show that it is essential to undertake planned preventive maintenance (PPM) for the mechanical category as this sub-dimension (PPM) contributes to having a significant impact on the project's operations. Poor maintenance of facilities under the mechanical category, will inevitably lead to defects and malfunction of the asset and significantly contribute to the low level of achieving acceptable performance.

For the **electrical** category, the most important value of sub-dimension within this dimension is *power factor* (0.385). This sub-dimension affords a significant impact on the overall operation of PPP projects if an electrical breakdown occurs. The power factor readings set by Tenaga National Berhad (TNB) must not less than 0.85. The organisation will be penalised if the power factor reading is less than 0.85 as this will cause damage to TNB's electrical component. This is followed by the sub-dimensions of *3 phase load & balancing*

(0.331), *lighting* (0.109), *utilities* (0.106) and *customer rating feedback for electrical* (0.068). The findings suggest that customer rating feedback for electrical contributes to a lower impact on the project's operations. This presumes that the overall project operations will not be significantly affected if this sub-dimension is not entirely achieved.

The next dimension is **telecommunication**. The findings show that the weight assigned for *action time for PABX breakdown* is at 0.516, followed by the *response time for PABX breakdown* with a weight at 0.367. These two sub-dimensions show the higher weightage assigned compared to the *customer rating feedback* which allocated a weight at 0.117. This result demonstrates that it is important to respond and take action to the complaints reported by the end users as they can influence the operation and performance of projects.

The next important sub-dimension is **civil, structural and architectural**. The findings show that the most important sub-dimension is on *planned preventive maintenance (PPM) for civil, structural & architectural* (0.625). This result demonstrates that PPM is the most important sub-dimension amongst the others (i.e., within civil, structural and architectural) throughout the O&M of PPP projects. Moreover, it indicates that if the concessionaire failed to deliver good quality service and maintenance of the building, it could affect the operation and performance of PPP projects. The second highest weight is a *low risk safety hazard for civil, structural & architectural* with an importance weight at 0.208, followed by *request for unscheduled maintenance for civil, structural & architectural* that obtained a weight at 0.168.

Notwithstanding, the most important sub-dimensions for **landscape and ground** is *planned preventive maintenance (PPM) for landscape and ground* (0.645) and the second important sub-dimensions rated by the experts is, a *low risk safety hazard for landscape and ground* with the assigned weight of 0.185. Finally, *unscheduled maintenance for landscape and ground* is 0.170 as rated by the experts. The findings, therefore, indicate that it is important to execute PPM works to maintain the landscape and ground. This PPM involves detailed scheduling prepared by the FM contractors to assist in maintaining the landscape according to the planned and standard required.

Finally, for the sub-dimension of **pest control and wildlife control** category. The findings indicate that the highest weightage is assigned between several sub-dimensions, firstly, *planned preventive maintenance (PPM) for pest control & wildlife control* (0.587) which is then followed by *request for unscheduled maintenance for pest control & wildlife control* (0.214) and *low risk safety hazards for pest control & wildlife control* (0.198). The results demonstrate that it is important to execute the PPM work in order to improve the performance and safety of the property and users. Likewise, implementation of PPM for pest control and wildlife control can help to keep the environment free from pests.

Step 3: Prioritisation Procedure

The third step was the prioritisation procedure (ranking) for the dimensions and sub-dimensions. To obtain the priorities of KPIs, the distribution mode was selected as it normalises the sub-dimension scores under each dimension in order to sum to one (1.00). This enables the local weight for each dimension to be obtained. Further, the global weight for each sub-dimension within the same group was next determined by multiplying the local weight of the sub-dimensions with the local weight of the dimensions. In this case, the determination of the global weight indicates the priority of the overall sub-dimensions according to the relative importance weight.

Table 3 reports the derivation of weightage for the KPIs and priorities. Based on the table, the local weight for the dimensions and sub-dimensions is derived from the PCJM, and the global weight can also be directly derived from the AHP software, (The Expert Choice 11). Based on Table 3, the priority of KPIs where the results indicate that the top priority for the importance of dimensions is *mechanical* (0.274), followed by the second priority of the relative importance weight being *electrical* (0.236), *operational element* (0.193), *civil, structural & architectural* (0.135), *telecommunication* (0.076), *landscape and ground* (0.044) and *pest control and wildlife control* (0.042). According to Isa et al. (2017), the mechanical elements recorded a high number of defects after the architectural elements. This circumstance is due to the FM contractor failing to perform maintenance work that ultimately contributed to damage and failure of a building function. As a result, it will affect and disrupt the entire project operations.

As for the overall findings regarding the sub-dimensions, it can be seen that *power factor* is ranked as the most important sub-dimension with a weight of 0.091, followed by *planned preventive maintenance (PPM) for civil, structural and architectural* at 0.084, *3 phased load and balancing* at 0.078, *action time* at 0.055 and 0.048 for *pending work instruction*. This result suggests that these five (5) indicators are the most important sub-dimensions that need to perform well to achieve good performance of a project given they can generate a much larger impact on the operations of the project. The results also indicate that *low risk safety hazard for landscape and ground*, *request for unscheduled for landscape and ground* and *low risk safety hazard for pest control and wildlife control* had the lowest weight at 0.008. The findings, therefore, show that although the weights assigned to these sub-dimensions were lower compared to the others, their contribution towards achieving good performance is similar. Moreover, what distinguishes these sub-dimensions from the other sub-dimensions is that the impact is less regarding the PPP project's operations and overall performance. Hence, the importance of the weight for all dimensions as rated by the respondents was determined. The priority of the KPIs also helps to demonstrate the level of importance and their significant impact on the operational performance of the PPP projects in achieving VFM.

Step 4: Consistency of Pairwise Comparison

Next, the calculation to measure the internal consistency of the pairwise comparison was conducted. Once the expert's judgements have been entered; the next step was to check the internal consistency. Given the numeric value derived from the subjective preferences of individuals, it is near impossible to avoid inconsistencies in the final matrix of the judgements. Therefore, it is important for the AHP to calculate a consistency ratio (CR). Here for instance, if the CR is less than 0.10, the comparisons are acceptable. For this application, the result of internal consistency for the combined instance for the overall sub-dimensions is 0.02. It also shows that CR is lower than 0.1 ($CR < 0.1$). Therefore, all judgements are consistent. This is aligned with Saaty (1990) where the results of internal consistency ratio (CR) must be less than 0.1 (10%) given that the main concern of the AHP is to obtain consistency in the judgements.

Table 3. Derivation of Weightage and the Priority of KPIs

Goal	Key Performance Indicators					Priority
	Dimensions	Local Weight	Sub-Dimensions	Local Weight	Global Weight	
Operational Performance of PPP Projects	Operational Element	0.193	Action Time	0.286	0.055	4
			Pending Work Instruction	0.247	0.048	5
			Maintenance Index	0.061	0.012	26
			Facilities Condition Index	0.085	0.016	22
			Condition Auditing	0.080	0.015	25
			Health, Safety and Environment	0.107	0.021	20
			Innovation and Learning	0.050	0.010	30
			End User's Satisfaction	0.083	0.016	21
	Mechanical	0.274	Availability Major Service	0.145	0.040	8
			HVAC Element	0.081	0.022	19
			Sewerage Treatment Plant	0.042	0.012	27
			Water Reticulation	0.099	0.027	14
			Lift Element	0.142	0.039	9
			Fire Fighting	0.045	0.012	28
			Building Management System	0.059	0.016	23
			Energy Management	0.040	0.011	29
			Planned Preventive Maintenance for Mechanical	0.158	0.043	6
			Compliance to Statutory Requirements	0.153	0.042	7
			Customer Rating Feedback for Mechanical	0.035	0.010	31
	Electrical	0.236	Power Factor	0.385	0.091	1
			3 Phase Load & Balancing	0.331	0.078	3
			Lighting	0.109	0.026	15
			Utilities	0.106	0.025	16
			Customer Rating Feedback for Electrical	0.068	0.016	24
	Telecommuni-cation	0.076	Response Time for PABX Breakdown	0.367	0.028	12
			Action Time for PABX Breakdown	0.516	0.039	10
			Customer Rating Feedback for Telecommunication	0.117	0.009	32
	Civil, Structural & Architectural	0.135	Low Risk Safety Hazards for Civil, Structural & Architectural	0.208	0.028	11
			Request for Unscheduled Maintenance for Civil, Structural & Architectural	0.168	0.023	18
			Planned Preventive Maintenance for Civil, Structural & Architectural	0.625	0.084	2
	Landscape & Ground	0.044	Low Risk Safety Hazards for Landscape & Ground	0.185	0.008	34
			Request for Unscheduled Maintenance for Landscape & Ground	0.170	0.008	35
			Planned Preventive Maintenance for Landscape & Ground	0.645	0.028	13
	Pest Control & Wildlife Control	0.042	Low Risk Safety Hazards for Pest Control & Wildlife Control	0.198	0.008	36
			Request for Unscheduled Maintenance for Pest Control & Wildlife Control	0.214	0.009	33
			Planned Preventive Maintenance for Pest Control & Wildlife Control	0.587	0.025	17
Total		**1.000**			**1.000**	

DISCUSSION OF FINDINGS

In the context of this research, the AHP technique was employed to facilitate the prioritisation and assigning a weight to the KPI for assessing the operational performance of PPP projects. This approach resulted in a systematic decision-making approach in order to assist stakeholders in determining which KPIs would have a greater impact on the operations of the project. A simple demonstration or development hierarchical of the AHP technique was also used to demonstrate the principle and to avoid in the complex evaluation. The applicability of these approaches has been employed for many topics of research within the PPP approach, such as by Esmatullah et al. (2016); Doloi et al. (2010); and Li and Zou (2008). However, the specific area of KPIs for assessing operational performance using the AHP approach by applying this weightage and prioritisation for KPI's is limited. Therefore, findings provide a significant contribution to the body of knowledge in this field of study and also for the construction industry in assessing PPP project performance.

There are different reasons to prioritise and assign a weight to KPIs. For example, adopting the AHP approach, the most important KPIs that have a greater impact on the operations of the project can be determined which is crucial in performing maintenance works, and to assist in monitoring these works. Similarly, the determination of the priority and importance of KPIs with relative importance weight will help stakeholders in tracking KPIs that achieve low-level performance. These weighted KPIs can also be used to determine the elements that need to be improved to achieve better performance. Therefore, appropriate action can be taken to enhance the level of performance through close monitoring of KPIs via continuous improvement. However, Shahin and Mahbod (2007) argued that, although the outcome of the AHP can help to determine which dimensions and sub-dimensions require improvement, it fails to guide an appropriate action to address any deficiencies. Therefore, the stakeholders still need to plan appropriate actions and methods for continuous improvement in order to enhance the level of performance as well as the implementation of KPIs in PPP projects.

Overall, the results of the AHP survey specified that each sub-dimension had been assigned with a relative weight. The obtained weight for the KPIs facilitated the development of the performance measurement tool for PPP projects. As mentioned by Esmatullah et al. (2016) and Doloi et al. (2010) AHP is one of the most comprehensive systems for multi-criteria decision making which it has an ability to formulate problems based on a paired comparison. From the AHP analysis that was carried out, the results ranked the dimensions according to the weight assigned, such as mechanical (0.274), electrical (0.236), operational element (0.193), civil, structural and architectural (0.135), telecommunication (0.076), landscape and ground (0.044) and pest control and wildlife control (0.042). It was indicated that, the mechanical element was the most critical KPI that would significantly impact the operations of the project if not maintained. This may be due to most of the major elements such as HVAC, lift, firefighting, sewerage treatment plant, and water reticulation grouped under this element having the greatest contribution towards the operations of the project.

The findings of this research also show that there is a significant difference in the relative importance of the dimensions based on the judgement of experts. Indeed, this result may suggest that stakeholders involved in managing PPP projects particularly regarding performance management should place greater emphasis on the priority of KPIs (weighted KPIs) to ensure project operations are not disrupted and KPIs can be successfully achieved.

CONCLUSION

This research discussed the application of the AHP as a method of the decision-making technique to assign a weightage for the dimensions and sub-dimensions derived from the results employing the qualitative approach. A total of 23 experts, as respondents, were shortlisted based on purposive sampling, with pre-determined criteria. However, only 19 experts were agreed to participate in this survey. The selection was based on their knowledge and experience in managing PPP project performance. Further, the results of the main survey generated valuable data for the development of a performance measurement tool, which is the main aim of this research. The prioritisation of the dimensions and sub-dimensions was successfully achieved in accordance with the weight assigned. The priority of the dimensions based on the weightage assigned highlighted the significant impact on the operations of PPP projects. Therefore, the obtained weightings achieved the objective of this research; to determine the relative importance weight for KPIs for the purpose of assessing the operational performance of PPP projects.

REFERENCES

Akbiyikli, R. (2013). Performance assessment of a private finance initiative road project. Transport, 28(1), 11-24.

Akbiyikli, R., Eaton, D., & Dikmen, S. U. (2012). Achieving sustainable construction within private finance initiative (PFI) road projects in the UK. Technological and Economic Development of Economy, 18(2), 207-229

Almarri, K., & Boussabaine, H. (2017). Interdependency of value for money and ex-post performance indicators of Public Private Partnership projects. *Journal of Engineering, Project, and Production Management*, *7*(2), 90–98.

Carlucci, D. (2010). Evaluating and selecting key performance indicators: an ANP-based model. Measuring Business Excellence, 14(2), 66-76.

Carrillo, P. M., Robinson, H. S., Anumba, C. J., & Nasreddine, M. (2006). A Knowledge Transfer Framework : the PFI context A Knowledge Transfer Framework : the PFI context. *Construction Management and Economics*, *(December 2014)*, 37–41.

Cox, R. F., Issa, R. R. A., & Ahrens, D. (2003). Management's perception of key performance indicators for construction. *Journal of Construction Engineering and Management*, *129*(2), 142-151.

Doloi, H. K., & Ma, Z. (2010). Balancing value for money and operational performance of public-private partnerships projects. In: Research Conference: Defining the Future of Project Management, 2010, (pp.1-15). Washington, DC. Newtown Square, PA: Project Management Institute.

Esmatullah, N., Gharouni Jafari, K., Heshmatnezhad, R., & Vahedi, B. (2016). Implementing AHP approach to select an appropriate financing method for PPP highway projects in Iran. International Journal of Structural and Civil Engineering Research, 5(1), 67-73

Garvin, M., Molenaar, K., Navarro, D., & Proctor, G. (2011). Key Performance Indicators In Public-Private Partnerships: A State-of-the-Practice Report. Washington, DC: International Technology Scanning Program.

Hashim, H., Che-Ani, A., & Ismail, K. (2017). Public Private Partnership (PPP) Project Performance in Malaysia : Identification of Issues and Challenges. *International Journal Supply Chain Management, 6*(2), 265–275.

Hashim, H., Che-Ani, A. I., Ismail, K., Isa, H. M., & Wahi, W. (2018). Procedures and Implementation of Defect Management in Malaysian Public Private Partnership (PPP) University Projects. *Malaysian Construction Research Journal (MCRJ), 3*(1), 232–244.

Haponava, T., & Al-Jibouri, S. (2012). Proposed system for measuring project performance using process-based key performance indicators. Journal of Management in Engineering, 28(2), 140-149.

Holman, V. (2009). Developing performance metrics that drive decision making. Retrieved October 12, 2016, from Lifecycle Performance Professionals, http:// www.slideshare.net/victorholman/developing-metrics-that-drive-performance-success

Javed, A. A., Lam, P. T. I., & Zou, P. X. W. (2013). Output-based specifications for PPP projects: lessons for facilities management from Australia. *Journal of Facilities Management,11*(1), 5-30.

Ismail, S. (2009). *Key performance Indicator for Private Finance Initiative in Malaysia.* Universiti Teknologi Malaysia. PhD Thesis.

Ismail, S., & Yusuf, A. M. (2009). Benchmarking the performance of Malaysia's construction industry. *Management Research and Practice, 1*(1), 1-13.

Ismail, K. (2012). A Value for Money Assessment Framework for Public Private Partnership Approach. Universiti Teknologi MARA. PhD Thesis.

Kagioglou, M., Cooper, R., & Aouad, G. (2001). Performance management in construction: A conceptual framework. *Construction Management & Economics*, *19*(1), 85-95.

Khaderi, S. S., & Aziz, A. R. A. (2010). Adoption of Private Finance Initiative (PFI) in Malaysian Public Works Projects: Are We Ready ? *CIB TG72 World Building Congress,* 105–120.

Khalil, N., Kamaruzzaman, S. N., & Baharum, M. R. (2016). Ranking the indicators of building performance and the users' risk via Analytical Hierarchy Process (AHP): Case of Malaysia. Ecological Indicators, 71(2016), 567-576.

Lawther, W. C., & Martin, L. (2014). Availability payments and key performance indicators: Challenges for effective implementation of performance management systems in transportation public-private partnerships. Public Works Management & Policy, 19(5), 219-234.

Li, J., & Zou, P. X. W. (2008). Risk identification and assessment in PPP infrastructure projects using fuzzy analytical hierarchy process and life-cycle methodology. Australasian Journal of Construction Economics and Building, 8(1), 1-15.

Liu, J., Love, P. E. D., Sing, M. C. P., Smith, J., & Matthews, J. (2016). PPP Social Infrastructure Procurement: Examining the Feasibility of a Lifecycle Performance Measurement Framework. *Journal of Infrastructure Systems, (04016041),* 1-12.

Liu, J., Love, P. E. D., Palaneeswaran, E., Regan, M., & Smith, J. (2015). Review of performance measurement: Implications for public–private partnerships. *Built Environment Project and Asset Management, 5*(1), 35-51.

Liu, J., Love, P. P. E. D., Smith, J., Regan, M., & Davis, P. R. (2014). Life cycle critical success factors for Public-Private Partnership infrastructure projects. *Journal of Management Engineering*, 1-7.

Locke, E. A., & Latham, G. P. (2006). New directions in goal-setting theory. Current Directions in Psychological Science, 15(5), 265–268.

Lop, N. S., Ismail, K., & Isa, H. M. (2020). Exploring Private Finance Initiative Implementation Issues in Malaysia Construction Projects: A Way Forward. *Environment Behaviour Proceedings Journal, 5*(S13), 41-46.

Lop, N. S., Ismail, K., & Isa, H. M. (2018). The Execution of Key Performance Indicators in the Operational Phase of PFI Projects in Malaysia. *Asian Journal of Quality of Life, 3*(12), 157.

Lop, N. S., Ismail, K., & Isa, H. M. (2017b). The implementation of key performance indicators in the Malaysian private finance initiative projects. Environment-Behaviour Proceedings Journal, 2(5), 95-104.

Mladenovic, G., Vajdic, N., Wundsch, B., & Temeljotov-Salaj, A. (2013). Use of key performance indicators for PPP transport projects to meet stakeholders' performance objectives. Built Environment Project and Asset Management, 3(2), 228-249.

Mustapa, M., & Carrillo, P. M. (2008). The potential of knowledge management processes for facilitating PFI projects. In: Healthy and Creative Facilities, Proceedings, Facilities Management and Maintenance, CIB W070, 16-18 June 2008, (pp. 1-7). Herriot Watt University, Edinburgh, UK.

National Audit Office (NAO). (2003d). The Operational Performance of PFI Prisons. A Report by the Comptroller and Auditor General, HC 700, Session 2002–2003. London: The Stationery Office.

Neely, A., Gregory, M., & Platts, K. (2005). Performance measurement system design: A literature review and research agenda. International Journal of Operations and Production Management, 25(12), 1228-1263

Ogunsanmi, O. E. (2013). Stakeholders' perception of key performance indicators (KPIs) of public private partnership (PPP) projects. *International Journal of Construction Supply Chain Management, 3*(2), 27-38.

Oyedele, L. O. (2013). Avoiding Performance Failure Payment Deductions in PFI/PPP Projects: A Model of Critical Success Factors. *Journal of Performance of Constructed Facilities, 27*, 259.

Reh, J. (2018b). The Importance of Benchmarking in Improving Business Operations. Retrieved December 2, 2018, from The Balance Carreers: Management and Skills, https: //www.thebalancecareers.com/overview-and-examples-of-benchmarking-in-business-2275114

Sabaei, D., Erkoyuncu, J., & Roy, R. (2015). A review of multi-criteria decision making methods for enhanced maintenance delivery. Procedia CIRP, 37(2015), 30-35.

Saaty, T. L., & Ozdemir, M. S. (2014). How Many Judges Should There Be in a Group? Annals of Data Science, 1(3-4), 359-368

Saaty, T. L. (2008). Decision making with the Analytic Hierarchy Process. International Journal of Services Sciences, 1(1), 83-98.

Saaty, T. L. (1990). How to make a decision: the analytic decision process. European Journal of Operational Research, 48, 9-26.

Saaty, T. L. (1980), The Analytic Hierarchy Process. New York: McGraw-Hill.

Shahin, A., & Mahbod, M. A. (2007). Prioritization of key performance indicators. International Journal of Productivity and Performance Management, 56(3), 226-240.

Smith, M. (2001). *Getting construction back on track. Beyond the bottom line*. The Industrial Pioneer. Birmingham, U.K: Change Magazine.

Toor, S. R., & Ogunlana, S. O. (2010). Beyond the 'iron triangle': Stakeholder perception of key performance indicators (KPIs) for large-scale public sector development projects. International Journal of Project Management, 28(3), 228-236.

UKAS. Public Private Partnership (PPP) Guideline (2009).

Yescombe, E. R. (2007). *Public-Private Partnerships, Principles of Policy and Finance (First Edit)*. England: Elsevier.

Yuan, J., Zeng, A. Y., Skibniewski, M. J., & Li, Q. (2009). Selection of performance objectives and key performance indicators in public–private partnership projects to achieve value for money. *Construction Management and Economics, 27*(3), 253–270.

Yuan, J., Wang, C., Skibniewski, M. J., & Li, Q. (2012). Developing key performance indicators for public-private partnership projects: Questionnaire survey and analysis. Journal of Management in Engineering, 28(3), 252-264.

Yuan, J., Skibniewski, M. J., & Li, Q. (2008). Managing the performance of public private partnership projects to achieve value for money: Key performance indicators selection. In: CIB W112 International Conference on Multi-national construction Projects: Securing High Performance Through Cultural Awareness and Dispute Avoidance, 21-23 November 2008, (pp. 1-16). Shanghai, China.

BIM-BASED PROJECT CONTRACTORS' PERSPECTIVE OF BUILDING INFORMATION MODELING (BIM) USES IN THE BIM EXECUTION PLAN

Wan Nur Syazwani Wan Mohammad[1*], Shahela Mamter[1], Raja Nurulhaiza Raja Nhari[1], Nurhasyimah Ahmad Zamri[1], Hasni Suryani Mat Hasan[1] and Norzaidi Haron[2]
[1]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, Seri Iskandar Campus, 32610 Seri Iskandar, Perak, Malaysia
[2]Sunway Construction Group Berhad, Level 8, Menara Sunway, Jalan Lagoon Timur, Bandar Sunway, 47500 Selangor Darul Ehsan

**Corresponding Email: wannur956@uitm.edu.my*

Abstract
Building Information Modelling (BIM) is an important technology enabler for digital transformation in the construction industry. It is a highly collaborative process that allows architects, engineers, contractors, and other construction professionals to plan, design and construct a building or facility in the form of a 3D model based. Despite the advantages of BIM, the adoption level of BIM among contractors in developing countries, particularly Malaysia, remains lower than expected. This is due to the fact that the contractors have no profound understanding of BIM and its' requirement. Hence, the aim of this paper is to explore the uses of BIM focusing on the planning-to-design stage based on the BIM execution plan from the perspective of the BIM-based project contractors. The data was gathered through semi-structured interview sessions with the six (6) respondents and evaluated using a content analysis approach via the software ATLAS-Ti 9. The findings showed that the planning phase via 4D modelling was remarked as the upmost significant use in the planning-to-the-design stage. The 4D modelling involves time-related information, installation periods and sequences, workflow rescheduling, construction visualization, material optimization, project coordination, and project safety. This study also showed that the PWD DB, PWD203A and PAM2018/2006 contract has been used by the BIM-based project contractors. Thus, the results of the study provide insight into the BIM-based project contractors' that have taken into consideration the uses of BIM for future BIM-based project contractors.

Keywords: *Building Information Modelling (BIM); Uses; BIM-based Project Contractor; Planning; Design stage*

INTRODUCTION

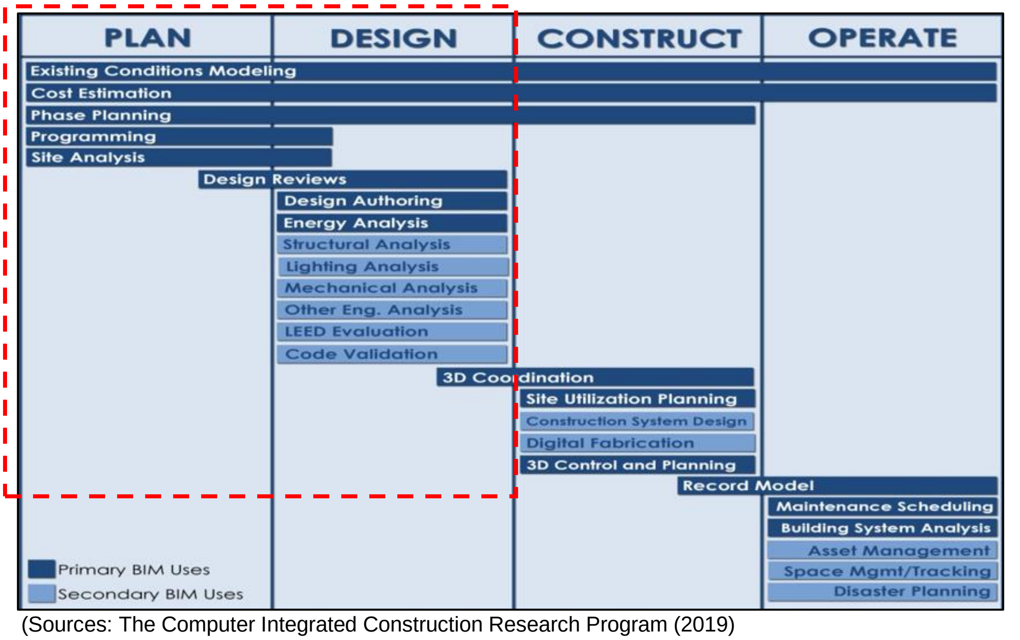
Building Information Modelling (BIM) is a digital repository integrated system that organizes the appropriate building design and project data throughout the building's life cycle (HKIBIM, 2020). Similarly, BIM serves to share knowledge through a digital presentation and forms a reliable basis for decision-making during the entire life-cycle of the project (National Institute of Building Sciences, 2007). Apart from that, BIM is a methodology that would improve the construction players' work performance throughout the project life-cycle (Brahim, 2018). In Malaysia, Building Information Modelling (BIM) is a new shift of information technology (IT) in the construction industry. The BIM wave has also spread tremendously in Malaysia as it is able to generate income through time and cost savings that can be seen in the Cost Performance Index (CPI); earning value over actual cost and Schedule Performance Index (SPI); actual progress over planned progress. One of the Malaysian government's agenda in the 12th National Key Economic Area (NKEAs) is to enhance business growth in the Architecture, Engineering, and Construction (AEC) industry. BIM is also relevant to the Eleventh Malaysian Economic Plan in achieving Vision 2020 as one of the Malaysian National Development Strategy (MyNDS) as it contributes to high impact, rapid execution and implementation, and sustainability (RMK11). The Construction Industry Transformation Program (CITP) 2016-2020 developed four (4) strategic thrusts, and BIM has been emphasized as a productivity-strategic thrust. The purpose of this strategic thrust is that it is beneficial to the construction industry in terms of careful planning and selection before construction begins, which therefore reduces the need for rework and redundancies, thus leading to cost savings (CIDB, 2016). The importance of BIM is continued in Malaysia's current agenda, such as the Construction 4.0 Strategic Plan (2021-2025), where BIM acts as an accelerator in embracing Industry 4.0 (IR4.0) (CIDB, 2020). It is also supported by the Policy Enablers of the Twelfth Plan (Accelerating Technology Adoption and Innovation), which highlights the application of digital technology to create new opportunities in preparing Malaysia to achieve a high technology-based economy (Economic Planning Unit, 2021).

Despite the embracing of BIM by the Malaysian government, sadly the adoption of BIM among contractors is relatively low compared to the other stakeholders in Malaysia. CIDB (2019) revealed that the contractors score showed the lowest percentage of BIM adoption (16%) compared to Architects (19%) and clients and developers (23%). The percentage of adoption level by contractors is stagnant and remains less than 20% (Idrus & Bahar, 2018); (Wan Mohammad et al., 2020). According to Wan Mohammad et al. (2020), the low adoption of BIM among Malaysian Contractors is due to several reasons: 1) having no profound understanding of what BIM is all about and what its requirements are; 2) producing uncertain outcomes and; 3) inability to obtain the benefits offered by BIM. As a result, the BIM uses among BIM-based project contractors are required to reap the advantages and benefits of BIM. Hence, this paper aims to investigate and explore the significant uses of BIM, particularly during the planning to design stage based on the BIM Execution Plan, focusing on the BIM-based project contractors' perspective. To achieve this aim, this paper further discusses the followings; 1) uses of BIM during the planning-to-design stage based on the BIM execution plan; 2) methodology; 3) results and discussions; and 4) conclusion.

USES OF BIM DURING THE PLANNING TO DESIGN STAGE BASED ON THE BIM EXECUTION PLAN

The Computer Integrated Construction Research Program (2019) recommended twenty-five (25) uses of BIM during the planning to maintenance stages. The identification of uses for BIM projects is also dependent on the measurable goals created by the project and company. According to Rojas et al. (2019), the uses of BIM are a set of actions and conditions that are created and associated with a defined objective or application for the construction project. This is also agreed by The Computer Integrated Construction Research Program (2019), which explicated that the use of BIM is a unique task or procedure on a project which can benefit from the integration of BIM into that process.

From twenty-five (25) modelling uses of BIM, there are fourteen (14) uses (shown in Table 1 and Figure 1) that are involved during the planning to design stage based on the BIM execution plan that will be further emphasized in this study. The importance of BIM to be implemented during the planning-to-design stage is required in this study in order to investigate the uses of BIM among contractors. The involvement of the contractor during the earlier stages (i.e., the planning and design stage) contributes a great impact on the entire project, due to the reason whereby most of the information is derived from these stages. This is in line with the McLeamy curve, which enables the identification of the conflicts and errors ahead, thus the project modification can be done at an early stage of delivery (Trach et al., 2019). Furthermore, the involvement with other stakeholders (i.e., Architect, Structural Engineer, and MEP Engineer) enables the prevention of project cost overruns and construction site time delays (Rojas et al., 2019).



(Sources: The Computer Integrated Construction Research Program (2019)

Figure 1. BIM Uses During the Planning to Design Stage in the BIM Execution Plan

Table 1. Description of Uses of BIM During the Planning to Design Stage in BIM Execution Plan

Uses of BIM	Descriptions
Existing Condition Modelling	The development of a 3D model which consists of existing conditions such as site conditions, facilities on site, or a specific area within a facility
Cost Estimation	To generate accurate quantity take-offs and cost estimation throughout the project life-cycle. Furthermore, it aids contractors in quantity and material estimation accuracy, as well as cost control efficiency.
Phase Planning	The development of a 4D model to show the construction sequence, resource allocation, and space requirements on the building and construction site.
Programming	The BIM model serves to analyse space and the complexity of space by using the spatial program.
Site Analysis	The process is to evaluate the properties in a given area, such as to determine the most optimal site location for the next projects.
Design Authoring	The first purpose of the BIM Model is to develop a Building Information Model based on the translation of the building design.
Design Review	The process in which the contractors can review the 3D model and provide feedback to validate multiple design aspects.
Structural Analysis	The development of the 3D model to determine the most effective engineering method based on design specifications.
Energy Analysis Lighting Analysis Mechanical Analysis Other Eng. Analysis LEED Evaluation	The analysis tools from the development of the 3D model for performance simulations to improve the design and facility or energy consumption across the project life-cycle.
Code Validation	The validation software checks the model parameter against the project's specific code.

(Source: The Computer Integrated Construction Research Program (2019); Wan Mohammad et al. (2020))

Procurement is a process of purchasing goods or services from outside companies. The companies can either be sellers or buyers of the product and services (PMBOK, 2008). According to Abdul Rashid et al. (2006) the most frequently construction procurement method in Malaysia is the traditional/conventional method, design and build method, management contracting and construction management. Various sources have come up with procurements where the contractors will be involved in BIM projects (Raja Berema et al., 2023).

Chong et al. (2017) discovered that the procurement contract for BIM is separated into three main phases, which are the pre-construction stage, construction and the post-construction stage. Unfortunately, since the evolvement of BIM in Malaysia, there is an absence of appropriate BIM contracting documents, particularly in the Malaysian construction industry (Abd. Jamil & Fathi, 2018; Kamal Hasni et al., 2019; Teoh et al., 2018). Interestingly, Aina et al. (2021) observed that the Integrated Project Delivery (IPD) has emerged in Malaysia acting as a new procurement method that has a huge settlement in the delivery of BIM-based projects. Hence, Raja Berema et al. (2023) stated that comprehensive systematic reviews were inclined towards identifying the standard form of contract for BIM-based public projects, but they did not dig deeper into the BIM-based project contractors in Malaysia. Accordingly, this gap gave rise to the research inquiry of this study. This research also deviated from past studies by first describing the BIM uses in the BIM execution plan stage (planning-design stage) related to the procurement type in BIM-based project contractors.

METHODOLOGY

The qualitative study design was employed in the form of semi-structured interviews among the BIM-based project contractors in Kuala Lumpur and Selangor. The purpose of the semi-structured interview is to explore the significance of BIM uses during the planning-to-design stages among BIM-based project contractors in Malaysia. Purposive sampling involved six (6) respondents (as shown in Table 3) from various positions, such as BIM Managers, BIM Coordinators, and BIM Executives that was selected. According to Moser & Korstjens (2018), Samsuddin et al. (2017) recommended six to ten respondents for phenomenological directed towards discerning the essence of experience. As a result, six (6) respondents involved in this research were acceptable and reliable. The selection of the respondents was based on the following criteria: 1) acquiring BIM knowledge; 2) experience in BIM-based projects (5 years or above 5 years) and willing to cooperate with the researcher. On the other hand, Saunders et al., (2018) mentioned that the rule of thumb for saturated data and emerging findings is that when it begins to hear similar instances over and over again, there are no further new findings as the data is further collected.

Prior to the interviews taking place, the proper guidelines and protocols are established. For example, the respondents provided an information sheet including open-ended questions (table 2), a briefing of the research, a university permission letter, and ethical issues (including confidentiality) of the interviews. Furthermore, the respondents were also given a copy of questions one week before the interview was held and informed that the interviews were recorded using a recorder and noted by the researchers. In addition, the interview process was held in the respondent’s office, site office, and other places which was convenient and preferable by the respondents to be interviewed. During the interview process, the respondents were asked on their personal information background and previous and current background of BIM-Based projects that they were involved with. Then, the respondents moved on to the main study of this research to explain the significant uses of BIM during the planning-to-design stage. The respondents also took about forty-five (45) minutes to one (1) hour for the interviews. After that, for each interview, follow-ups by phone call were carried out to clarify the unclear points, further feedback, reviews, and comments from the respondents. Nevertheless, this was done by a few of the respondents according to the information that was needed only. ATLAS-ti 9 software-assisted content analysis was utilized to assess the interview findings. Hence, in the next section, the results and discussions from these interviews were explained.

Table 2. Interview Questions

Questions
Section 1:
Q1: What are your responsibilities?
Q2: How long is your experience in the construction industry and BIM-based projects?
Q3: What type of procurement is used?
Section 2:
Q3: What are the significant uses of BIM during the planning to design stage for BIM-based projects?

RESULT AND DISCUSSIONS

The data gathered from the data collection is discussed in the following section. It consists of two sections as captured from the semi-structured interviews (i.e., section 1; respondents' background, and section 2; the significance of BIM uses among the BIM-based project contractors during the planning-to-design stage based on the BIM execution plan stage.

Respondents Background

The six (6) interview sessions with the six (6) respondents were conducted for this research. The respondents involved in this interview were selected based on their designation in the company, years of experience in the construction field, and their usage of BIM in their projects.

Table 3. Respondents Background

R	Designation	Years of Experience in Construction	Years of Experience in BIM-Based Projects
R1	BIM Manager – Senior C&S Engineer	11–20 years	Above five (5) years
R2	BIM Executive – Senior M&E Engineer	11–20 years	Above five (5) years
R3	BIM Executive – Quantity Surveyor	6–10 years	Above five (5) years
R4	BIM Coordinator – Senior Architect	11–20 years	Above five (5) years
R5	BIM Manager – Head BIM Department	11–20 years	Above five (5) years
R6	BIM Executive – Project Manager	6–10 years	Above five (5) years

(Remarks: R – Respondents)

Table 3 shows the respondents' background and indicates that 4 out of 6 respondents (66.7%) have experience in the construction industry for more than ten (10) years, while only two (2) respondents have experience between 6-10 years. Based on the table, it can also be seen that all six (6) respondents (100%) have five (5) years of experience in BIM-based projects. It shows that the data collected is appropriate as 66.7% of respondents have experience of ten (10) years and above in the construction industry (Masrom, 2012: Mohd Nordin et al., 2018) and five (5) years of experience in projects using BIM which shows the respondents are familiar with the BIM concept (Ku & Taiebat, 2011).

Figure 2 shows the network view for BIM uses during the planning-to-design stage. Ten (10) uses of BIM: Phase Planning, Design Review, Cost Estimation, Existing Condition Modelling, Design Authoring, Programming, Structural Analysis, Site Analysis, Energy Analysis, and Lighting Analysis (coded in green) are associated with the BIM uses during the planning to design stages (coded in yellow). From the figure, it can be deduced that these ten (10) BIM uses are significant during the planning-to-design stage from the perspective of BIM-based contractors, while the four (4) uses (i.e., Mechanical Analysis, Other Engineering Analysis, LEED Evaluation, and Code Validation) were insignificant.

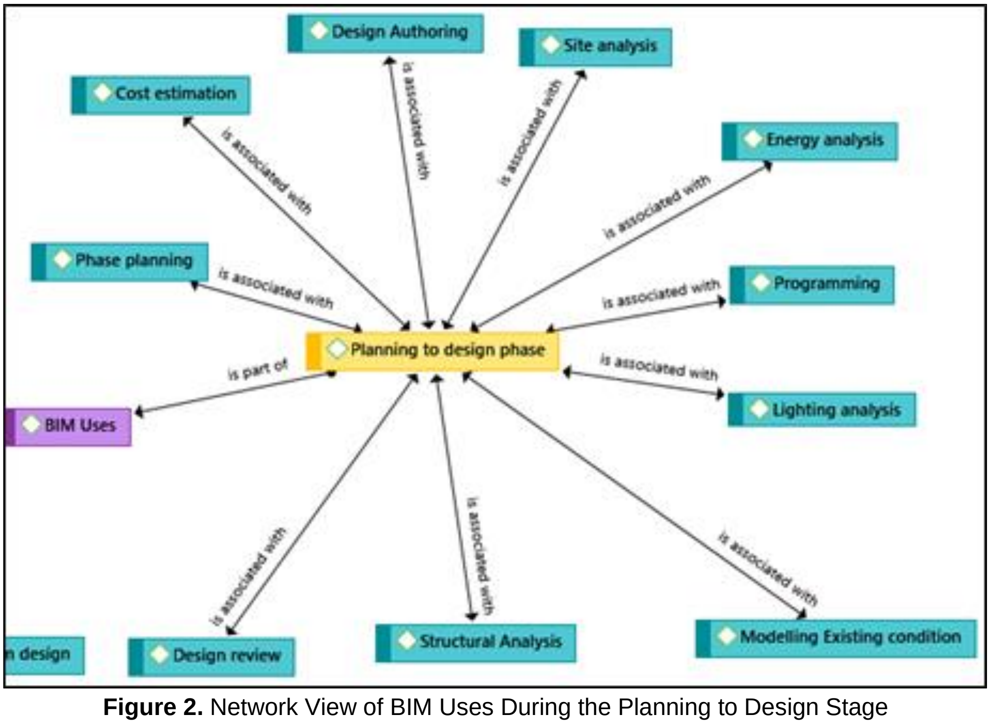


Figure 2. Network View of BIM Uses During the Planning to Design Stage

Table 4 illustrates the interview's findings that a significant understanding of BIM uses based on the BIM execution plan relates to the procurement types concerning the BIM-based project contractors in Malaysia. The most-used standard form applied by the contractors of BIM projects was the PAM contract, propounded by the Pertubuhan Akitek Malaysia (PAM). All respondents mentioned that the procurement contract which has been used were the traditional contract and the design & build contract. For the Design & Build contract, respondents (R1) explained that the uses of BIM utilized during the process of planning to design stage were carried out by the contractors almost in parallel and concurrently with each other. However, the uses of BIM are for tendering public and private projects where the full involvement of the contractors for traditional contracts is mostly after the project is secured. Besides, in traditional contracts, the private client will be closely involved in the planning to construction stage through its BIM team that is technically and commercially resourceful in assessing the recommendations of the BIM manager in taking the necessary actions (R2, R4, R5 & R6). Interestingly, BIM uses in cost estimation are essential during bid preparation for public project (R3).

Table 4. BIM Uses and Procurement Types in BIM-Based Project Contractors

Respondents (R)	The BIM Uses During to Planning-To-Design Stage	Types of Projects	Types of Procurement
R1	Phase planning, programming, design authoring, design review, structural analysis.	Public project (government client-main contractor)	Design & Build contract (PWD DB)
R2	Phase planning, energy analysis & lightning analysis.	Private project (client-main contractor)	Traditional contract (PAM2018 with quantities)
R3	Cost estimation	Public project (government client-main contractor)	Traditional contract (PWD203A)
R4	Existing modelling, phase modelling, programming, design authoring, design review	Private project (client-main contractor)	Traditional contract (PAM2006 with quantities)
R5	Existing Condition Modelling, Cost Estimation Phase Planning, Programming, Site Analysis, Design Authoring, Design Review, Structural Analysis, Energy Analysis.	Private project (client-main contractor)	Traditional contract (PAM2006 with quantities)
R6	Existing Condition Modelling, Cost Estimation Phase Planning, Design Authoring, Design Review, Structural Analysis.	Private project (client-main contractor)	Traditional contract (PAM2006 with quantities)

The following Table 5 shows the percentage of respondents that agree with the use of BIM during the planning-to-design stage. Five respondents (83.3%) agreed that phase planning is the <u>most significant (first-ranked)</u> use of BIM during the Planning Design Stage based on the BIM execution plan.

Table 5. Uses of BIM During the Planning to Design Stages

BIM Uses	Respondents						Frequency	Percentage
	1	2	3	4	5	6		
Existing Condition Modelling				√	√	√	3	50.0%
Cost Estimation			√		√	√	3	50.0%
Phase Planning	√	√		√	√	√	5	83.3%
Programming	√			√	√		3	50.0%
Site Analysis					√	√	2	33.3%
Design Authoring	√			√	√		3	50.0%
Design Review	√			√	√	√	4	66.7%
Structural Analysis	√				√	√	3	50.0%
Energy Analysis		√			√		2	33.3%
Lighting Analysis		√					1	16.7%
Mechanical Analysis							0	0
Other Eng. Analysis							0	0
LEED Evaluation							0	0
Code Validation							0	0

"By applying 4D modelling to our project, it facilitates us to support site personnel and to also efficiently coordinate equipment space requirements compared to the conventional Critical Path Method Network (CPM) and 2D model" ***(R5)***

"Demonstrating 4D modelling to our client during the tender stage helps us to present our construction planning more efficiently" ***(R6)***

"Based on my view, 4D modelling can enhance our construction planning regarding site logistics, site layout traffic, and identification of safety hazards prior to the commencement of construction" ***(R4)***

From the respondents' feedback (R5 and R6), it has been deduced that the planning phase with the appliance of 4D modelling allows BIM-based project contractors to visualize the construction sequence of the projects. The BIM-based project contractors are able to create, review, edit, and simulate the 4D models frequently to obtain a better and more reliable schedule. This is in line with Doukari et al. (2022); Alzarrad et al. (2021); and Rafael Sacks et al. (2018), who revealed that 4D modelling facilitates the BIM-based project contractors to visualize the planning information and assists in understanding the problems associated with the schedules earlier prior to the start of the construction. As revealed by respondent R5, 4D modelling has a great impact on BIM-based project contractors. This implies that the current traditional construction planning method (i.e., using the Critical Path Method Network (CPM)) is not running effectively and affects the project performance parameter (i.e., Time, Cost, and Quality). Moreover, the existing CPM appearance is rather confusing and is not easily understood by the BIM-based project contractors. As such, a complex project may require more effort to replan and redraw the network each time it needs to be updated (Pitake & Patil, 2013). With the aid of the 4D model, facilitates the BIM-based projects to overcome the following: 1) miscommunication of project information, 2) disappointment in project performance due to inappropriate design, 3) improper construction planning, and 4) lack of communication between project teams. Other than that, respondent R4 disclosed that 4D modelling enhances the safety of a construction project. It shows the usage of 4D modelling in assessing, preventing, and detecting safety risks and avoidance from accidents prior to the commencement of construction and throughout the construction process.

The <u>second-ranked</u> BIM use during the planning-to-design stage is design review, with 66.7% agreement from the respondents.

"After the 3D model is completed and designed, we normally use it for design review. As such, during the design coordination meeting, we review the design workflow and design aspects (i.e., design layout, space allocation, and colours)" ***(R4)***

"The design review process enables the project teams, including designers and project owners, to easily collaborate on design and constructability issues prior to the start of the construction" ***(R5)***

The results from respondents R4 and R6 revealed that the use of the BIM model for design review is to obtain feedback and validation from the project team from various aspects. This practice facilitates the project teams to quickly analyse design alternatives and solve the design and constructability issues (The Computer Integrated Construction Research Program, 2019). As a result, this process will assist the project teams in reducing their time in rectifying similar models frequently, thus saving cost and increasing the quality of design. The <u>third, fourth, fifth, sixth, and seventh-ranked</u> BIM usages during the planning-to-design stage are design authoring, cost estimation, existing condition modelling, programming, and structural analysis, with a score of 50% cut-off point agreed by the respondents.

> *"In our projects, we author, create, and build a BIM model in Revit Architectural, and the model becomes a powerful database as all properties, quantities and measures, costs, and schedules are inserted. Furthermore, it facilitates our designer and consultant in producing a good quality model"* ***(R5)***

> *"Currently, we are using the BIM model to extract quantities and to produce a simple cost estimation. It is much easier and quicker compared to traditional cost estimating"* ***(R3)***

> *"With the integration of the BIM model and LiDAR scanner, the project teams are able to capture the existing conditions and existing structural data much faster and digitally"* ***(R6)***

> *"During the process of developing the BIM model by using 3D software, we also apply the spatial program which allocates and analyses the space requirement that is with accordance to the rules and regulations"* ***(R4)***

> *"The BIM model helps us to draw and model our structural details such as bolts and nuts connections, structural jointing as well as generating the structural costing"* ***(R1)***

From the results of respondent R5, it can be construed that the primary use of BIM is design authoring. The developed BIM model has become the main model for other uses of BIM (i.e., cost estimation, structural analysis, 4D model, and other analyses). The BIM-based project contractors have created and designed the 3D model, which consists of component information, parametric information, and other extra information from the supplier's specifications and products. The following use is cost estimation. As mentioned by respondent R3, it is proven that the use of BIM in cost estimation by BIM-based project contractors is crucial in establishing accurate quantity, labor and equipment costs. With the aid of BIM software tools to extract the quantities, it helps to avoid costly mistakes, delays, and double counting. On the other hand, the result from respondent R6 explicated that with the ability of BIM to capture the existing conditions of buildings, sites, and facilities, BIM has transformed the way existing buildings are renovated and innovated. As a result, this process contributes to up-to-date and sustainable documentation with high accuracy of data.

As highlighted by respondent R4, it shows that the use of BIM in programming involves a spatial program that is used to assess the design performance accurately in the form of spatial requirements (The Computer Integrated Construction Research Program, 2019). The use of the BIM model enables to facilitate the BIM-based projects architect to assist and analyse the complexity and uses of space according to the function of the space and facilitates the decision-making process during the design stages. Whilst for structural analysis, as mentioned by respondent R1, it aids the BIM-based project contractors, particularly structural engineers, to simulate the analysis of structural behavior related to the force equilibrium, frame and truss analysis, support reactions, shear force, and bending moment, and concrete, steel, and timber design. Therefore, this process assists them to promote the understanding of the fundamentals of structural analysis through virtual presentation.

The eighth, ninth, and tenth-ranked BIM usages are site analysis, energy analysis, and lighting analysis. These uses of BIM (i.e., site analysis, energy analysis, and lighting analysis) are less mentioned by the respondents (<50%). As such, the use of the BIM model for site analysis with the integration of the Geographic Information System (GIS) is to evaluate the site area and determine the optimum site location for future projects. The use of BIM-GIS in the Malaysian Construction Industry is still at its infant stage, and research on BIM-GIS is currently still ongoing (Wan Abdul Basir et al., 2020). Therefore, the knowledge of understanding BIM-GIS among BIM-based project contractors is also limited. Whereas for energy analysis and lighting analysis, Hussain & Choudhry (2013) revealed that specialist contractors are majorly involved in these uses. Since the sample of this study is limited to BIM-based project contractors, that are mainly targeted for the Malaysian G7 contractors, therefore these uses are less obtaining attention from the respondents. In addition, they disclosed that these uses (i.e., energy analysis and lighting analysis) require highly skilled personnel that are multidisciplined to be applied. The remaining uses of BIM (i.e., mechanical analysis, other engineering analysis, LEED evaluation, and code validation) obtained 0% agreement from the respondents and indicated that these uses of BIM are insignificant for the BIM-based project contractors.

CONCLUSION

This paper presented the findings on the uses of BIM during the planning-to-design stage based on the BIM execution plan from the BIM-based project contractors' perspective. Ten uses of BIM (i.e., Phase Planning, Design Review, Cost Estimation, Existing Condition Modelling, Design Authoring, Programming, Structural Analysis, Site Analysis, Energy Analysis, and Lighting Analysis) have been addressed as significant uses from the BIM-based project contractors' perspective. In relation to that, the respondents pointed out that the planning phase in the form of 4D modelling is the upmost significant use. The 4D model provides a comprehensive site management tool for the BIM-based project contractors during the planning-to-design stage, which enables them to visualize planning, linkages, 3D geometrical models, bar chart schedules, resource requirements, material allocation, and cost breakdown. Apart from that, the extensive use of 4D models using BIM with the safety aspect such as monitoring job site safety and safety planning boosts the powerful tool for construction planning and provides a good impact to the BIM-based project contractors. This study also found that the PWD DB and PAM2018/2006 contract has been used by BIM-based project contractors.

The contributions of this research are twofold. First, its knowledge contributions as extending and improving the existing uses of BIM designed by The Computer Integrated Construction Research Program (2019). Secondly, the output of this research provides a guide for BIM-based project contractors in understanding the uses of BIM as well as achieving the benefits of BIM. This research is in line with the Malaysian National agendas (i.e., Malaysia's National Policy on Industry 4.0, Sustainable Development Goal (SDG 9), the 12th Malaysian Plan Agenda, the Shared Prosperity Vision 2030 and the Construction 4.0 Strategic Plan

(2021-2025), which highlights in embracing the digital technologies to reduce uncertainty, promote quality, improve safety and timely delivery of completed construction products.

REFERENCES

Abd Jamil AH, Fathi MS (2020) Enhancing BIM-based information interoperability: Dispute resolution from legal and contractual perspectives J. of Const. Engineering and Management 146 (7)

Abdul Rashid, R., Taib, I.M., Ahmad, W.N.W, Nasid, M.A., Ali, W.N.W., and Zainordin, Z.A. (2006). Effect of Procurement Systems on the Performance of Construction Projects. Conference on Construction Industry, Padang, Indonesia.

Alwee SN, Salleh H, Zulkifli UK (2021) Strategic process protocol for building information modeling (BIM) contract administration in malaysia–a concept paper Malaysian Construction Research J. (MCRJ) 37-52.

Alzarrad, M. A., Moynihan, G. P., Parajuli, A., & Mehra, M. (2021). 4D BIM Simulation Guideline for Construction Visualization and Analysis of Renovation Projects: A Case Study. *Frontiers in Built Environment*, *7*(March), 1–10.

Brahim, J. (2018). *Development of Migration Path Model of BIM for Construction Professional*. Universiti Tun Hussein Onn Malaysia (UTHM).

Chong, H. Y., Fan, S. L., Sutrisna, M., Hsieh, S. H. and Tsai, C. M. (2017). "Preliminary 450 Contractual Framework for BIM-Enabled Projects." Journal of Construction Engineering 451 and Management, 143(7), pp. 1-8.

CIDB (2016). Construction Industry Transformation Programme (CITP) 2016-2020. In *Construction Industry Development Board Malaysia*. https://doi.org/10.11113/jt.v78.4056

CIDB (2019). *Malaysia Building Information Modelling Report*.

CIDB (2020). Construction 4.0 Strategic Plan (2021-2025). *Construction Industry Development Board (CIDB)*.

Doukari, O., Seck, B., & Greenwood, D. (2022). The Creation of Construction Schedules in 4D BIM: A Comparison of Conventional and Automated Approaches. *Buildings*, *12*(8).

Economic Planning Unit. (2021). Twelfth Malaysia Plan (2021-2025). In *12th Malaysian Plan*.

Hasni, M. I. A.K., Ismail, Z., & Hashim, N. (2019). Contractual Aspects in the Utilisation of Level Two Building Information Modelling (BIM) within Malaysian Public Construction Projects. MATEC Web of Conferences, 266, 05002. https://doi.org/10.1051/matecconf/201926605002

Hussain, K., & Choudhry, R. (2013). Building Information Modeling (BIM) Uses Applications in Pakistan Construction Industry. *Proceedings of the 13th International Conference on Construction Applications of Virtual Reality*, *October*, 30–31.

Idrus, A., & Bahar, N. (2018). *Level of Implementation of Building Information Modelling (Bim) Among Construction Contractors*. *Febuary*, 53–55.

Ku, K., & Taiebat, M. (2011). BIM experiences and expectations: The constructors' perspective. *International Journal of Construction Education and Research*, *7*(3), 175–197.

Masrom, M. A. N. (2012). *Developing A Predictive Contractor Satisfaction Model (CoSMo) For Construction Projects*. Queensland University of Teachnology.

Moser, A., & Korstjens, I. (2018). Series: Practical guidance to qualitative research. Part 3: Sampling, data collection and analysis. *European Journal of General Practice*, *24*(1), 9–18. https://doi.org/10.1080/13814788.2017.1375091

National Institute of Building Sciences. (2007). National BIM Standard - United States ™ Version 2 - Chap.5 (+CMM). *Nbims-Us*, 182. www.nationalbimstandard.org/nbims-us-v2/pdf/NBIMS-US2_aB.pdf

Nordin, Mohd, E Latip, E M Ahmad Zawawi, Z. I. (2018). Opportunities for corruption across Flood Disaster Management (FDM). *IOP Conference Series: Earth and Environmental Science*.

Pitake, S. A., & Patil, P. D. S. (2013). Visualization of Construction Progress by 4D Modeling Application. *International Journal of Engineering Trends and Technology (IJETT)*, *4*(7), 3000–3005.

PMBOK (2008). Project Management Body of Knowledge. ISBN: 978-1-62825-664-2. 7th Edition.

Rafael Sacks; Charles Eastman; Chang Lee; Paul Teicholz. (2018). *BIM Handbook* (Third Edit). Wiley.

RK Raja Berema, Z Ismail, J Brahim, NA Nordin (2023). A Systematic Review of Existing Standard Form of Contract for Building Information Modeling (BIM) Public Projects in Malaysia. IOP Conf. Series: Earth and Environmental Science 1217 (2023) 012006 doi:10.1088/1755-1315/1217/1/012006.

Rojas, J., Herrera, R. F., Mourgues, C., Ponz-tienda, L., Pellicer, E., & Alarc, L. F. (2019). *BIM Use Assessment (BUA) Tool for Characterizing the Application Levels of BIM Uses for the Planning and Design of Construction Projects*. *2019*.

Samsuddin, N. M., Takim, R., & Nawawi, A. H. (2017). Human Behaviour and Resilience Hospital. *Asian Journal of Behavioural Studies*, *2*(5), 21.

Teoh Ming Jo, Siti Salwa Mohd Ishak, Zul Zakiyuddin Ahmad Rashid (2018) Overview of the Legal Aspects and Contract Requirements of the BIM Practice in Malaysian Construction Industry. MATEC Web of Conferences 203, 02011 (2018) https://doi.org/10.1051/matecconf/201820302011 ICCOEE 2018.

The Computer Integrated Construction Research Program. (2019). *BIM Project Execution Planning Guide, Version 3.0*.

The Hong Kong Institute of Building Information Modelling (HKIBIM) - Home. (2020). https://www.hkibim.org/index.php?mid=1

Trach, R., Polonski, M., & Hrytsiuk, P. (2019). Modelling of Efficiency Evaluation of Traditional Project Delivery Methods and Integrated Project Delivery (IPD). *IOP Conference Series: Materials Science and Engineering*, *471*(11).

Wan Abdul Basir, W. N. F. A., Ujang, U., Majid, Z., Azri, S., & Choon, T. L. (2020). The integration of bim and gis in construction project - A data consistency review. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *44*, 107–116.

Wan Mohammad, W. N. S., Abdullah;, M. R., Ismail;, S., & Takim;, R. (2020). An Exploratory Factor Analysis (EFA) of Building Information Modelling Uses Towards Bim Adoption for BIM-Based Projects: Contractors Perspective. *Journal of Critical Reviews*, *7*(5), 101–108.

A MODEL FOR ASSESSING THE COMPETENCY OF FACILITY MANAGERS IN PRE-CONSTRUCTION HOSPITALS IN MALAYSIA

Norsyazwana Jenuwa[1*], Wan Norizan Wan Ismail[1], Norhafizah Yusop[1], Siti Sarah Mat Isa[1] and Mohd Saidin Misnan[2]
[1]Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610, Seri Iskandar, Perak, Malaysia
[2]Department of Quantity Surveying, Faculty of Built Environment, Universiti Teknologi Malaysia, Skudai, Malaysia

**Corresponding Email: syazwana@uitm.edu.my*

Abstract
This study was conducted to develop a model for assessing a facility manager's competency in a complex construction project such as a hospital construction. The involvement of a facility manager during the construction phase is highlighted as a means to reduce operating costs for the building in the long run. The study examines the relationship between facility managers' competence with six relevant competencies namely leadership and strategy, finance and business, operation and maintenance, communication, human factors, and real estate management. The data were analysed using the analysis technique of Modelling Structured Equations Partial Smallest Square Estimation (SEM-PLS). This statistical software assesses the psychometric characteristics of model measurements and estimates the parameters of structural models. A total of 262 respondents from the facility and construction fields participated in the study. The results show that only the null hypotheses (H0) for competencies in leadership, finance, and business were rejected. The null hypothesis for other competencies namely operation and maintenance, communication, human factors, and real estate management were accepted. This paper is the first in its category to relate a competent facility manager with relevant competencies such as leadership and strategy, finance and business, operation and maintenance, communication, human factor, and real estate management. The model developed in the study would assist Human Resource professionals to design more effective training programs and to make more effective recruitment processes.

Keywords: *Competent Facility Manager; Assessment of Competency; Probability of Success*

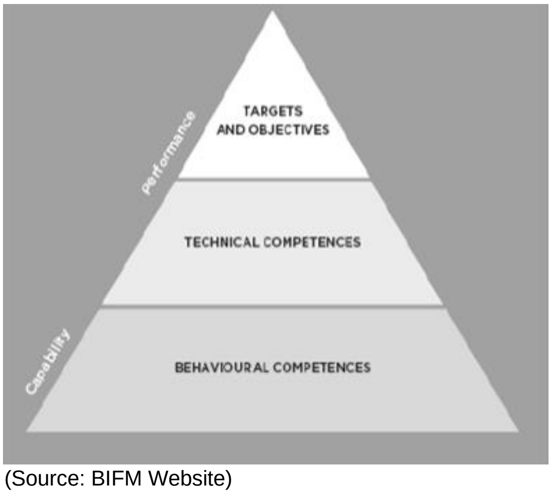
INTRODUCTION

Facility management (FM) is a discipline that assists an organization in efficiently providing its primary business, (IFMA, 2003). FM is a profession that offers a range of services to assist a company's main line of business. It is responsible for overseeing the services needed for any structures, machinery, furnishings, or other items that could aid businesses in competing in a dynamic environment (Nordiana et al., 2016). Facility managers and stakeholders involved in the building process must consider the long-term implications of construction choices. Balancing initial construction costs with future operational expenses is essential for creating buildings that are both cost-effective and conducive to occupants' needs and comfort over time. Effective facility management strategies that integrate considerations for both construction and ongoing operations can significantly impact a building's lifecycle cost and overall success (Potkany, 2015).

Competency research gained steam after it was established that competency was a more important differentiator for success than intelligence (McClelland, 1973). The idea of competency has been employed more and more over the past forty years in a variety of private and public sector organizations to hire successful human resources, utilize them to their fullest potential, and create effective plans for gaining an advantage in a cutthroat business environment. Compelling definitions of competency have been offered by experts in human resources over time and from many angles. While the majority of these classifications are based on performers' fundamental characteristics, some are based on observable performances or outcome quality (Hoffman, 1999). The cost-effectiveness of operating a building is significantly impacted by various factors involved in the building process. These factors include the materials utilized during construction and the design choices made to ensure not only immediate functionality but also long-term sustainability and safety for future occupants (Potkany, 2015).

FACILITY MANAGEMENT IN MALAYSIA: STANDARD AND CURRENT PRACTICE

The FM discipline is still relatively new in Malaysia. Norafiziah and Zairul (2017) claimed that the lack of a specialized entity to provide norms and control over the quality and performance of FM practice is the root of the difficulties in analysing FM in Malaysia. Because there is no reliable framework that can be used to compare the effectiveness of FM methods, comparisons cannot be made. Due to this conundrum, it is challenging to identify real FM professionals from whom necessary knowledge and abilities may be obtained. Since it is impossible to determine the knowledge and competencies that are acceptable for the industry and professions of FM, it is also difficult to construct a (structured) FM standard. Professional organizations like IFMA and BIFM and MAFM have adopted the competency framework as the foundation for professional accreditation in the field of FM (Nordiana et al, 2016).



(Source: BIFM Website)

Figure 1. BIFM Professional Standard Pyramid

According to BIFM (2010), the technical competencies included in the Professional Standards reflect what employees do in their work and the standards they are required to uphold constantly, as seen in Figure 1. The underlying behavioral skills describe the desirable traits and behaviors for success in the workplace. FM essential skills have been established by the International Facility Management Association (IFMA, 2010), which also accredits FM academic programs globally.

Figure 2 lists them in the following order: Communication, Business continuity planning, Emergency preparedness, Environmental stewardship, Finance, Human factors, Leadership, Operations and maintenance, Project management, Quality, Real estate and property management, and Technology.

(Source: IFMA, 2008)

Figure 2. IFMA 11 Core Competency Circle

The core competency of facility managers is to identify and consult defects which is appropriate to the competency of sustainability, where the facility managers must be able to preserve the environment and the people who use their facilities while also enhancing organizational effectiveness and reducing risks and liabilities, which are well suited for the study's keywords. In all phases of facility planning, design, construction, and management, the facility manager is required to assess the overall environmental impact of the facilities as early as it is practically possible. They are also supposed to adhere to and carry out rules and guidelines for maintaining, safeguarding, and repairing structures, grounds, ecosystems, and the environment.

Five areas of FM capabilities were identified by Seong et al. (2017) and Mariah (2012), which are financial control and change management, support, user engagement, and maintenance operations. According to Mariah's research, there is an overall level of efficiency, which is crucial for facility management. These results could be used to improve Malaysian facility managers' associated training modules for sustainable development, as well as to help management organize and plan the facility managers' training requirements for carrying out facility management tasks. They also learned that the management had made a decision based on this finding that only people with this level of competency could handle tasks related to facility management.

The competency and proficiency of a facility manager are pivotal in ensuring the effective functioning and maintenance of a building. Facility managers hold a comprehensive role encompassing various responsibilities crucial for the optimal operation of a facility. Competent facility managers possess a diverse skill set that includes leadership, communication, problem-solving, technical knowledge about building systems, regulatory compliance, financial acumen, and strategic planning abilities. They play a crucial role in ensuring the smooth functioning of a building, meeting the needs of its users, and effectively managing resources to maintain the facility's longevity and efficiency (Syahrul et al., 2017).

Previous studies have shown that the varied approaches used by civilizations to foster leadership and organizational success have been significantly influenced by heterogeneity during the course of social evolution. According to Nordiana et al. (2016), the International Facility Management Association's (IFMA) guidelines and standards are broken down into eight categories which include real estate, planning, budgeting, space management, interior planning, interior installation, architecture or engineering services, and building maintenance and operations.

Table 1. Barriers in Implementing Competency Facility Manager by Past Researchers

Competency	Barriers in Implementing for Competency Facility Manager by Past Researchers										Total
	Hariati A.H., & Maimunah S. (2019)	Mariah A. & Mohammed, A. H., Maimunah S. (2014)	Nor Diana (2017)	Potkany (2015)	Jim Curtis (2017)	Nethmin (2016)	Oladejo (2015)	Dubem Ikediaski (2015)	Floren Yean (2014)	Cheng Peng (2017)	
Leadership and Strategy	x	x	x	x	x	x	x	x	x	x	10
Finance and Business	x	x	x	x		x		x	x	x	8
Operation and Maintenance	x	x	x	x	x	x	x	x	x	x	10
Communication	x	x	x		x	x			x	x	7
Human Factor	x	x			x	x	x	x	x		7
Real Estate Management	x	x	x	x	x			x	x	x	8

Based on past studies, much emphasis has been put on leadership competency and strategy, communication competency, operational and maintenance competency, and business continuity competency.

HYPOTHESES

To establish a facility manager's competence in relation to the competencies of leadership and strategy, finance and business, operation and maintenance, communication, human factor, and real estate management, six hypotheses were formulated:

i. Hypothesis 1: Leadership and strategy competence has a relationship with the competency of the Facility Manager
ii. Hypothesis 2: Communication competence has a relationship with the competency of the Facility Manager
iii. Hypothesis 3: Operational and maintenance competence has a relationship with the competency of the Facility Manager
iv. Hypothesis 4: Human factor competence has a relationship with the competency of the Facility Manager
v. Hypothesis 5: Real estate management competence has a relationship with the competency of the Facility Manager
vi. Hypothesis 6: Finance and business competence has a relationship with the competency of the Facility Manager

RESEARCH METHODOLOGY

Building and facility management is complex because buildings and facilities are significant parts of valuable fixed assets for most organizations. Pay attention to the complexity of the task, and the competence of the facility manager. Generally, experienced facility managers can provide the services required by the organization or customers, at a satisfactory level ensuring that all tasks are done efficiently to provide excellent building performance.

This research adopted a quantitative method in order to achieve the research aim and objectives. The data collection was conducted in two stages, starting with a questionnaire survey followed by semi-structured interviews. The participants in the study were facility managers, architects, engineers, and quantity surveyors in the Klang Valley especially where the respondents work in hospital construction projects. The respondents for this study are usually involved and responsible for making decisions for the best procurement for building construction, especially the construction of hospitals. The data collection started by sending out 500 questionnaires to the targeted populations. This questionnaire survey was conducted by posting and distributing the questionnaires directly to the respondents. A total of 262 respondents completed and returned the questionnaires to the researchers.

Table 2. Guidelines Used for Structural Model-Inner Model

No	Structural Model-Inner Model Criteria	Guidelines
1	Coefficient determination (R^2) for endogenous variables	When value: 0.25 - large 0.13-moderate; And 0.02-less (Cohen, 1988) When value: 0.67-large 0.33-moderate; And 0.19- less (Chin, 2010) When value: 0.75-large 0.50-moderate; And 0.25- less (Hair et al, 2014)
2	Path coefficient (β)	The value of the coefficient for path coefficient is as follows: 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)
3	Effect size (f^2)	When value: 0.35-big impact 0.15-moderate effect and 0.02-small effect
4	Relative impact (q^2)	When value: 0.35-large 0.15-moderate and 0.02-weak

(Source: Ramayah, 2018)

Important criteria used for the structural model-inner model are composed of coefficient determination or R^2 for endogenous variables, estimated value path coefficient or β, effect size or f^2, predictive relevance or Q^2, and relative impact or q^2. The results of the evaluation of the structural model were obtained after analysis using Smart PLS 3.0 software through the Bootstrapping function was conducted. Table 2 shows the guidelines used for the structural model-inner model.

To obtain the value of R^2 and path coefficient (β), the SEM-PLS model was analysed using a bootstrapping approach generated from 500 samples from 262 cases to obtain the standard error value, t-statistical value, and test significant levels to determine the evaluation criteria of this structural model.

ANALYSIS OF DATA AND DISCUSSION OF FINDINGS

Out of 262 respondents, 208 (79.4%) were facility managers,39 (14.9%) were architects, 9 (3.4%) were engineers, and 6 (2.3%) were quantity surveyors.

To assess the influence of a variable, the R^2 Value is used against a leaning pendant variable by measuring the degree of correlation strength of both variables. When the R^2 value is high, it means that the forecast of the model has increased capabilities and thecloser the value is towards a strong value angle.

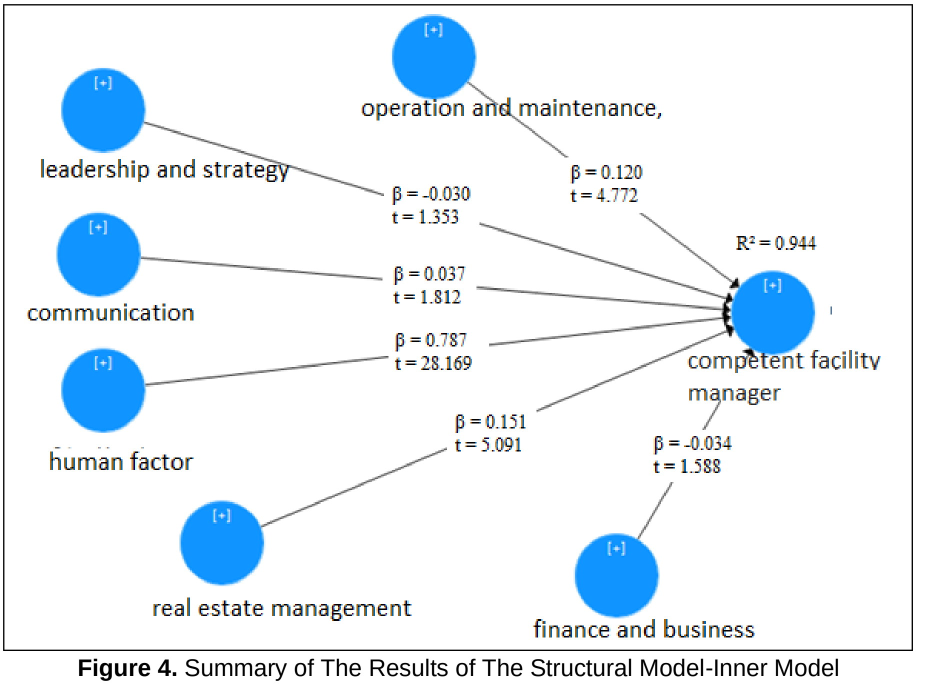


Figure 4. Summary of The Results of The Structural Model-Inner Model

As portrayed in Figure 4, the R^2 value of this structural model was 0.944. According to Cohen (1988), the R^2 value of the endogenous variable is evaluated from the following angle where the value 0.25 is strong; 0.09 is moderate and 0.01 is weak. Thus, the R^2 value of 0.944 is considered strong.

To test the hypothesis that has been proposed, the level of importance of each independent variable was checked. The determination of whether the proposed hypothesis is accepted or rejected depended on the t-statistical values of the structural model. The summary of whether the proposed hypothesis was rejected or accepted is shown in Table 3. If the level of interest falls between 0.1 or 10% two-tailed or when the t-statistic value is above 1.645 and and p exceeds 0.1, the hypothesis is accepted otherwise, the hypothesis is rejected.

Table 3. The Results of The Analysis of Hypothetical Testing

Hip.	Relation	Path Koefision (β)	Standard Error	Value of t-statistics	Result
H1	Human Factors > Competency of Facility Manager	0.787	0.028	28.169**	Accepted
H2	Communication > Competency of Facility Manager	0.037	0.022	1.812**	Accepted
H3	Real Estate Management > Competency of Facility Manager	0.151	0.021	5.091**	Accepted
H4	Operation and Maintenance > Competency of Facility Manager	0.120	0.021	4.772**	Accepted
H5	Finance and business > Competency of Facility Manager	-0.034	0.025	1.588	Rejected
H6	Leadership and strategy > Competency of Facility Manager	-0.030	0.03	1.353	Rejected

**Note: The value of t-statistics should exceed 1.645 where p>0.10

According to Table 3, of the six main factors of competency for facility managers, only four factors recorded a band coefficient value of more than 0.1, whilst the other two factors, finance and business; and leadership and strategy competencies recorded band coefficients below 0.1, which are -0.033 and -0.035 respectively. This is aligned with the study conducted by Dubem Ikediashi et al. (2015) that mentioned a competent facility managers prioritize the well-being of the people in the facility. This includes ensuring a safe and comfortable work environment, managing ergonomic considerations, and addressing any health and safety concerns. The findings have significantly aligned with study by Hariati et al. (2019); Syahrul Nizam and Nik (2017). As supported by Florence (2011), the competency of a facility manager is intertwined with their ability to understand and manage the human factor within a facility and to communicate effectively with a diverse set of stakeholders. Human factors often lead to conflicts or disputes in a workplace. A skilled FM should be adept at resolving conflicts, promoting a harmonious work environment, and ensuring that the facility meets the diverse needs of its occupants. According to Hariati et al. (2019), FMs need to understand the needs and expectations of the occupants of a facility. This involves effective communication and engagement to identify and meet user requirements, creating a positive experience for everyone in the facility. Competent FMs maintain accurate and up-to-date documentation to facilitate smooth operations and decision-making Potkany et al. (2015). Proper documentation of facility-related information and procedures is essential. This includes maintenance records, safety protocols, and communication logs. By prioritizing the well-being of occupants, resolving conflicts, and maintaining clear and open lines of communication, a skilled FM contributes significantly to the overall success and efficiency of the facility.

Overall, the results of the analysis show that H1, H2, H3, and H4 were accepted, while H5 and H6 were rejected. In addition, out of these six competencies, human factor competencies are strong predictors or have a strong relationship with the competency of the facility managers followed by real estate management competencies, operational and maintenance competencies, and lastly the communication competency.

CONCLUSION

In conclusion, out of the six main factors of the facility manager's competency tested only four factors were accepted and another two were rejected. The quantitative values of competency levels of different performers in different tasks or activities, assessed from the relation, would be useful for all organisations to manage and develop the performance of their human resources more effectively by designing training programs, non-training interventions, and recruitment processes.

REFERENCES

BIFM. (2010). Homepage of British Institute of Facilities Management.

Cheng P., Azlan S. A. and Faizah A. (2017), Competency and Commitment of Facilities Managers: Keys to Safeguard Maintenance Performance, *Malaysian Construction Research Journal, 2*: 115-136.

Chin, W. W. and Dibbern, J. (2010), "An introduction to a permutation based procedure for multigroup PLS analysis: results of tests of differences on simulated data and a cross cultural analysis of the sourcing of information system services between Germany and the USA", in Esposito, V.V., Chin, W.W., Henseler, J. and Wang, H. (Eds), *Handbook of Partial Least Squares: Concepts, Methods and Applications, Springer, Berlin*, 171-193.

Cohen, J. (1988), Statistical Power Analysis for the Behavioral Sciences, NJ, Lawrence Erlbaum, Mahwah.

Dubem Ikediashi, Anyiekere M. Ekanem (2015), "Outsourcing Of Facilities Management (FM) Services In Public Hospitals", *Journal of Facilities Management*, 13: 85-102.

Florence Yean Yng Ling, Weiyan Toh (2014). "Boosting Facility Managers' Personal And Work Outcomes Through Job Design", *Facilities*, 32(13/14): 825 – 844

Florence (2011). An Empirical Analysis of Asset Replacement Decisions and Maintenance Culture in Some Government Organizations Located in Ogbomoso and Ilorin Metropolis as Case Study. *Journal of Management and Society*, 1(3): 01-09.

Hair, J. F., Hult, G. T. M., Ringle, C. M. and Sarstedt, M. (2014), A Primer on Partial Least Squares Structural Equation Modeling, Thousand Oaks, CA. Sage.

Hariati A. H., & Maimunah S. (2019), Strategic Facilities Management Functions For Public Private Partnership (PPP) Healthcare Services In Malaysia, *Journal of The Malaysian Institute of Planners*. 17(1): 35-47.

Hoffmann, T. (1999). The Meaning of Competency. *Journal of European Industrial Training*, 23(6), 275-285.

International Facility Management Association (2003), Facts about the International Facility Management Association, available at: www.ifma.org

Mariah A. & Mohammed A. H. (2012). Facility Management Competencies in Technical Institutions, Procedia - Social and Behavioral Sciences, Volume 65, 3 December 2012, Pages 755-760

Mariah A. & Mohammed A. H., Maimunah S. & Mohd S. A. R., (2014), Requisite Facilities Management Competencies For Sustainable Development At Higher Education Institutions, Journal of Sustainability Science and Management, 9(2): 71-89.

McClelland, D. C. (1973). Testing for Competence Rather Than for Intelligence. American Psychologist, 28(1), 1-14.

Nordiana., M.I., Syahrul., N.Z., Othman., M., Aini., J., & Asra Z.A. (2016), Facilities Management Practices in Malaysia: A Literature Review, MATEC *Web of Conferences* 66, 00054.

Norafiziah and Zairul (2017) Defining the Current Practice of Facilities Management Service Delivery in Klang Valley (KV) Shopping Centres, Journal of Surveying, Construction and Property (JSCP), Volume 8, 2017 Issue 1

Oladejo, E. I., Umeh L. O. and Egolum C. C., (2015), "The Challenges Of Healthcare Facilities Maintenance In Tertiary Hospitals In South East Nigeria", *International Journal of Civil Engineering Construction and Estate Management*, 3: 1-6.

Potkany M., Vetrakova M., and Babiakova M., (2015) "Facility Management and Its Importance in the Analysis of Building Life Cycle,.", *Procedia Economics and Finance* 26: 202 – 208.

Ramayah, T. (2018), - *Partial Least Squares Structural Equation Modelling (PLS-SEM) using SmartPLS 3.0*, 2nd Edition. Pearson Malaysia.

Seong et al. (2017), Effects of the Self-Directed Individualized Education Program on Self-Determination and Transition of Adolescents With Disabilities, Career Development and Transition for Exceptional Individuals 38(3):132-141.

Syahrul Nizam Kamaruzzaman and Nik Elyna Myeda (2017), Developing facilities management (FM) competencies for Malaysia Reference from international practice, Journal of Facilities Management, Vol.16 No.2, 2018, pp.157-174

eISSN 2590-4140

9 772590 414000