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Systematic literature review on green maintenance principles and maintenance performance indicators for green buildings design

Systematic Literature Review on Green Maintenance Principles and Maintenance Performance Indicators for Green Buildings Design

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The UNEP Emissions Gap Report 2020 highlighted buildings and cities as one among six sector solutions for climate change through enhanced energy efficiency and carbon reduction. A good performing green building is seen as a solution for energy efficiency and environmental protection, but performance of green building is largely affected by maintenance management. Studies have suggested that green buildings might not be performing as intended. While maintenance management has been widely researched, green maintenance performance has rarely been studied. Hence, a systematic literature review was conducted on the integration of green maintenance principles into maintenance performance indicators for green buildings. This review was based on the publication standard, namely RepOrting Standards for Systematic Evidence Syntheses (ROSES) and integrated multiple research designs. Two leading databases (Web of Science and Scopus) were utilized. Based on the data, for green maintenance principles and performance indicators, 4 main aspects were established, namely environment, economy, technical and social with 5 green maintenance principles. For green maintenance performance, 11 green maintenance indicators and 25 sub-indicators were identified. This study has offered significant contribution to the body of knowledge on this topic. The findings explained the importance of integrating green maintenance principles into maintenance performance for green building to ensure desired maintenance performance, as follows: 1) to encourage green building managers to realise their role in maintenance performance; 2) to plan integration strategies according to the desired maintenance performance; and 3) to inform on the knowledge gap existence on specific areas and future studies suggestions.

Keywords: *Green Buildings, Green Maintenance Performance, Green Maintenance Principles, Maintenance Management, Indicators, Systematic Literature Review, Design.*

1. INTRODUCTION

Year 2015 became a turning point in global efforts to transform the social and economic development into a more sustainable activity after decades of attempts to become climate neutral. On 12 December 2015, during the United Nations Framework Convention on Climate Change (UNFCCC), Conference of the Parties (COP) 21 in Paris, Malaysia was one of the signatory countries among 196 countries that adopted the Paris Agreement, where they committed to achieve below 2 degrees Celsius global temperature rise, preferably to 1.5 degrees Celsius (United Nations, 2015).

The UNEP Emissions Gap Report 2015 notes that to close the gap, enhanced energy efficiency in buildings, industry and transport, and increased renewable energy, are essential (UNEP, 2015). Moreover, the UNEP Emissions Gap Report 2020 highlighted buildings and cities as one among six sector solutions for climate change. According to the report, by 2030, buildings will account for 12.6 gigatons (Gt) of energy-related emissions but 70% of the infrastructure has yet to be built. Hence, by mandating the building sector to be fit for low-carbon age and retrofitting the existing infrastructure, up to 5.9 Gt emissions could be potentially reduced.

Consistent with the commitment made in 2015, the 'Green Growth' agenda with consideration of all the three bottom lines of sustainable development (economic, social and environment) is given a priority in the Eleventh Malaysia Plan, 2016-2020 (RMK11) (EPU, 2015). One of the strategies includes the green building revolution.

The focus on green building for achieving the outcomes are due to the fact that the largest potential for significantly reducing greenhouse gas emissions is through the building sector compared to other major emitting sectors (Baynes et al., 2018; Herazo & Lizarralde, 2015; Lemmet, 2013; Rock et al., 2019; Xu et al., 2021). Globally, the building sector accounts for 32% of energy consumption and 19% of energy-related greenhouse gas emissions (IEA, 2015; Xu et al., 2021). Without intervention to improve buildings' energy efficiency, most likely the negative impacts to the environment will continue because reports posit that global energy consumption in the building sector will double or triple by 2050 (Xu et al., 2021). Thus, a good performing green building is seen as a solution for energy efficiency and environmental protection.

It is crucial for building managers to pursue efficient and green post-occupancy operations and maintenance, even though green buildings are built to be green (Chew et al., 2017; Lu et al., 2018; Olanrewaju, 2011; Retno et al., 2021;Mohammad et al., 2014).

Other than the negative environmental aspect, from an economic point of view, costs of operations and maintenance contribute significantly to total costs of a building throughout its lifecycle, up to five or seven times higher compared to the initial construction cost (Hosseini et al., 2018). Maintenance costs have always been seen as a burden and common issue in construction projects (Au-Yong et al., 2016; Chew et al., 2004, 2017; Galar et al., 2017; Geekiyanage & Ramachandra, 2020; Straub, 2009). However, previous research suggests that it is crucial to embrace green concept from early stages such as design and planning to improve the performance of green buildings (Ajukumar & Gandhi, 2013; Kang et al., 2013; Means, 2011; Rocha & Rodrigues, 2017).

Another issue that needs to be noted is the number of certifications of green buildings. According to GBI (2021) as of 31 March 2021, 983 buildings registered for rating, but less than 16% (157 buildings) have been certified and only 21 buildings (13%) out of the final certification have been awarded renewal certifications. These numbers suggests that the intended green buildings did not fit the sustainable criteria of green building. Furthermore, this low number of certifications depicts an issue in ensuring the sustainability of the green building. This would hinder the effort or actions taken to minimise the building sector's effect with focus on the three bottom lines (environment, economy, social). Thus, this urgent need for energy conservation and reduction of greenhouse gas (GHG) emissions in the building sector shows how crucial green maintenance needs to be implemented for green buildings to ensure buildings' energy efficiency.

For supporting the green building revolution, the stakeholders or professionals involved in the green construction or building sectors require the latest information and trends to assist in making informed decisions on greener buildings. However, based on the initial literature review conducted, studies on relationship of green maintenance principles and performance are almost non-existent. Currently there are limited studies about green strategy in relation to operation and maintenance of green buildings (Ibrahim et al., 2019; Zhang et al., 2017; Chew et al., 2017). According to

Franciosi et al. (2020), although there is an increase in interest relating to maintenance impact on sustainability, only few studies have studied and proposed sustainability performance measuring indicators and maintenance impact. Most of the papers found are related to sustainable development particularly construction and green building certification. There seem to be lack of scientific knowledge in the topic of maintenance strategy or approach for green building. It was found that there is insufficient number of systematic reviews conducted on this issue. Compared to traditional literature reviews, it is important to conduct systematic reviews which have higher scientific value because of validity, reliability and repeatability (Kitchenham, 2004; Xiao & Watson, 2019b).

This study attempts to contribute to the existing body of knowledge by developing a systematic literature review on the integration of green maintenance principles into maintenance performance assessment. Systematic reviews start by defining a review protocol, specifying the research question, and addressing the methods to perform the review. The search strategy used enable detection of relevant literature and selection through inclusion and exclusion criteria (Mohamed Shaffril, Ahmad, et al., 2020; Xiao & Watson, 2019b). Although there are systematic reviews conducted on sustainability management of green buildings, these studies are not specifically on green maintenance issues. Lack of reviews on green maintenance performance has caused absence of comprehension on existing literature. Therefore, the aim of this study is to fill the knowledge gap that exists by reviewing existing related articles systematically and describing the findings for better understanding. This review is guided by the central research question and objective:

RQ: What are the green maintenance principles and maintenance performance indicators for green building?

RO: To investigate the green maintenance principles and maintenance performance indicators for green building.

The study provides significant practicality and knowledge in this area. The findings would be useful in creating awareness among green building and maintenance management stakeholders. As an essential component of green building, green maintenance is a current practise that will ensure sustainability aims are achieved (Chew et al., 2017). The knowledge acquired through this research would benefit stakeholders in decision-making process by producing a comprehensive insight of the intricacies of green maintenance. It would support the current initiative by the government to go green and drive more action by stakeholders to holistically develop green maintenance policies through the knowledge shared. For researchers, the study informed future studies that could be conducted on specific areas.

2. METHODOLOGY

This study has applied Systematic Literature Review (SLR) since it is systematic, method-driven and the approach is replicable (Booth, A., Sutton, A., & Papaioannou, 2016). According to Khan et al. (2003), the adjective systematic is used in a review when it is based on clearly formulated questions, identifying relevant studies, appraising the quality and summarizing the evidence by using explicit methodology. The systematic and explicit method distinguishes systematic reviews from traditional reviews (Khan et al., 2003; Kitchenham, 2004; Tranfield et al., 2003; Xiao & Watson, 2019a). SLR is conducted to overcome the shortcomings of traditional literature review method by reducing bias, while ensuring that the reviewed documents were consistent with the objectivity of the study area and provide transparency based on the search criteria (Khan et al., 2003; Webster & Watson, 2002). SLR is concept centric and differs from traditional review which are normally author centric and starts from a primary article journal and the sequence documents reviewed comes from the reference list of the primary article (Webster & Watson, 2002).

Several studies have been done on how to conduct SLR (Khan et al., 2003; Kitchenham, 2004; Tranfield et al., 2003; Xiao & Watson, 2019a). Generally, a systematic literature review involves three main stages which are planning, conducting and reporting (Kitchenham, 2004; Tranfield et al., 2003; Xiao & Watson, 2019a). In the planning stage, the processes involved are identification of the need for a review or research gap followed by development of a review protocol and research question formulation. In the conducting stage, the processes include identification of research articles, screening, eligibility, quality assessment, data extraction, and data synthesis. The final stage is reporting whereby the findings derived from the systematic review is disseminated (Kitchenham, 2004; Tranfield et al., 2003; Xiao & Watson, 2019a).The steps taken in conducting this systematic literature review is shown in Figure 1

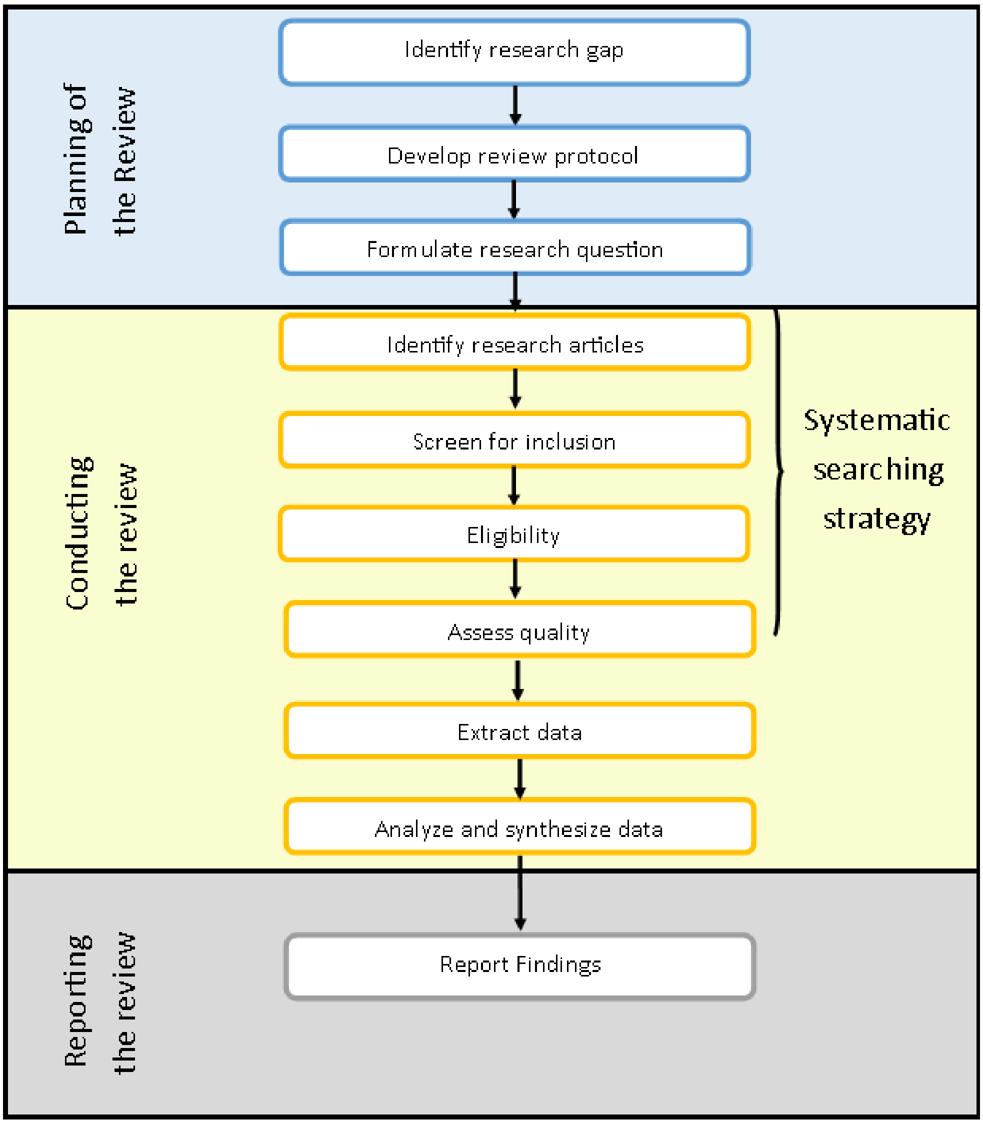

Figure 1: Process of Systematic Literature Review (SLR)

2.1 ROSES review protocol

This study has been guided by the Reporting Standards for Systematic Evidence Syntheses (ROSES) review protocol. The review protocol was designed by Haddaway et al. (2018) to ensure high standards of conduct through better transparency, and facilitate quality assurance of systematic reviews particularly in environmental management field. Moreover, ROSES provides precise and detailed instructions for all phases of review process – planning, conduct and reporting reviews. Based on the ROSES review protocol, the systematic literature review was started by formulating the research question, followed by explanation of the searching strategy. The systematic searching strategy consists of three processes, which are identification, formulation of inclusion and exclusion criteria (screening) and eligibility selection. Thereafter, strategy of quality control is explained for the appraisal of the quality of selected articles. Finally, explanation on the process of abstracting data for review, analysis and validation is clarified.

2.2 Formulation of Research Questions

PICo which is based on Population or Problem, Interest, and Context is a tool that has been used for the formulation of the research question for this study. PICo is a tool that assist researchers to develop appropriate research question and search strategy for the systematic review using qualitative method (Cooke et al., 2012; Mohamed Shaffril, Samsuddin, et al., 2020). Based on the three items, the authors have included three main aspects in the review namely green maintenance principles (Population/ Problem), maintenance performance indicators (Interest) and green building (Context) to guide the formulation of the main research question for this systematic literature review which is – What are the green maintenance principles and maintenance performance indicators for green building?

2.3 Systematic Searching strategies

Systematic searching strategies consist of three main processes – identification, screening, eligibility and quality appraisal (Mohamed Shaffril, Samsuddin, et al., 2020). The processes involved is depicted in Figure 2.

2.3.1 Identification

The identification of relevant research was started by breaking down the research question into individual components which are population/problem (green maintenance), interest (maintenance performance) and context (green building maintenance). After that, the synonym, abbreviations, and alternative spellings are listed to ensure all the relevant keywords have been included based on online thesaurus, past research keywords and experts' suggestion. This identification process was done according to guidelines provided by Kitchenham (2004) Mohamed Shaffril et al. (2020) and Okoli (2015). In order to search the keywords in the selected databases, full search strings were designed using Boolean operators, phrase searching and truncation functions available in the two databases, as shown in Table 1. Web of Science and Scopus were selected as main databases. These databases were chosen because they are the two leading databases for scholarly research and with several advantages, such as advanced search functions, comprehensive indexing of publishers, reproducible (identical results for repeated identical queries), quality control of articles and are multidisciplinary by covering all topics or subject areas, over other available databases (Gusenbauer & Haddaway, 2020; Martín-Martín et al., 2018). The initial total search results from both databases produced 2,683 articles.

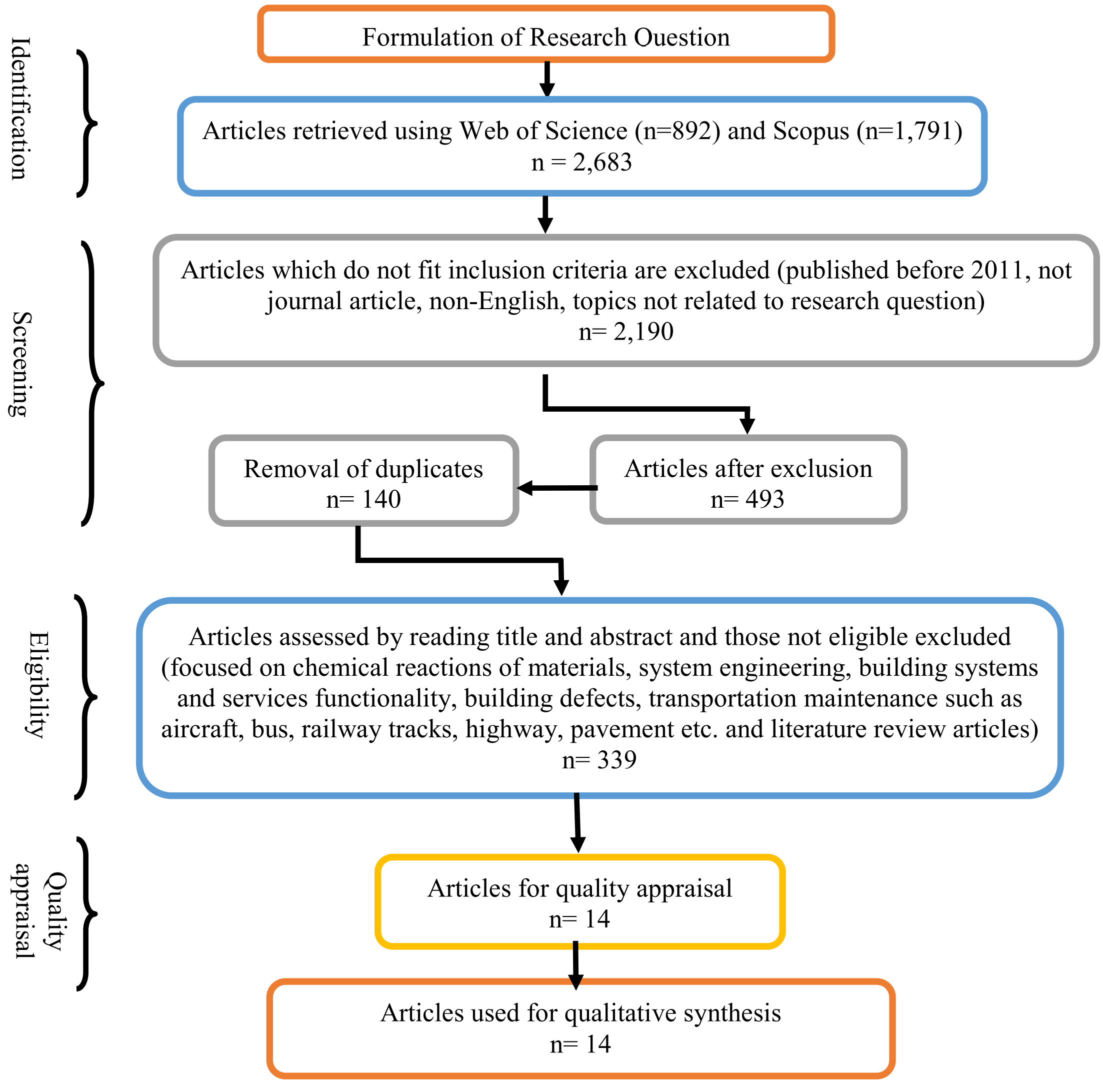

Figure 2: Flow of the Strategic Search Process

Table 1: Search String

Database	Search string	Results
Web of Science	TS= ("green maint*" OR "green maintenance*" OR "green building* maint*" OR "Green building* maint*" OR "green facilit* maint*" OR "sustainable building* maint*" OR "green building* manage*" OR "green facilit* manage*" OR "sustainable building* manage*" OR "green maint* manage*" OR "sustainable facilit* maint*" OR "maintenance performance*" OR "maintenance cost performance*" OR "maintenance effectiveness" OR "maintenance cost plan*" OR "maintenance budget*")	892
Scopus	TITLE-ABS-KEY ("green maint*" OR "green maintenance*" OR "green building* maint*" OR "Green building* maint*" OR "green facilit* maint*" OR "sustainable building* maint*" OR "green building* manage*" OR "green facilit* manage*" OR "sustainable building* manage*" OR "green maint* manage*" OR "sustainable facilit* maint*" OR "maintenance performance*" OR "maintenance cost performance*" OR "maintenance effectiveness" OR "maintenance cost plan*" OR "maintenance budget*")	1,791

2.3.2 Screening

The aim of this process is to identify main studies that are capable of providing direct evidence in relation to the research question (Kitchenham, 2004). All the 2,683 articles were screened according to the selection criteria (as shown in Table 2) that had been established during the protocol definition. The screening was done through the inclusion and exclusion function available in both databases which includes publication year, language, type of publication and subject area.

The timeline between 2011 and 2021 was selected as the inclusion criteria for publication year. Mohamed Shaffril et al. (2020) and Okoli (2015) suggested that researchers should determine a period of time that they are able to review, and in which related studies have been reported. Only articles starting from year 2011 were selected since it was found that the number of articles only started to multiply after year 2010. However, for year 2021, articles were only selected up to July 2021. In terms of language, only articles published in English were included to avoid confusion in understanding the content of the articles. Moreover, only journal articles were selected to ensure the quality of the review. Subject areas that were not relevant to the review were also excluded. Subject areas that were included in Scopus were Business, Management and Accounting, Social Sciences, Environmental Sciences, Chemical Engineering, Economics, Econometrics and Finance, while in Web of Science, the research areas included were Energy Fuels, Science Technology Other Topics, Environmental Sciences Ecology, Business Economics, Construction Building Technology, Operations Research Management, Engineering, Urban Studies, Public Environmental Occupation, Water Resources, Behavioural Sciences, Public Administration, and Architecture. This process of screening excluded 2,190 articles as they did not fit the inclusion criteria and from the remaining 493 articles, 140 duplicates were removed, bringing down the number of articles to 353, which were put through the eligibility process

.

Table 2: Selection Criteria (Inclusion and Exclusion)

Criteria	Inclusion	Exclusion
Timeline	2011- June 2021	≤2010
Document type	Journal article	Non journal articles
Language	English	Non-English
Subject area	Business, Management and Accounting, Social Sciences, Environmental Sciences, Chemical Engineering, Economics, Econometrics and Finance, Energy Fuels, Science Technology Other Topics, Environmental Sciences Ecology, Business Economics, Construction Building Technology, Operations Research Management, Engineering, Urban Studies, Public Environmental Occupation, Water Resources,	Other subject areas

	Behavioural Sciences, Public Administration, Architecture.

2.3.3 Eligibility

Eligibility of the 353 articles were manually monitored by authors to ensure that the articles are relevant with the criteria by reading the title and abstract. A total of 14 articles which were related to either one of the three aspects (green maintenance, maintenance performance and green building maintenance management) were included for the next process, while 339 articles were excluded since the articles focussed of chemical reactions of materials, system engineering, building systems and services functionality, building defects, and transportation maintenance (aircraft, buses, railway tracks, highway pavement etc.).

2.3.4 Quality Appraisal

For the quality appraisal, the 14 articles were presented to expert in the field for verification of the quality of the articles. The articles that are ranked as moderate and high quality are selected for the review through ranking based on the methodology quality as suggested by Mohamed Shaffril et al. (2020).

2.4 Data Abstraction and Analysis

The articles with all research designs including quantitative, qualitative and mixed-method were included in the review because this study used the integrative approach which was introduced by Whittemore & Knafl (2005) to transform the extracted data into systematic review. This study has been done using a qualitative technique, namely thematic analysis. The selected 14 articles were read thoroughly with focus on abstract, findings, discussion and conclusion sections. Abstraction of data that were able to answer the research question were tabulated and thematic analysis was performed. The thematic analysis was carried out by grouping, reduction and analysing the similarities and relationships to identify recurring themes (Hawkins, 2018). This analysis method has been found to be the most suitable when synthesizing mixed research design data (Flemming et al., 2019). The thematic analysis was started by generating main themes from the abstracted data, which had been grouped based on pattern matching. Then, the groups of data were examined, and sub-groups were identified. After that, the accuracy of the themes generated was reviewed for accuracy.

3. RESULTS

As indicated in 2.5 above, 14 articles were used for data abstraction. For green maintenance principles, 4 main themes were identified, namely, environment, economy, technical and social, with 5 sub-themes were identified – minimize environmental impact, resource consumption efficiency, financial efficiency, minimize risk and, safety and wellbeing. For green maintenance performance indicators, 11 main themes and 25 sub-themes were identified. The background of the 14 articles is shown in Table 3. As can be seen in Table 3, about 78% of the articles were published in the last five years, indicating that majority of the articles included in the review represent the most recent discourse on the subject matter. The articles showed a diverse mix of methodologies, although majority (57%) of the articles used quantitative research methods.

Table 3: Background of Articles Selected

Details		Total
Timeline	2013	1
	2014	1
	2016	1
	2017	3
	2018	4
	2019	2
	2020	1
	2021	1
Method	Quantitative	8
	Qualitative	4
	Mixed-method	2
Journal	Journal of Cleaner Production	2
	Smart and Sustainable Built Environment	1
	Chemical Engineering Transactions	2
	International Journal of Building Pathology and Adaptation	1

Facilities	1
International Journal of Technology	1
Building and Environment	1
Eksploatacja i Niezawodnosc	1
Journal of Quality in Maintenance Engineering	1
Journal of Green Building	1
Theoretical and Empirical Research in Urban Management	1
Recovery, Utilization and Environmental Effects	1

For green maintenance principles, four main themes were identified, namely environment, economy, technical and social. Five sub-themes were identified – 1) minimize environmental impact; 2) resource consumption efficiency; 3) financial efficiency; 4) minimize risk; and 5) safety and health. The main themes are the principles criteria while the sub-themes are the principles of green maintenance as shown in Table 4. Under the environment aspect, it was found that all the articles reviewed included minimizing environmental impact and resource consumption efficiency. Whereas for the economic aspect, the principles included were efficient resource consumption that leads to reduced cost incurred or financial efficiency. For the technical aspect, financial efficiency and minimizing risk were grouped together. 64% of the articles reviewed considered minimizing risk under the technical aspect. Technical aspects such as operations and maintenance, construction and fittings affect costs, and, safety and health of users too. Thus, it was found that 64% of the articles reviewed included safety and health of building users and minimizing risks for the social aspect.

The green maintenance performance indicators identified are as shown in Table 5. For each indicator, sub-indicators were identified. Altogether 11 green maintenance performance indicators and 25 sub-indicators were identified. Under the environment aspect 4 indicators were identified, namely 1) resource efficiency; 2) resource usage; 3) waste and emissions; and 4) legal and regulations. In total 10 sub-indicators for the environment aspect were identified, namely, E1 Energy efficiency; E2 Embodied energy; E3 Renewable energy use; E4 Water use and conservation; E5 Material use efficiency; E6 Biodegradable components use; E7 Waste reduction and management; E8 Greenhouse gas emission and other pollutants; E9 Minimise transportation and E10 Building and construction standards. A total of 3 indicators were identified under the economy aspect, namely, 1) financial efficiency; 2) building management; and 3) performance audit. Six sub-indicators were identified thereafter for the economy aspect, namely, F1 Cost effectiveness; F2 Maintenance budget; F3 Sustainable asset usage/ innovation; F4 Building Management Systems; F5 Productivity benchmarks; and F6 Knowledge and skills. For the technical aspect, 3 indicators were identified, which include, 1) operations and maintenance; 2) design; and 3) construction and installations. The sub-indicators for the technical include T1 Maintenance policies and strategies; T2 Green procurement strategy; T3 Design for maintainability; T4 Green maintenance considerations; T5 Structural integrity; T6 Material durability; and T7 Construction quality. Social aspect indicators were safety and health, with 2 sub-indicators, namely, 1) users' safety and 2) users' health.

Table 4: Classification of Green Maintenance Principles

	Studies	Year	Green maintenance principles				
			Environment	Economy		Technical	Social
			Minimize Environmental Impact	Resource Consumption Efficiency	Financial Efficiency	Minimize Risk	Safety & Health
1	Ajukumar & Gandhi	2013	/	/	/	/	/
2	Mohammad et al.	2014	/	/	/	/	/
3	Kayan et al.	2016	/	/	/		
4	Kayan et al.	2017	/	/	/		
5	Kayan	2017	/	/	/		
6	Chew M.Y.L et al.	2017	/	/	/	/	/
7	Jasiulewicz-Kaczmarek & Zywica	2018	/	/	/	/	/
8	Kayan et al.	2018	/	/	/		
9	Kayan, Mohamed Zaid, et al.	2018	/	/	/		
10	Lu et al.	2018	/	/	/	/	/
11	Aghili et al.	2019	/	/	/	/	/
12	Asmone et al.	2019	/	/	/	/	/
13	Franciosi et al.	2020	/	/	/	/	/
14	Sari et al.	2021	/	/	/	/	/
	Total		14	14	14	9	9

Table 5: Classification of Green Maintenance Performance Indicators

Green maintenance performance indicator			Ajukumar & Gandhi, 2013	Mohammad et al., 2014	Kayan et al., 2016	Kayan et al., 2017	Kayan, 2017	Chew M.Y.L et al., 2017	Jasiulewicz-Kaczmarek & Zywica. 2018	Kayan et al., 2018	Kayan, Mohamed Zaid, et al.. 2018	Lu et al., 2018	Aghili et al., 2019	Asmone et al., 2019	Franciosi et al., 2020	Sari et al., 2021	Total
Aspect	Indicator	Sub-indicator															
Environment	Resource efficiency	E1 Energy efficiency	/	/	/	/	/	/	/	/	/	/	/	/	/	/	14
		E2 Embodied energy	/		/	/	/	/			/	/		/			8
		E3 Renewable energy use	/							/			/		/	/	5
	Resource usage	E4 Water use and conservation	/					/	/	/			/	/			6
		E5 Material use efficiency	/	/	/	/	/	/		/	/	/	/	/	/	/	13
		E6 Biodegradable components use	/												/	/	3
	Waste and emissions reduction	E7 Waste reduction and management	/					/	/	/			/	/	/	/	8
		E8 Greenhouse gas emission and other pollutants	/	/	/	/	/	/		/	/	/	/	/	/	/	13
		E9 Minimise transportation	/		/	/	/				/	/					6
	Legal and regulations	E10 Building and construction standards	/	/	/	/	/	/		/	/	/	/	/			11
Economy	Financial efficiency	F1 Cost effectiveness	/	/	/	/	/	/	/	/	/	/	/	/	/	/	14
		F2 Maintenance budget		/	/	/	/		/		/	/			/	/	9
	Building management	F3 Sustainable asset usage/ innovation	/	/	/	/	/	/	/		/	/	/	/	/	/	13
		F4 Building Management Systems	/					/	/					/	/	/	6
	Performance audit	F5 Productivity benchmarks	/					/						/	/	/	5
		F6 Knowledge and skills	/						/	/			/				4
Technical	Operations and maintenance	T1 Maintenance policies and strategies	/	/				/	/	/			/	/	/	/	9
		T2 Green procurement strategy		/				/	/				/	/	/	/	7
	Design	T3 Design for maintainability	/	/				/		/				/			5
		T4 Green maintenance considerations	/		/	/	/	/		/	/	/	/	/			10
	Construction & installations	T5 Structural integrity		/	/	/	/	/			/	/		/			8
		T6 Material durability		/	/	/	/	/			/	/		/			8
		T7 Construction quality		/	/	/	/	/			/	/		/			8
Social	Safety & health	S1 Users' Safety	/	/				/	/	/			/	/	/	/	10
		S2 Users' Health	/	/				/	/	/			/	/	/	/	10

4. DISCUSSION

Green buildings are built based on resource efficiency and ecological principles (Asmone et al., 2019). Green buildings play an important role in ensuring sustainable development goals are achieved, particularly in protecting the environment and improving quality of life (Mohammad et al., 2014). However, the design and construction of green building itself does not guarantee the intended performance. Proper maintenance after handover of project becomes the main factor that influences the effectiveness of the green building functions (Asmone et al., 2019). Maintenance is defined as all technical, administrative and managerial actions taken during the life cycle of an asset, required to retain or restore it to a state in which it can perform its required function (Franciosi, Pasquale, et al., 2020).

According to Mohammad et al. (2014) it has been established that many green buildings underperform especially with regards to energy performance, for example, green buildings using more energy than intended or even more than conventional buildings with several certified buildings performing worse than energy code and certification baselines. Operation and maintenance should be performed in a "green" way for a green building to be truly "green". Green building certification evaluation should include operations and maintenance criteria together with the existing design, construction and technology evaluation. Asmone et al. (2019) revealed that a solution for this under-performing issue is to integrate green maintenance principles during early design stage. Hence, proper assessment of maintenance performance for green buildings needs to be established to ensure that the maintenance activities are carried out according to green maintenance principles. Environmental issues, and commitment to tackle climate issues has encouraged innovation for new approaches to maintenance management that are more environmentally conscious, for example, green maintenance. The concept of green maintenance allow the goal of maintenance to be realised using advanced technology and equipment at the lowest cost of resources and energy use, waste, and environmental effects (Jasiulewicz-Kaczmarek & Zywica, 2018).

Through the systematic review reported in this study, four main themes and five sub-themes (green maintenance principles) were identified. The main themes included environment, economy, technical, and social, while the sub-themes included minimize environmental impact, resource consumption efficiency, financial efficiency, minimize risk, and safety and health. It can be seen, as shown in Table 4 that the sub-themes overlapped across the main themes. For example, it was found that the sub-theme of resource efficiency appeared as either or both an environment and economic principle, likewise minimize risk appearing as either or both a technical and social principle. Therefore, for the environment aspect, two principles were identified, namely minimize environmental impact and resource consumption efficiency. Minimize environmental effect included leakage prevention, using biodegradable products, upgradability during maintenance, waste management and longevity of materials. Resource consumption efficiency relates to energy efficiency, usage of renewable resources, usage of energy efficient equipment, paperless maintenance management system and minimizing unnecessary travel and transport. Kayan (2016) found that high proportion of carbon footprint in maintenance was contributed by transportation, particularly in usage of locally sourced materials or imported materials. Chew et al., (2017) highlighted that green maintenance implies efficient usage of resources such as energy and water with importance given to environmental awareness and sustainable practices to allow potential carbon emissions reduction, create better and healthier working environment for optimal productivity while considering the building's life cycle. For the economic aspect, the principles identified were resource consumption efficiency and financial efficiency. Improving energy efficiency and sourcing renewable energy not just improves air quality but also reduces the GHG emissions that impact climate change and ongoing operating costs such as utility bills, and thus benefits building owners economically. Moreover, sourcing locally available materials not only minimizes the carbon emissions, but also costs involved for transportation (Kayan et al., 2017). Hence green maintenance is adopted towards ensuring maintenance is more environmentally friendly by eliminating waste streams related to maintenance (Ajukumar & Gandhi, 2013). For the technical aspect, financial efficiency and minimize risk were identified as green maintenance principles.

Green maintenance is a crucial technological way to realise sustainability and achieve reductions that link to the recycling economy. Its activities encompass the integration of product design issues with maintenance planning and execution issues intended to minimise the negative environmental effect, whilst ensuring health and safety of personnel involved by minimizing risks involved during the maintenance activities (Ajukumar & Gandhi, 2013; Chew et al., 2017; Mohammad et al., 2014). For the social aspect, the minimization of risk also benefits safety and health of building users. Factors that are considered are enforcement of rules and regulations or standards, proper lighting, and ventilation, easy to follow and safe maintenance, and use of non-toxic products. With proper maintenance, in addition to energy efficiency and waste reduction, users' safety and comfort are guaranteed as well (Chew et al., 2017). As noted earlier, all green maintenance principles are indeed interlinked with one another and ultimately benefits not only environmentally but also economic and social benefits.

Following the determination of the principles of green maintenance, green maintenance performance indicators were identified from the systematic literature review done. Although there are studies on maintenance performance indicators, the performance indicators required to assess green maintenance performance vary. Green buildings comprise of various green technologies such as energy management systems, light-emitting diode lighting systems and solar roofs that makes buildings more innovative and sustainable compared to conventional building maintenance (Asmone et al., 2019; Lu et al., 2018). As shown in Table 5, this study identified 11 green maintenance performance indicators and 25 sub-indicators.

Under the environment aspect there were 4 indicators identified which includes resource efficiency, resource usage, waste and emissions reduction and legal and regulations. In total, 10 sub-indicators were identified for the environment aspect. Under the resource efficiency indicator, the 3 sub-indicators are energy efficiency, embodied energy and renewable energy use. Energy efficiency ensures that less energy is used to perform the same task through technological advancements (Ajukumar & Gandhi, 2013; Chew et al., 2017). Consideration of embodied energy during selection of building components and materials, and usage of renewable energy such as solar power not only enhances resource efficiency but also contributes to overall cost savings (Sari et al., 2021). Under resource usage indicator, the 3 sub-indicators identified were water use and conservation, material use efficiency and biodegradable components use. Installation of water-saving components contribute to resource usage reduction. Resource efficiency and conservation aspects when incorporated in the design aspect, guarantees material use efficiency (Asmone et al., 2019). Use of environmentally friendly materials that are biodegradable and durable also improves green options for maintenance (Ajukumar & Gandhi, 2013; Sari et al., 2021). 3 sub-indicators that were identified for waste and emissions reduction indicator are waste reduction and management, greenhouse gas emission and other pollutants reduction and minimise transportation. Greywater or rainwater recycling systems eliminates waste and contributes to resource efficiency. Usage of biodegradable components not only contributes to waste elimination but also reduction in greenhouse gas emission. Energy efficiency and resource conservation are the aspects incorporated in the designs to guarantee overall material efficiency. Proper care must be taken to segregate components that can be recycled and put back into use to reduce the requirements of fresh inventory. This reduces costs for new spare parts too (Ajukumar & Gandhi, 2013). Compliance to building and construction standards including green building certification ensures the environmental protection aspect is safeguarded (Asmone et al., 2019).

Under the economy aspect there were 3 indicators, which are financial efficiency, building management and performance audit. The 2 sub-indicators that were identified for the financial efficiency indicator were cost effectiveness and maintenance budget. Cost effectiveness ensures minimal expenditure and more profit. Other than technical and design factor, managerial aspects such as insufficient budget allocation influences the maintenance quality and time of execution (Mohammad et al., 2014). For building management indicator, 2 sub-indicators that were identified are sustainable asset usage/ innovation and building management systems. Sustainable asset usage and innovation together with maintenance communication and management improvement through digitalized Building Management Systems can act to deliver green maintenance benefits. An intelligent building management system provides continual performance monitoring and data retrieval such as actual energy and water savings that can be compared to desired targets (Asmone et al., 2019), and performance or productivity of the maintenance done should be regularly audited and benchmarked for improvements. Under the performance audit indicator, the 2 sub-indicators that were identified are productivity benchmarks and, knowledge and skills. Lu et al. (2018) found that to undertake green building maintenance, building managers should have the required green knowledge and skills for proper operation and maintenance. Hence, training for personnel up-skilling and knowledge should be done continuously. The performance benchmarking drives improvement on the maintenance activities. Asmone et al. (2019) found that benchmarking had the most relation to influencing the green maintenance success.

For the technical aspect, 3 indicators were identified, namely operations and maintenance, design and construction and installations. There were 7 sub-indicators for the technical aspect. Under the operations and maintenance indicator, 2 sub-indicators were identified which are maintenance policies and strategies, and green procurement strategy. Criteria for selection of maintenance policies and strategies for each procedure, equipment, machines and work instructions which prioritises preventive and condition-based maintenance are crucial for green buildings. With usage of advanced new information systems predictive maintenance could be carried out (Asmone et al., 2019; Sari et al., 2021). Green procurement strategy contribute to creating a paperless organisation and reducing use of hazardous material use throughout the lifecycle of green building (Asmone et al., 2019). Under design indicator, 2 sub-indicators that were identified are design for maintainability and green maintenance considerations. Design for maintainability and green maintenance considerations during early design has always been a critical issue for green buildings (Mohammad et al., 2014). Design for maintainability with consideration for green maintenance principles should be prioritised to avoid problems during the operation and maintenance phase and prevent additional cost burden for repair or retrofit (Chew et al., 2017). For construction and installation indicator, 3 sub-indicators that were identified are structural integrity, material durability and construction quality. Construction related indicators such as structural integrity, material durability and construction quality that are normally caused by contractors affect the building efficiency and durability leading to high costs of repair. This could be avoided if contractors are knowledgeable about the technologies and techniques required for green building construction and hire skilled labour (Mohammad et al., 2014). Lu et al. (2018) highlighted the importance of adequate green knowledge and skills in ensuring each characteristics of green building requirements are integrated in the operation and maintenance phase. It was recognized that inadequate knowledge and experience, inappropriate maintenance planning, and ignorance of the maintenance aspect in design were the most critical factors leading to problems in green building maintenance management.

For social aspect the indicator identified was safety and health, with 2 sub-indicators, namely users' safety and users' health. There are notable incidents pertaining to serious injuries and fatalities during maintenance of green buildings such as solar panel installation at a certain height and improper use of personal protection equipment (Chew et al., 2017; Franciosi, Pasquale, et al., 2020; Lu et al., 2018). Ensuring work is done at a certain noise level, proper ventilation, the right lighting and air quality provides a healthy place for building users and prevent workplace related illnesses (Ajukumar & Gandhi, 2013; Asmone et al., 2019; Chew et al., 2017).

5. LIMITATION AND RECOMMENDATION

The limitations of this SLR study which includes inclusion and exclusion criteria are time-period and document type. The articles included were between year 2011 and 2021 based on Scopus data which showed that the annual paper published related to green maintenance started to grow significantly from year 2011. As the concept of green maintenance emerged in the 1990s, it would be useful to extend the review starting from year 1990 for broader view. To have only high-quality results, only published journal articles were included. Inclusion of conference papers could have added more information on recent inputs since the journal publication process is structured and therefore normally time-consuming. Hence, this study did not consider latest research studies that were only published in conference proceeding and have yet to be published in high quality journals. This study suggested several research topics for future study. For future studies, further analysis could be done on articles published in conference proceeding. The systematic review revealed the need to conduct more studies and systematic literature reviews on related topics such as maintenance management for green buildings. Future studies could research the negative effect of improper maintenance management of green building particularly the environmental impact. It is important to conduct more studies as suggested since the largest potential for significantly reducing greenhouse gas emissions is through the building sector compared to other major emitting sectors; (Baynes et al., 2018; Herazo & Lizarralde, 2015; Lemmet, 2013; Rock et al., 2019; Xu et al., 2021) whereby 32% of energy consumption and 19% of energy-related greenhouse gas emissions were from the building sectors (IEA, 2015; Xu et al., 2021). Thus, it is crucial for building managers to pursue efficient and green post-occupancy operations and maintenance, even though green buildings are built to be green (Chew et al., 2017; Lu et al., 2018; Olanrewaju, 2011; Retno et al., 2021; Mohammad et al., 2014). Future studies on the suggested topics would provide crucial information for improvement of the green building performance and reduce negative environmental effects caused by the building sector.

6. CONCLUSION

The systematic review process revealed that the maintenance management for green building is not extensively researched even though it is crucial for achieving sustainability goals. The aim of this study was to synthesize existing knowledge on maintenance management of green buildings in order to understand green maintenance principles as well as green maintenance performance indicators. This study established that although there are a few studies on sustainable maintenance performance, most of those studies focus on heritage buildings, the manufacturing or production industry rather than green building maintenance. It is expected that the findings would be useful in creating awareness among green building and maintenance management stakeholders. Based on the findings, for green maintenance principles and performance indicators, 4 main aspects were established, namely environment, economy, technical and social with 5 green maintenance principles. For green maintenance performance, 11 green maintenance indicators and 25 sub-indicators were identified. The knowledge acquired through this research would benefit the stakeholders in their decision-making process for producing a comprehensive insight of the intricacies of green maintenance. It is also expected that the findings would support the current initiative by the government to go green and drive more action by stakeholders to holistically develop green maintenance policies through the knowledge shared. For researchers, the study informed future studies that could be conducted on specific areas. The review concluded that there is potential for this topic to be explored for achieving green building sustainability value. For example, green maintenance practicality and performance as well as integration of green maintenance principles during early stages of design and planning.

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