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Exploring Green Maintenance Research Through Science Mapping Approach

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Abstract

Increasing advancement in the technical systems and equipment centric industries have elevated along with the need for maintenance in the contemporary world. With the accelerated maintenance needs, consequential incautious maintenance practices have increased and negatively impact the people's environment, safety, and health. It has become a burden on the environment and pressures the industry and academia to explore and adopt safe, effective, and sustainable maintenance methods. Green maintenance has known as a solution to the environmental damage caused by conventional maintenance activities. It aligns with the sustainable principles and ensures effective maintenance while protecting the people's environment, health, and safety. It is significant to identify the mainstream research topics, influential authors, sources of publications to filter future research directions to explore in the domain of green maintenance. This article explores the existing literature on green maintenance using the Scopus database and the VOSViewer data mining tool.

A review process containing three steps (1) bibliometric review (2) Scientometric analysis followed by a (3) comprehensive discussion has been conducted to investigate an in-depth understanding of the evolvement of the research in green maintenance and to explore future research directions—the study analyses the keywords, influential journals, scholars and articles. The most emphasized research directions were incorporating green maintenance considerations in the design stage, exploring new green maintenance strategies, developing decision support systems harnessing advanced technology, and monitoring and diagnosing systems based on sustainability criteria.

Keywords- *Green maintenance, Green maintainability, Science mapping, VOSViewer*

I. INTRODUCTION

Maintenance is commonly expressed as a set of activities undertaken to ensure the optimal performance and the intended functions of an asset or a building structure throughout its life cycle [1]. It improves reliability, availability, quality, safety, and the value of the equipment production plant or a building [2]. Maintenance has been a part of human life since its existence. Maintenance directly supports the continuous operation of a core business but simultaneously influences humans' health and safety and natural environment factors [3]. As a

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result of the accelerated number of failures, breakdowns, maintenance needs also elevated and have become a burden on society and the economy [6]. Ill-defined maintenance practices lead to several environmental issues such as production waste, hazardous emissions, in-effective resource utilization, in-efficient energy usage, and spare materials wastage [5] [6] [7]. The hazardous discharge of maintenance such as greenhouse gas (GHG), pollutants of maintenance activities directly affects the humans' health and the environment by leading to climatic changes [8] [9] [10]. The ways and means of the negative impact of maintenance on society and the environment are often underestimated or overlooked [4].

It is established that incautions maintenance creates an unhealthy and unsafe condition for society at large while becoming a burden. Even though the thought and treatment of maintenance as "necessary evil" [11] [12] were no longer in practice, at present, it raises the question that indeed maintenance has its fair share of negative impact on the human health and environment and requires an immediate remedy.

The pressure caused by the environmental and safety issues forces the maintenance managers to search for safer yet efficient maintenance strategies besides current practices [13]. The green maintenance concept was introduced to the industry in the 1990s, aiming to utilize the energy and resources in an environmentally compatible way using advanced technologies and equipment [14]. Green maintenance is the incorporation of sustainable principles in maintenance processes, materials, and methods to reduce the negative impacts of maintenance to support the social, economic, and environmental pillars of sustainability [15] [16]. Green maintenance is more environmentally friendly by adhering that maintenance has minimum negative environmental impact while ensuring the health, safety, and protection of maintenance personnel [17].

Currently, the environmental damage caused by maintenance [6] [5] and compromisation of the health and safety of the maintenance stakeholders [10] [9] has been identified as one of the significant and urgent issues to be addressed. Green maintenance has emerged as a sustainable solution to lessen the burden [18] and address the mandatory need to incorporate green concepts into the construction and maintenance industry, as highlighted by McNeill [19].

This study focuses on recognizing the existing literature directing on green maintenance and determine future research directions. The study's base is scientific articles, which are the most valuable data sources of information for literature survey.

Besides their primary content, the metadata bears a significant amount of information [29]. The metadata includes keywords, citations, affiliations, etc. Among them, keywords hold a significant position to analyse and make conclusions by representing the main text of existing research and creating a frame that describes research topics with a clear focus within a given domain.

II. MATERIALS AND METHODS

An approach of science mapping literature review was adopted to identify the most focused areas of the green maintenance concept and the future directions.

Step 1 - Scopus is one of the two (web of science) most widespread databases [21], which is also famous as the largest searchable source of searching literature [22]. Peer-reviewed papers published on the

Scopus database and relevant keywords were used to conduct the study since they contain the most credible and recent journal publications [25] [26]. "Green maintenance" OR "green maintainability" OR "green building maintenance" keyword search was performed to search the related articles. The search engine refined the search by tracking the keywords in the article title, abstract, and keywords to screen the most relevant documents and explored 42 articles. By reading the abstracts, 14 articles were removed due to irrelevancy to the subject matter (e.g., green space maintenance, biological maintenance, software maintenance, etc.)

Step 2- VOSViewer was used to establish the relationships among the selected articles. It creates a network using nodes and connections. The nodes visualize an item's importance, whereas the connections indicate the closeness among them [27] [28]. In VOSViewer, the importance of an item indicates using weightages. In visualization maps, items with higher weightages are displayed more prominently (using the size of the circles and labels) compared to items with lower weightages. Thus, the items with much weightage indicate with larger labels and circles.

Step 3 - Important articles selected using step 1 were used to explore the existing literature and identify future research trends by conducting a qualitative discussion.

III. RESULTS

Article Distribution

Twenty-eight important articles identified from the bibliometric search were used for analysis. Results showed that the origin of the green maintenance concept in 1990. However, the number of articles produced related to green maintenance since 1990 to date is limited. As shown in figure 1, the first article was generated in 1996, and until 2008 no scholarly articles were published in Scopus. Between 2010 and 2019, 26 articles were published. Since 2016, the number of articles produced has been increasing clearly every year and thus shows the concept's novelty.

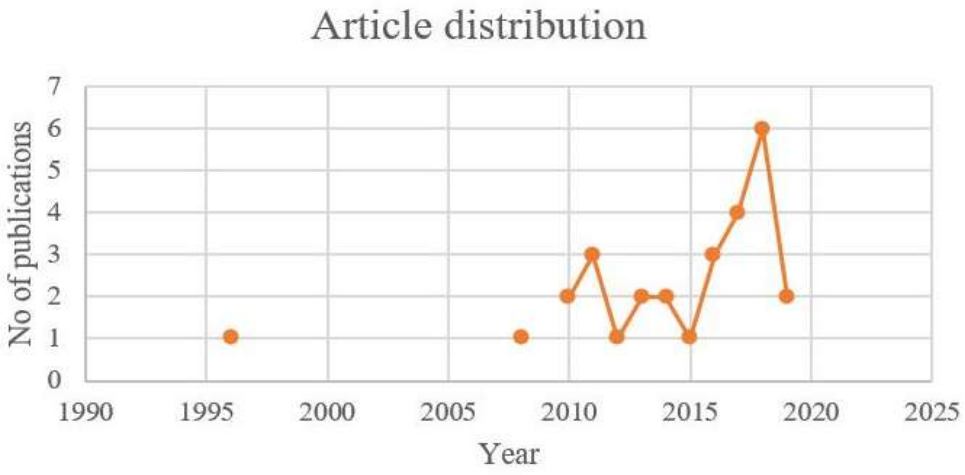

Figure1. Article Distribution by the publication year

Most productive Journal sources of green maintenance

The minimum number of articles and the citations were set to be 02 to obtain the most productive journal sources for green maintenance. Four journals, including "Facilities," "International Journal of Building Pathology and adoption," "Smart and Sustainable built environment," and "Chemical Engineering transaction," were met the threshold out of 20 journals.

The colors indicate the different clusters that maintenance focus areas belong to, and lines indicate the journals' interrelatedness, showing the journals that have cited each other's articles. Facilities and International journal of building pathology and adoption belong to one cluster. Facilities Journal is the most-cited journal among the interrelated journals focusing on the built environment's ecological maintainability; International Journal of Building Pathology and adoption can also be considered one of the most influential sources.

The distance between two journals in the visualization map approximately stipulates the relatedness between the journals according to the co-citation links. Generally, the closer the two journals are located to each other, their relatedness is strong. The shortest distance exists between Facilities journal and the International Journal of Building Pathology.

International journal of building pathology and adaption is displayed in the middle of the map, indicating that it has been co-cited most by the remaining journals.

Figure2. Highly impact Journal sources of green maintenance research

Keyword analysis

The selected articles were further analysed to identify different keywords used by the authors. VOSViwer network shown in Figure 3 indicates all keywords in the selected literature sample under 12 clusters.

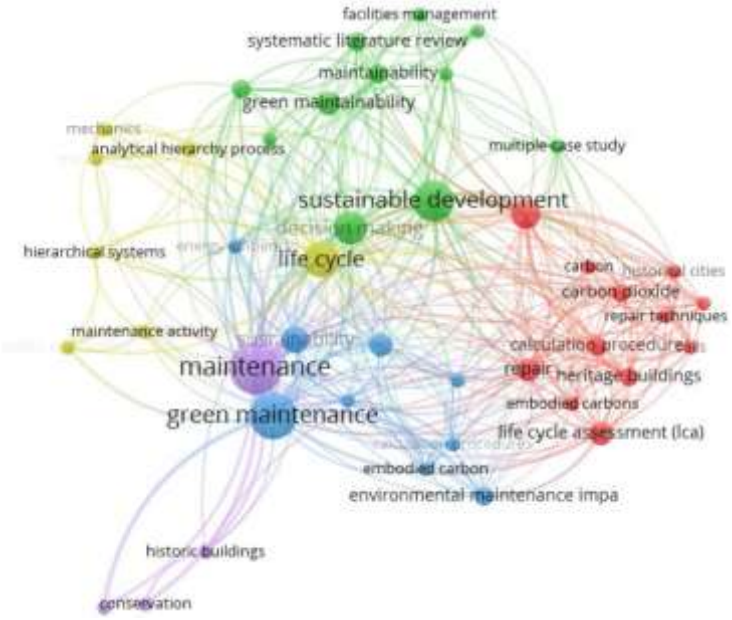

Figure2. Network visualization of the all keywords

Keywords that belong to the same cluster normally have a closer internal relationship. The clearer terms are having much weightage than the other keywords, which indicates the most repetitive keywords. The most prominent keywords are “green maintenance”, “maintenance”, sustainable development”, “life cycle” and “green maintainability”. Even though they stood prominent, it does not suffice to say much about the content or the scholarly articles' study focus. The co-occurrence feature was used to derive the most impacted keywords in the literature to eliminate this gap.

“Co-occurrence” of keywords were evaluated by using “Author Keywords” and “Fractional Counting” by setting minimum occurrence of keywords at 2 in VOSViewer, 11 out of total 84 keywords were originally selected. Among them, repetitive keywords; “maintenance” and ‘Life cycle approach (LCA)” were removed and the remaining 9 keywords were used to perform the keyword analysis. Results showed “green maintainability”, ‘building maintainability” “environmental maintenance impact (EMI)”, “embodied carbon”, “LCA”, “historic buildings”, “calculation procedures” and “sustainability” are highly relevant to the focused research area.

The connecting lines in Figure 4 show the interrelatedness between a pair of keywords. For example, “life cycle assessment” is often co-studied with “embodied carbon emissions” in the same article or with the EMI in the same article. EMI is the most corresponding keyword associated with green maintenance. Since green maintenance has been introduced to reduce the negative maintenance impact on nature, it can be said that most of the scholars made EMI base of their study [30] [18] [31]. Figure 4 shows two clusters of keywords: (1) LCA, EMI, and embodied carbon and (2) sustainability, green maintainability, and building maintainability.

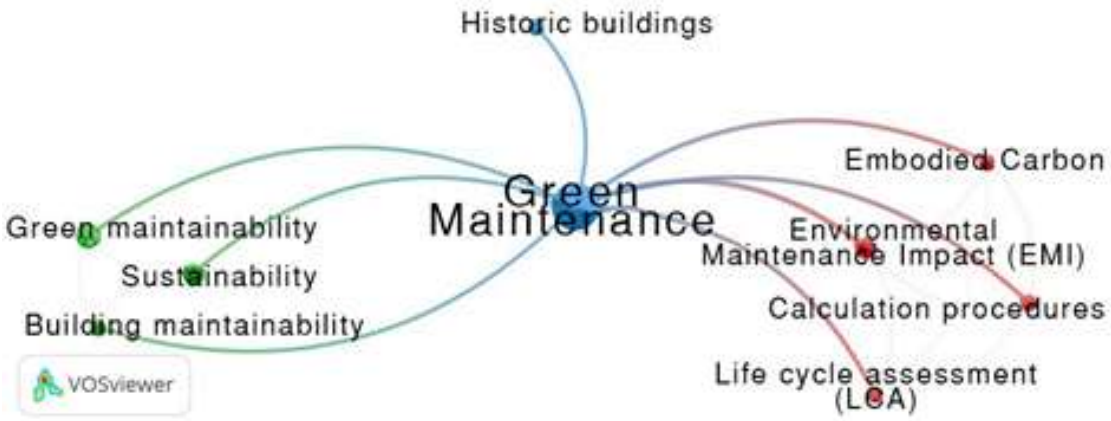

Figure 4. Highly impact author keywords

Scholar in green maintenance domain

To identify the most active and influential scholars, a scholar's minimum number of documents and the minimum number of citations was set at 2 and 10. A total of 10 authors met the baseline, as shown in Figure 5. Van Eck and Waltman [26] recommended using fractional counting in VOSViewer to lose the limitation of an unnecessary repeating of the same citation, which will display as a highly weighted item but a considerable weight lower than that.

Each author's font and circle size display their number of publications in the domain of green maintenance. Scholars shown in Figure 5 belong to two separate clusters based on the scholars' citation networks. For example, Kayan B, Banfil F.G.A, Forster A.M, and Carter K. unfolded to belong to the same cluster, suggesting that their high frequency of citing each other's work. Further, it is possible to measure scholars' influence by the connection lines and distance shown in figure 5. For example, Chew M.Y.L., Kayan B, Forster A.M., and Banfil F.G.A, can be found with strong linkage in green maintenance research.

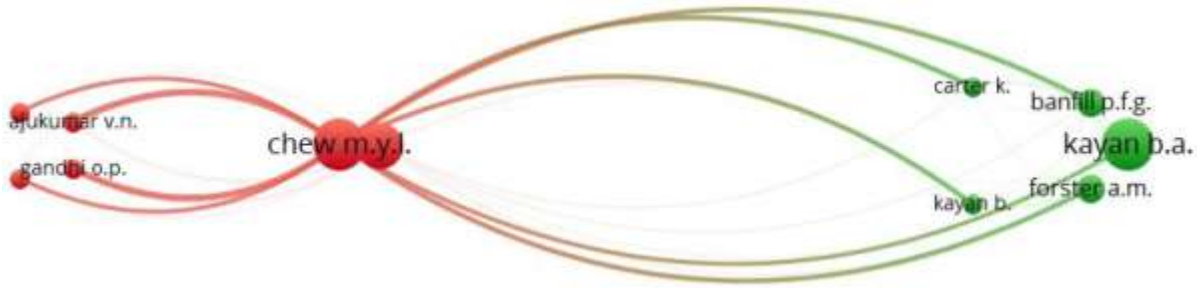

Figure5. Scholars in the field of green maintenance

The closet two clusters were shown separately. Chew M.Y.L appears to be highly connected to every author who has cited each other's work frequently. Chew M.Y.L, Ajukumar V.N, and Gandhi O.P. have developed frameworks to assist in green maintenance decision making. The Ajukumar V.N. identified green maintenance requirements in 2013, and Chew M.Y.L.and, his team, developed a green maintenance model encompassing green maintenance parameters. While Chew and his team focus on green building maintainability

and features, Gandhi and Ajukumar focused on mechanical systems. The cluster, including Kayan B.A., focuses on green maintenance in heritage buildings of Malaysia. In 2011 Forster A.M. published the first article on historic building maintenance on Scopus, and Kayan B.A. carries out further research until 2018. The link strength is one of the criteria which grouped authors into one cluster. The link indicates the number of co-authorship links of a given researcher with other researchers. The authors who belong to the same cluster have cited each other's work frequently.

IV. DISCUSSION

Table 1. Quantitative summary of impacts of scholars in the field of green maintenance

Author	No. of documents	Total citation	Normal citation	Avg. Pub. Year	Average citations	Avg. Normal citations
Forster A.M.	2	36	4.29	2013	18	2.15
Ajukumar V.N.	1	52	1.82	2013	52	1.82
Iung B.	1	32	1.31	2014	32	1.31
Keeping M.	1	18	1.00	1996	18	1.00
Chew M.Y.L.	6	22	5.57	2017	3.67	0.93
Kayan. B.	6	28	5.26	2016	4.67	0.88
Asmone A.S.	3	10	2.60	2018	3.3	0.87
Jasiulwicz-Kaczmarek M.	1	17	0.69	2014	17	0.69

The Average Normal Citation indicates the normalized number of citations of an author. It is derived by dividing the average number of citations published in the same year by the total number of citations [27]. The normalization offers a solution to the misinterpretation of many citations older documents gain due to the advantage of more time to receive to be cited than recent articles [27]. Setting the minimum citation number at 10 and minimum publication number 1 in filtering the literature sample, a total of 15 authors' articles met the requirements.

The study of Forster et al. [31] has received the highest average standard citation, which focuses on heritage building maintenance with lesser carbon emissions. According to Table 1, the influential articles focuses on identifying green maintenance requirements [17], explore green maintenance as a support to the industrial ecosystem [33], green refurbishment techniques [35], a framework for green maintainability [45][46] and selecting green maintenance strategy based on the amount of carbon emissions associates with the life cycle approach of different maintenance activities [18][48][49].

Evolution of Green maintenance models

The keywords associated with carbon frequently accompany the green maintenance concept. Several authors have researched in the area of achieving green maintenance through reducing carbon emissions of the maintenance activities and calculating embodied carbon amount, and choosing the least carbon generating option [18] [16] [30] [31]. With the existing sustainable pillars introduced to the world by Brundlant report

(1987), Froster et al., [30] developed a model overlaying the environmental impact into the triple bottom line of sustainability. They evaluated the maintenance of historical buildings in terms of cost, philosophical principles, and environmental considerations.

Zhu et al., [44] emphasized the importance of designing the buildings to support the effectiveness, efficiency, and ease of maintenance, known as building maintainability. Chew et al.[45] have developed a green sustainable framework by expanding traditional sustainability parameters to maximize performance, minimize costs, minimize risk by adding parameters that minimize negative environmental impact, and minimize material and energy consumption. After a comprehensive literature study, the authors identified that hardly any protocols are available to assess the maintainability of green technologies in terms of sustainable performance [6] [17] and the total life cycle cost of a building45]. The existing green maintenance model has been modified by adding Performance indicators of performance, productivity, resource stewardship, and health and wellbeing. The indicators which belong to these indicators are discussed in figure 6.

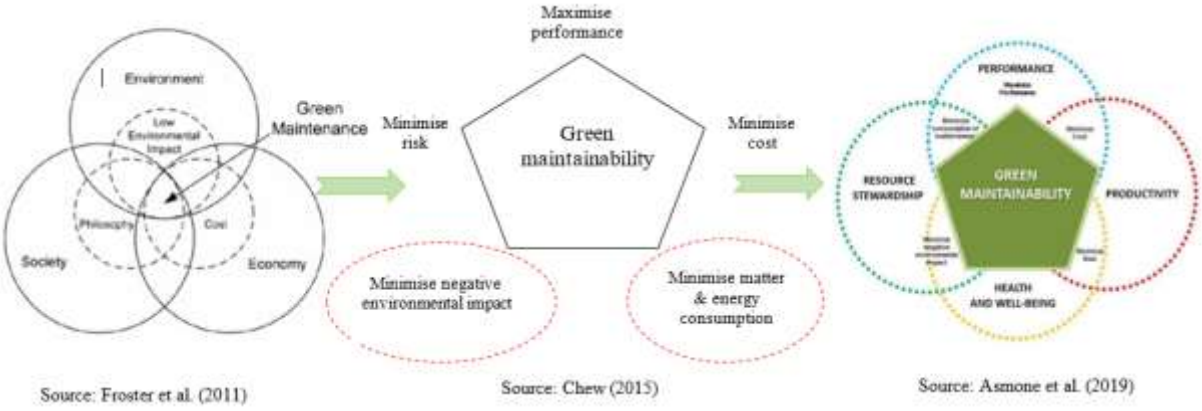

Figure 6. Synthesized green maintenance models developed by scholars

Kazemi [6] identified the gap of existing maintenance models, such as lack of consideration given to the overall system's profitability, impact to the environment and green maintenance index, etc. Using system dynamics, the author has developed a green maintenance model and derived activities such as: investing in new and modern green technologies of maintenance and operation, reducing negative environmental impacts and waste generation, increasing equipment reliability and ensure green maintainability, paying attention to resources utilization and performance of maintenance department which is significant in maintenance paradigm which consists of the overall effectiveness of human resource, equipment effectiveness, and maintenance effectiveness.

Research direction in green maintenance

The previously conducted keyword analysis highlighted the life cycle assessment, maintenance environmental impact, embodied carbon, energy conservation, environmental pollution, multi-criteria decision making, and sustainable development in different clusters. However, these are not studied separated but discussed jointly in the literature. The origin of green maintenance was introduced to the industry with the green

wave, which happens by identifying critical environmental issues such as greenhouse gas emissions (GHG), ozone depletion, air pollution, global warming, and glacier melting.

Keeping and Shiers in 1996 [34] first discuss the green aspects when performing refurbishments to the existing commercial building stock in London as an answer for the increasing environmental issues. Earlier articles highlighted the need to consider green maintenance aspects in the design stage [35] [36] [3] [17] [33] [37] to be prominent. Along with the design considerations, the life cycle approach was discussed parallel [35], where cradle to grave environmental aspects of product manufacturing [38] and building construction [19] are considered.

A relationship between the number, type, and longevity of maintenance interventions undertaken and the embodied energy and CO2 expended in repairs were studied by Forster et al., Kayan B.A., Bertolin C., and Loli A. from 2011 to 2018. A durable and reliable repair requiring fewer repeat interventions proven to incur less energy over the building's lifecycle compared to a less durable alternative, and the authors proved it. Several scholars have defined green maintenance as a method of maintenance that aims to reduce negative environmental impact [39] [31] [17] [14]. Green maintenance is also designated as a fulfillment of three pillars of sustainability, which are social, economic, and environmental parameters [15] [40] [41].

The ideology of sustainable maintenance and green maintenance seems to be close to identical and difficult to demarcate. In the literature, green maintenance has been mentioned as a sustainable approach [40] [41] and [17] [33] identified maintenance, which turns towards sustainability as green maintenance. Where sustainable maintenance stood for all three economic, social, and environmental pillars with the same weightage, green maintenance strives hard to minimize the negative environmental impact and ensure the people's health and safety. According to figure 5, green maintenance is majorly associated with environmental impact reduction than economic and social impacts. However, assurance of the health and safety of the stakeholders was emphasized frequently [42] [39] [17] [41]. Diez [43] stated that using multi-criteria decision making green maintenance fulfil the sustainable requirements.

Future research trends in green maintenance

Based on the keyword analysis within the green maintenance domain and studying the current works done, Table 2 is proposing a research framework suggesting future research directions. It should be noted that the research directions shown in Table 2 are not in a particular order but possible areas to explore simultaneously. To conduct this part of the study, articles were screened using the most cited (5<) option in Scopus and also most recent articles regardless of the cited amount to identify patterns. As shown in Fig. 2, articles published between 2011 to 2019 were analysed due to the accelerated number of articles generated. For example, EMI calculation based on embodied carbon emission [31] [49] has been explored based on historical buildings, and its high time to adopt for other buildings. Green building, green maintenance criteria have been developed based on the green maintainability model [45], and exploration of further parameters to be added is needed. As a green maintenance parameter adopting advanced maintenance techniques [50] [33] and utilizing information technological aspects for green maintenance decision making [47] [33] has been discussed. The prevailing fourth industrial revolution facilitates exploring the smart green maintenance approach.

Table 2. Green maintenance research directions

Sources	Existing researcharea	Focus	Future Trends
[35]	Negative maintenance environmental impact	Green refurbishment techniques for green buildings	Identification of more green refurbishment techniques to gain the advantages.
[30] [16] [49] [48]	Green maintenance for historic building	Green maintenance decision making based on embodied carbon emissions of maintenance activities	Assess the life cycle approach of maintenance and repair based on their quantification of embodied carbon based on the formula developed.
[17]	Green maintenance aspects of mechanical systems	Identification of green Maintenance requirements and environmental conscious decision making	Need of holistic approach in the designing stage not focusing on a single entity (ex; design for maintainability, design for the environment)
[3]	Building maintenance strategies (lean/sustainable)	Sustainable maintenance assessment criteria identification	The necessity to employ IT to retrieve, process data and to make decision
[46] [45]	Green maintenance framework	Identification of green maintenance parameters and indicators	The need for a decision support system for green maintenance
[32]	Green maintenance as a support for industrial eco systems & circular economy	Support that maintenance is an inherent property of an product and the role of maintenance in supporting sustainability	Development of additional models for monitoring, diagnostics, prognostics, decision making processes able to address sustainability considerations
[6]	Environment and Green Maintenance Index	Green maintenance model	Consider green maintenance as a reform to the traditional maintenance which goes hand in hand with technologies

V. CONCLUSION

This study was carried out using a science mapping approach consisting of a three-step bibliometric search, a scientific analysis, and an in-depth qualitative discussion. Twenty-eight peer-reviewed articles in the domain of green maintenance were selected after screening. It was discovered that over the past ten years, there had been a significant increase in green maintenance publications, especially since 2010. Facilities journal, International Journal of building pathology and adaption, and Smart and sustainable built environment were identified as the most productive journals. Keyword analysis revealed main topics within the green maintenance domain, including "green maintainability", 'building maintainability," "environmental maintenance impact (EMI)", "embodied carbon", "life cycle assessment (LCA)", "historic buildings", "calculation procedures" and "sustainability". Favorably mentioned green maintenance parameters were evaluated to understand the principle of green maintenance better.

It is also found that most productive scholars in green maintenance according to the literature sample included Ajukumar N, Gandhi O.P, Kayan B.A., Chew M.Y.L, Forster A.M., Iung B. and Kazemi S. Although not all the authors categorized depending on the highest number of publications, some are with the highest citations.

Future research directions were derived from the reviewed articles. Both academic and industry practitioners will benefit from further researching and applying the research findings for the betterment of the future of society and earth. More importantly, this article will be an immense support for the scholars in green maintenance to identify the relevant literature.

Data Availability

The findings of the research article are based on secondary sources mainly published on the Scopus database and other sources including Emerald Insight, Elsevier, Science Direct, American Society of Civil Engineers and IEEE XPLORE. VOSViewer data mining tool has been used to conduct the data analysis.

Conflicts of Interest

"The authors declare that there is no conflict of interest regarding the publication of this paper."

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