Science Mapping of Sustainable Green Building Operation and Maintenance Management Research

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Science Mapping of Sustainable Green Building Operation and Maintenance Management Research

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Abstract Green building is a solution to address the impact of buildings on the environment. In its development, green buildings require sustainable green management during the operational and maintenance phase in order to meet the current and future needs of users. As the longest phase in the green building life cycle, it is important to track and map the development of studies related to this field. This paper aims to map the development of literature related to the operational and maintenance phases of sustainable green buildings from 1999 to 2019. Literature data were obtained from the Scopus database and the analysis was conducted using a science mapping approach with VOSviewers. Based on literature data, 746 publications are found to be relevant to this study, the results of this study are in the form of scientific mapping covering wave of research, source and publication types, influential countries, references with strongest citation burst, author contributions, research subjects, and major research areas divided into three categories (frequent, medium and rare). The results of this study are quite important, because they not only provide a mapping of existing research developments, but can also serve as a reference for researchers who have an interest in developing sustainable green building operations and maintenance studies in the future.

Keywords Green Building, Operation and Maintenance, Science Mapping, VOSviewers

1. Introduction

Recently, many countries pay much attention to the increasing global warming, high energy consumption, and greenhouse gas emissions produced by buildings [1]. This condition requires immediate solutions in order to avoid serious risks that can impact on future generations [2], and one of the solutions is green building. Green buildings can be defined as how to produce structures by using environmentally responsible processes and using efficient resources during the life cycle of the building [3].

Green buildings are one way to reduce the significant impact of building on the environment, society, and economy. Along with the increasing attention to this issue, related scientific works also evolve over time. Given the importance of green buildings in reducing the environmental impact in the world, mapping the development of scientific works in this field is important.

Some systematic studies based on a bibliography of the development of green building research have been conducted. Among them are current research reviews of green buildings and agendas in the future [4], a review of the bibliometrics improvement of building maintenance within the period of 2000 to 2016 [5], a scientometric study of green buildings using Data envelopment Analysis (DEA) during the period of 1965 to 2019 [6], scientometric review of the recycling industry from 1996 to 2018 [7], scientometric review trend of green manufacturing publications in the period of 1996 to 2018 [8], and research challenges and barriers in obtaining GBCA ratings for office buildings in Australia using literary studies during the period of 2004 to 2011 [9].

However, from many studies which try to map the development of literature related to green buildings, a gap is found, namely the mapping of Scientific works that

review the operational and maintenance phases of green buildings. Green buildings include all operations from planning, construction, operation, maintenance, repair and demolition of buildings [10]. So far, much research has focused on investigating obstacles of the design and construction of green buildings with very little focusing on the operation and maintenance phases [11]. This condition is quite interesting to do a mapping, considering that the operation and maintenance phase is the longest phase of a building life cycle and this study is also expected to complement other existing green building phase mapping studies. Some studies show that this phase plays an important role in maintaining the current user value system without compromising the ability to meet the value system for users in the future [12].

This paper is aimed at filling the existing gaps of research on green buildings, especially publications discussing the operational phase and maintenance of sustainable green buildings from 1999 to 2019. The activity of mapping scientific boundaries requires more than merely presenting an intuitively designed and presented science [13], and to bridge the matter in this study using a science mapping approach.

Scientific mapping is very useful to know the development of literature in relation to the development of science that is reviewed, because scientific mapping aims to build a bibliometric map describing how certain disciplines, scientific domains, or research areas are conceptually arranged, intellectually, and socially [14].

In this paper, the scientific mapping activity was done by using VOSviewers software and the Bibliometric data were obtained from the metadata owned by Scopus. The research on studies will feature analyses and discussions that include the development of literary publications covering the number of publications, sources and types of publications, number of citations, author contributions, research subjects, and major research areas of the topic being reviewed.

2. Research Methods

This paper encapsulates Published research on Sustainable Green Building Operation and Maintenance Management obtained from Scopus metadata within the period of 1999 to 2019. This study employed science mapping approach with VOSviewers software. This paper does not provide a detailed analysis of all available studies. It quantitatively summarized the conditions of existing literature and trends in the development of literature on the management of operation and maintenance of sustainable green buildings so that readers can systematically understand the development of existing publications, sources and types of publications, contributions of countries of origin of publication, developments in the number of citations, contributions of authors, subject areas research and key research areas.

The stages of this study started from identifying the research gap of existing green building literature-based studies. From this activity, a gap in the literature discussing the operation and maintenance of sustainable green buildings was found. Based on the gap, the purpose of the study to be done was then formulated. The primary objective of the study is to conduct science mapping on sustainable green building operation and maintenance management research. The next stage was the withdrawal of literature metadata based on the selected bibliography database (obtained from Scopus). Then, the next step was an analysis using VOSviewers software followed by discussions of the findings. At last, conclusions were drawn.

2.1. Database Selection

This paper uses a bibliography data in CSV format, which were withdrawn from Scopus database. For directing the study, this paper uses keywords from titles, abstracts and keyword of database literature consisting of "sustainable green building operation and maintenance management", "Sustainable Green building operation Management", "Sustainable green building Maintenance management", "Sustainable Green building operation" and "sustainable green building maintenance". This paper also limits the subject of research which covers only the fields of Engineering, Environmental Science, Energy, Social Sciences, Business, Management and Accounting, Computer Science, Materials Science, Earth and Planetary Sciences, and Decision Sciences.

2.2. Science Mapping

Science is a gateway to understanding the position of humans in the universe, and a foundation for social and economic welfare [13]. Using the science mapping method, the development of science can be mapped properly and this map can change and develop along with the development of science itself. The science mapping approach displays the structural and dynamic aspects of scientific research; it is a spatial representation of how disciplines, fields, and writers relate to one another [15]. A mature visual analytical field can provide promising pursuit directions. Visual analytics can be seen as the second generation of information visualization [13].

Basically, the process of science mapping consists of 3 conceptual steps to produce a natural map [13]. These steps are: selection of analytical units consisting of basic particles of the universe of science reviewed, defining the size of the relationship between units, and describing units and relationships reviewed in low-dimensional space (generally using two dimensions).

Nowadays, many computer applications can be used for science mapping, such as CiteSpace (2003), Science of Science Tool (2009), VOSviewers (2010), and SciMAT (2012) [13]. In this study, the mapping process used VOSviewers software. VOSviewers is one of the computer applications that is considered capable and is widely used in processing metadata sourced from Scopus. VOSviewer is used to establish a network of scientific

publications, scientific journals, researchers, research organizations, countries, keywords, or terms [16]. VOSviewers can create maps based on network data and visualize the maps in the form of network visualization, overlay visualization, and density visualization [16].

3. Results and Discussion

3.1. Wave of Research on Sustainable Green Building Operation and Maintenance

Figure 1 indicates the development of publications starting from the beginning of publication that correlates with sustainable green building operation and maintenance within the period of 1999 to 2019. Based on data from Scopus, 746 documents were identified, with 116 open-access documents and 630 non-open access documents.

Publications related to sustainable green building operations and maintenance first appeared in 1999, comprising research on the selection of cost effective using the BEES method [17], a comparison between embodied energy and energy use in the operational phase of the wooden row house [18], the development of scenarios of green building challenges (GBC) using the life cycle assessment method in the operational phase and refurbishment of existing buildings [19], and the assessment of green building challenges in the UK [20].

Between 1999 and 2004, the number of publications was still very small (less than 10 documents). In this period, many researchers tended to focus primarily on the initial challenges faced by green buildings which began to develop and spread around the world. Therefore, the scope of the study mostly revolves around the design and construction of green buildings. However, over time the publications that discussed the operation and maintenance phases grew gradually. This can be seen from the number of publications that grew rapidly, especially in 2005 to 2013. Although after that, the number of publications seemed stagnant, but the quantity was quite large. This shows the longest phase in the green building life cycle. The operation and maintenance phase is starting to get the attention of researchers to conduct studies specifically to maintain the condition of existing green buildings.

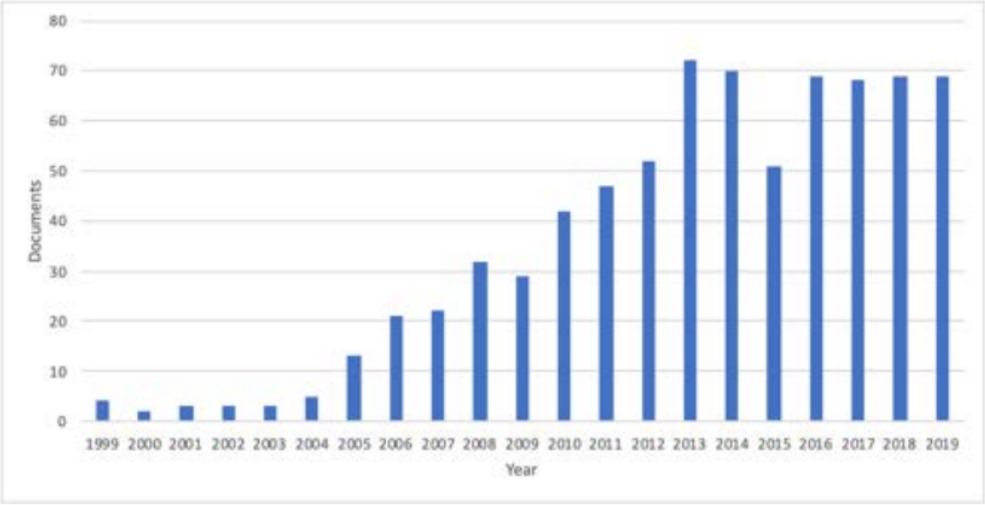

Figure 1. Publication Developments (1999 – 2019)

3.2. Top Research Outlets

Based on Scopus metadata from 1999 to 2019, of the 746 publications found, article publications and conference proceedings contributed the most (86.2 %) compared to other sources and contributes greatly to the development of studies in this field. Based on **Table 1** it can be noted that article (322 publications) accounted for 43.2%, conference paper (321 publications) 43.0%, and conference review (32 publications) 4.3%. This condition shows that publication through journal articles and conference papers is the main channel for researchers to convey the results of their studies, thoughts and opinions on this topic.

Table 1. Publication type

Document type	Documents	%
Article	322	43.2%
Conference Paper	321	43.0%
Conference Review	32	4.3%
Review	30	4.0%
Book Chapter	26	3.5%
Book	9	1.2%
Short Survey	5	0.7%
Undefined	1	0.1%

According to the metadata of Scopus, it is known that there are 88 sources of publications during the period of 1999 to 2019. Based on **Figure 2**, the top 10 sources of the highest contribution consisting of: *Journal of Green Building* (25 documents), *Advance Material Research* (24 documents), *Applied Mechanics And Materials* (21 documents), *Journal of Cleaner Production* (20 documents), and the *Earth and Environmental Science IOP Conference Series* (17 documents), *Procedia Engineering* (17 documents), *Building Research and Information* (11 documents), *Sustainability Switzerland* (11 documents), *Energy and Buildings* (10 documents), and *Energy Procedia* (10 documents).

The Advance Material Research Journal is a journal that first published the results of research in early 1999, 2001, 2002, 2007, 2008, 2011, 2012, 2013 and 2014. The *Journal of Green Building* first published research in this field in 2006 to 2018, where papers on this topic could always be found in each publication. *Energy and Building* published articles in 2007, 2010, 2011, 2013, 2014, 2015, and 2017. *Journal of Cleaner Production* published articles in 2011, 2013, 2014, 2015, 2017, and 2019. *Energy Procedia* published articles in 2011, 2014, 2016, 2017, and 2019. The journal of *Procedia Engineering* published literature related to topics in the years of 2011, 2014, 2015, 2016, and 2017. *Applied Mechanics and Materials* publications were found in 2012, 2013 and 2014. For *IOP Conference Series Earth and Environmental Science*, articles are found in the year of 2013, 2014, 2015, 2017, 2018, and 2019. In *Building Research and Information*, relevant articles are found in the years of 2015 and 2018. *Sustainability Switzerland* published articles from 2014 to 2019.

Based on the previous explanation, in this study, the Journal of Green Building is the main choice outlet for researchers to publish their articles, while the IOP Conference Series Earth and Environmental Science is the largest outlet that publishes conference papers that have a correlation with the operation and maintenance phases of green buildings.

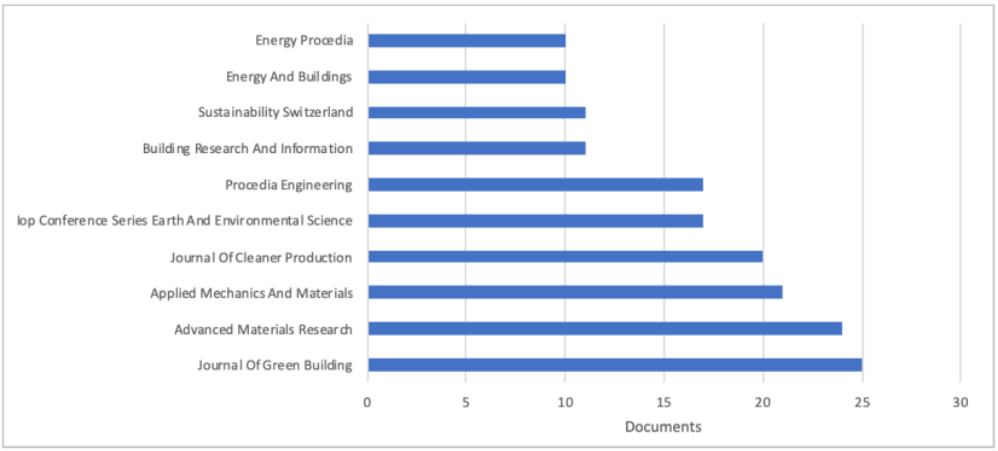

Figure 2. Top 10 Research Outlets

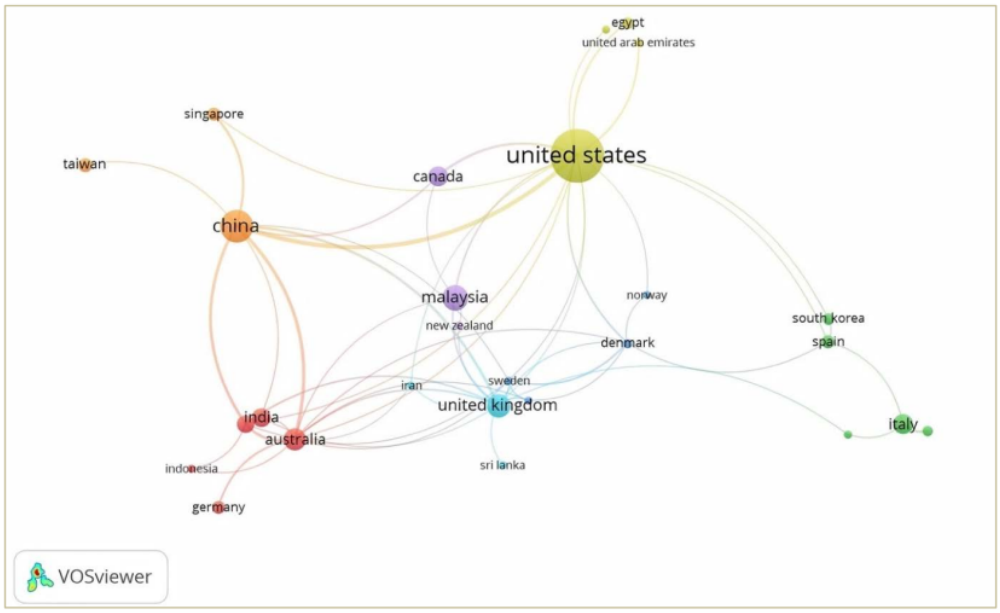

Figure 3. Network Visualization

3.3. Influential Countries

Academic paper publications can usually be considered as indicators of a scientific discipline development [7] and changes in the number of publications can indicate the development or change of a science [13].

Based on the Scopus dataset, 82 countries have contributed during the period of 1999 - 2019. Productivity mapping based on the contribution of these countries used co-authorship analysis and full counting calculation methods with a minimum number of publications = 5. The results obtained are 28 countries with 7 clusters from 82 countries that meet these requirements. Cluster 1 consists of Australia, Germany, Hong Kong, India, and Indonesia. Cluster 2 consists of Italy, the Netherlands, Russia, South Korea, and Spain. Cluster 3 consists of Brazil, Denmark, Norway, and Sweden. Cluster 4 consists of Egypt, Turkey, the United Arab Emirates, and the United States. Cluster 5 consists of Canada, Malaysia, and New Zealand. Cluster 6 consists of Iran, Sri Lanka, and the United Kingdom. Cluster 7 consists of China, Singapore, and Taiwan. The results are visualized in **Figure 3**. The size of the contribution of a country is represented by the size of the node.

Measuring the number of citations, based on **Figure 3,** for the 5 countries with the largest contributions, the 3 publications with the most citations in each country are as follows: in the United States, research on *The moderating effects of institutional pressures on emergent green supply chain practices and performance* [21] have 509 citations, then *Balancing priorities: Decision-making in sustainable supply chain management* [22] with 361 citations, and research on *Sustainable energy performances of green buildings: A review of current theories, implementations and challenges* [22] with 155 citations. In China, 3 publications with the highest number of citations consisted of *The moderating effects of institutional pressures on emergent green supply chain practices and performance* [21] with 509 citations, *Green strategy for gaining competitive advantage in housing development: A China study* [23] with 163 citations, *Urbanization and its impact on building energy consumption and efficiency in China* [24] with 130 citations. Malaysia with the publication of *Sustainable energy performances of green buildings: A review of current theories, implementations and challenges* [25] with 155 citations, *A vision on the role of environmental higher education contributing to sustainable development in Malaysia* [26] with 46 citations, and *Green maintenance for historic masonry buildings: an emerging concept* [27] with 27 citations. In the UK the publication of *Urbanization and its impact on building energy consumption and efficiency in China* [24] with 130 citations, *Green operations initiatives in the automotive industry: An environmental reports analysis and benchmarking study* [28] with 110 citations, *Sustainability: A new imperative in contaminated land remediation* [28] with 105 citations. From Australia, the publications of the *Sustainable construction-The role of environmental assessment tools* [29] with 571 citations, *Barriers to implement extensive green roof systems: A Hong Kong Study* [30] 94 citations, *Eco-resorts vs. Mainstream accommodation providers: An investigation of The viability of benchmarking environmental performance* [31] with 52 citations.

Table 2 shows the order of 28 countries based on the number of publication contributions including information on the number of citations and the total link strength

possessed. The 10 countries with the largest contributions are as follows: United States (221 publications), then China (84 publications), Malaysia (52 publications), United Kingdom (42 publications), Australia (38 publications), Italy (38 publications), Canada (31 publications), India (27 publications), Hong Kong (26 publications), and Taiwan (16 publications). These data show that the United States dominates the publication and makes a major contribution to the study of the stages of operation and maintenance of green buildings. This is indicated by the large number of publications, the number of citations and the total link strength generated.

Table 2. Country Rankings by Number of Publications

No	Country	Documents	Citations	Total link strength	No	Country	Documents	Citations	Total link strength
1	united states	217	2575	32	16	netherlands	9	184	3
2	china	84	1361	33	17	denmark	8	63	9
3	malaysia	52	386	7	18	brazil	6	200	4
4	united kingdom	42	558	19	19	indonesia	6	20	2
5	australia	38	963	22	20	iran	6	34	3
6	italy	32	469	5	21	new zealand	6	68	2
7	canada	31	826	7	22	russian federation	6	6	2
8	india	27	106	4	23	sweden	6	109	8
9	hong kong	26	640	15	24	turkey	6	31	1
10	taiwan	16	61	1	25	united arab emirates	6	26	2
11	germany	14	271	2	26	norway	5	90	2
12	singapore	14	183	4	27	poland	5	28	0
13	spain	13	75	4	28	sri lanka	5	14	1
14	egypt	11	50	2					
15	south korea	11	22	2					

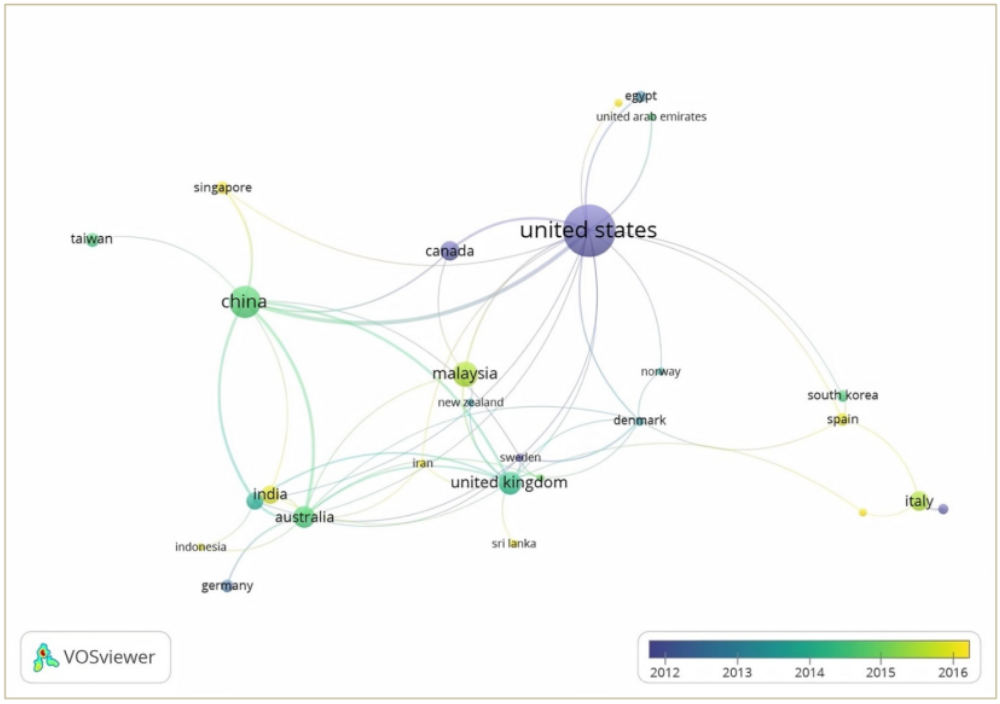

Figure 4. Overlay Visualization

The overlay visualization (**Figure 4**) presents the periodization of publications based on country contributions. The results of the overlay visualization show that the United States is the pioneer of publications dealing with research topics in this field. Publications that correlate with research topics were first discovered in the United States in 1999 on the selection of cost effective green buildings [32] with 79 citations and 3 other publications, such as research on the challenges of green buildings from the perspective of observers [19] with 113 citations, Green building challenges in England [20] with 28, and solar and green calculations on the Norwegian Row House [18] with 76 citations.

3.4. Author Contributions

Analysis of the authors ' contributions was done using the co-authorship analysis with the authors as a unit of analysis with full counting calculation method. The threshold used is the minimum number of documents of an author numbering 3 documents and a minimum number of citations of an author amounting to 3 citations.

Based on the Authorship mapping (**Figure 5**), 19 clusters consisting of 30 authors were obtained. Each cluster is marked with its own color. 10 authors with the largest contribution are Perini, K. (6 documents), Wang, Y. (6 documents), Chew, M.Y.L. (5 documents), Zhang, X. (4 documents) and Li, B. (4 documents), Roper, K.O. (4 documents), Che-ani, A.I (4 documents), Conejos, S. (4 **documents**), Shen, L. (3 documents) and Wu, Y. (3 documents). The 10 authors with the highest number of citations are Zhang, X. (300 citation), Shen, L. (284 citation), Wu, Y. (191 citation), Perini, K. (187 citation), Li, B. (171 citation), Ottelé, M. (166 citations), Lu, Y. (102 citations), Wang, Y. (92 citations), Lippiatt, B.C. (80 citations), and Hormones, M. (76 citations).

Figure 6 shows the results of the overlay visualization mapping authors. In the picture, the darker the color of the node indicates the older a literature and when it goes to bright yellow, the literature will get younger. The literature begins by Lippiatt, B.C, and Cole, L.J. Then, it proceeds with Horman, M., and Ropper, K.O. and publications related to this field continue to grow to this day.

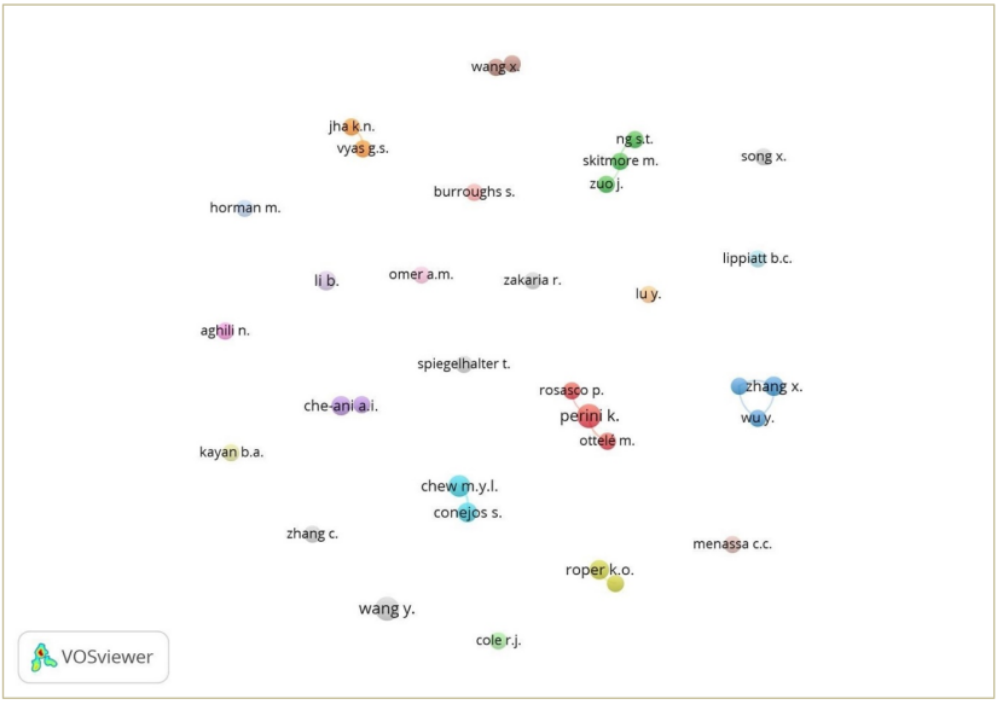

Figure 5. Authorship Network Visualization

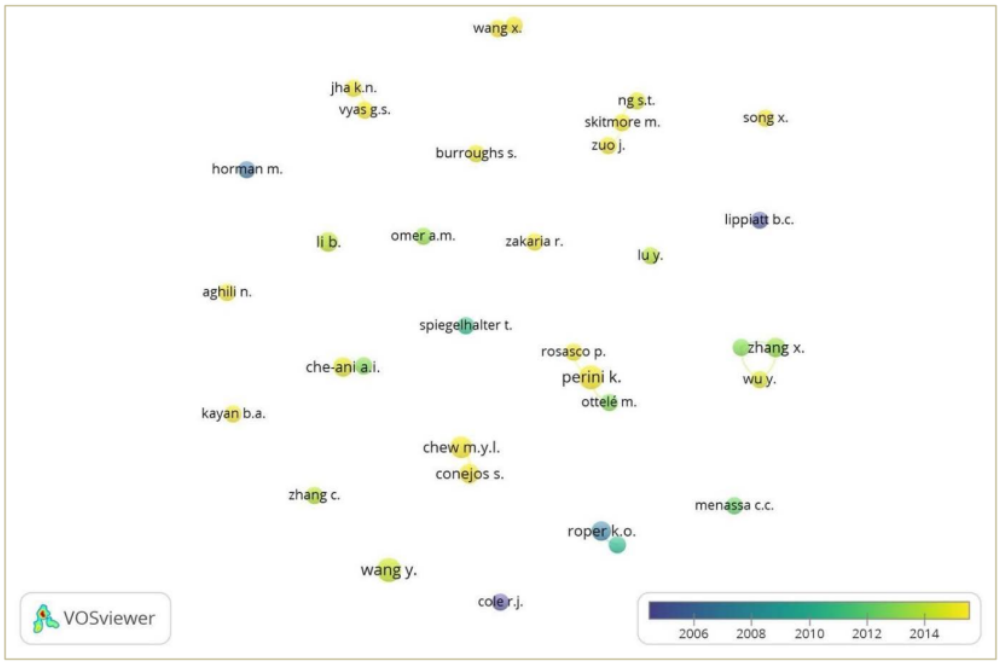

Figure 6. Overlay Visualization

Table 3. Top 20 References with Strongest Citation Burst

Documents	Publication Year	Country	Total Citation
Sustainable construction-The role of environmental assessment tools [29]	2008	Australia	562
The moderating effects of institutional pressures on emergent green supply chain practices and performance [21]	2007	China	498
Balancing priorities: Decision-making in sustainable supply chain management [22]	2011	US	355
Green strategy for gaining competitive advantage in housing development: A China Study [23]	2011	Hongkong	161
Energy analysis of building manufacturing, maintenance and use: Em-building indices to evaluate housing sustainability [33]	2007	Italy	155
Sustainable energy performances of green buildings: A review of current theories, implementations and challenges [25]	2013	Malaysia	151
Enhancing environmental sustainability over building life cycles through green BIM: A review [39]	2015	Hongkong	132
Urbanization and its impact on building energy consumption and efficiency in China [24]	2009	China	129
Comparative life cycle analysis for green façades and living wall systems [37]	2011	Netherland	115
Green Human Resource Management and Green Supply Chain Management: Linking two emerging agendas [35]	2016	Brazil	115
The relevance of Green Building Challenge: An observer's perspective [19]	1999	Germany	113
Green operations initiatives in the automotive industry: An environmental reports analysis and benchmarking study [28]	2010	UK	110
Decision making, planning and design for the conservation of indigenous vegetation within urban development [38]	2004	Austria	107
Building sustainability in logistics operations: A research agenda [36]	2011	US	103
Sustainability: A new imperative in contaminated land remediation [40]	2014	UK	95
Sizing of rainwater storage units or green building applications [41]	2007	Canada	94
Barriers to implement extensive green roof systems: A Hong Kong study [30]	2012	Hongkong	94
Economic returns to energy-efficient investments in the housing market: Evidence from Singapore [34]	2012	Singapore	90
The next generation of sustainable construction [42]	2007	US	83
Selecting cost-effective green building products: BEES approach [17]	1999	US	79

3.5. References with Strongest Citation Burst

The number of citations for publications that have relevance to research topics continues to grow from year to year. Based on the dataset used from the years of observation 1999 - 2019, 20 documents were obtained with the highest number of citations as shown in **Table 3**. The countries of origin for the 20 publications with the most citations were the United States with 4 documents, Hong Kong with 3 documents, China with 2 documents, England with 2 documents, while Australia, Italy, Malaysia, Netherlands, Brazil, Germany, Austria, Canada and Singapore each with 1 document.

Table 3 shows that research on environmental assessment of sustainable construction [29] has the highest number of citations with 562 citations. Based on 20 papers with top citation, it is known that the research area with the most citations is in the realm of energy [24] [25] [33] [34], Supply Chain [21] [22] [35] [36], and the use of vegetation in green buildings [30] [37] [38].

Based on the number of citations, it is known that the discussion of environmental assessment is still an interesting study and many other researchers have cited it, as well as the discussion of supply chains. This can be seen from the large number of citations held by titles that discuss this matter, such as: *Sustainable construction-The role of environmental assessment tools* [29] with 562 citations, *The moderating effects of institutional pressures on emergent green supply chain practices and performance* [21] with 489 citations, and *Balancing priorities: Decision-making in sustainable supply chain management* [22] with 355 citations.

3.6. Main Subject Area of Research

This paper reviews the 9 subjects of the research area consisting of engineering, environmental science, energy, social science, business, management and accounting, computer science material science, Earth and Planetary science, and the decision sciences. The number of publications and the percentage of contributions based on the subject area can be seen in **Table 4**.

Table 4. Subjects of Research Areas

Subject Area	%
Engineering	37.8
Environmental Science	17.6
Energy	11.6
Social Sciences	11.1
Business, Management and Accounting	7.2
Computer Science	5.3
Materials Science	4.3
Earth and Planetary Sciences	3.1
Decision Sciences	2.1

Within the period of 1999 - 2019, the subject areas that dominated the publications discussing the operation and maintenance phases of sustainable green buildings were engineering subject with 451 documents, environmental science with 210 documents, energy with 139 documents, social science with 132 documents, and business, management, and accounting with 86 documents.

Figure 7 shows the proportion of the size of subject areas contribution to the number of publications which are relevant to sustainable green building operations and maintenance. Engineering contributed 37.8%, followed by Environmental Science, 17.6%, Energy 11.6%, Social Sciences 11.1%, Business, Management, and Accounting 7.2%, Computer Science, 5.3%, Materials Science, 4.3%, Earth and Planetary Sciences 3.1%, and Decision Sciences 2.1%.

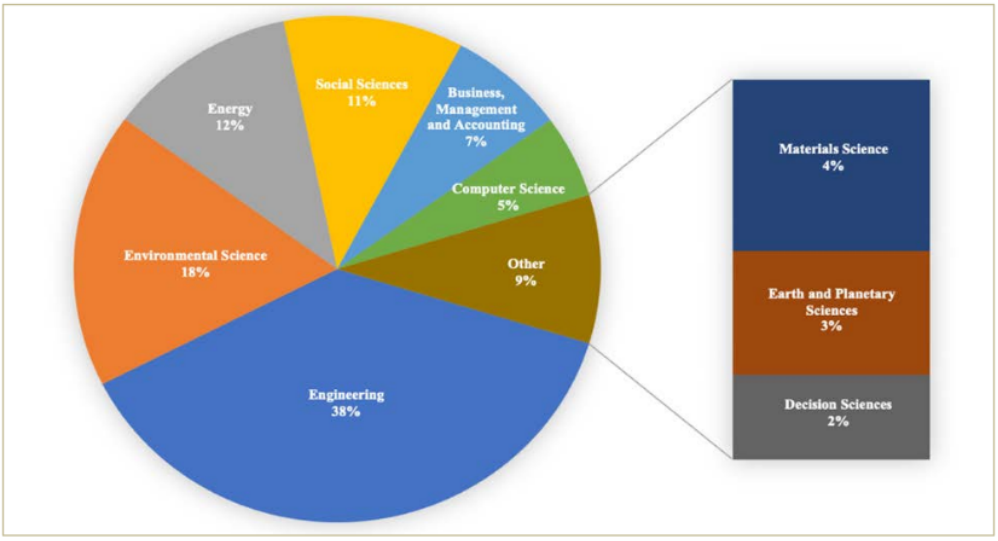

Figure 7. Distribution of Publications by Subject Area

This condition shows that the main subject areas of study so far are still in the areas of engineering, environmental science and energy, with very few links to other subject areas, such as: social science, computer science and materials science and others. Considering the operation and maintenance phase is a phase that consists of a compilation of many disciplines, it very possible to open up other opportunities for studies using various perspectives of scenarios and other scientific field approaches.

3.7. Major Research Areas (Analysis of Keywords Co-Occurrences)

Mapping all keywords can provide an overview of the main research areas that have been investigated [43]. This study found 5285 keywords that have a relationship with the phase of operation and maintenance of sustainable green buildings. However, in order to dissolve the study, the number of keywords will be limited using the following parameters: analysis based on co-occurrence, calculation using full counting and all keywords as an analysis unit [44][45][46], and using the threshold occurrence of a keyword of 20. Based on the parameters, 53 keywords that can fulfill these requirements are obtained and these keywords can be grouped into 5 clusters as shown in **Figure 8**.

As **Figure 8** shows, cluster 1 is a collection of 13 items consisting of buildings, cost-benefit analysis, costs, decision making, environmental impact, environmental sustainability, housing, life cycle, life cycle assessment, LCA, maintenance, operation and maintenance, and sustainability. Cluster 2 is a collection of 12 items consisting of water quality, buildings, carbon dioxide, energy conservation, energy efficiency, energy use, energy utilization, global warming, historic preservation, investment, office building, and Solar energy. Cluster 3 is a collection of 12 items consisting of building codes, building materials, design, ecology, environmental protection, green buildings, planning, societies and institution, strategic planning, structural design, sustainable design, and sustainable development. Cluster 4 is a collection of 10 items consisting of building construction, carbon, climate change, construction, industrial construction, environmental management, green building, greenhouse gases, project management, and sustainable construction. Meanwhile, cluster 5 is a collection of 6 items consisting of architectural design, environmental design, intelligence building, leadership in energy and environmental design, LEED, and sustainable building.

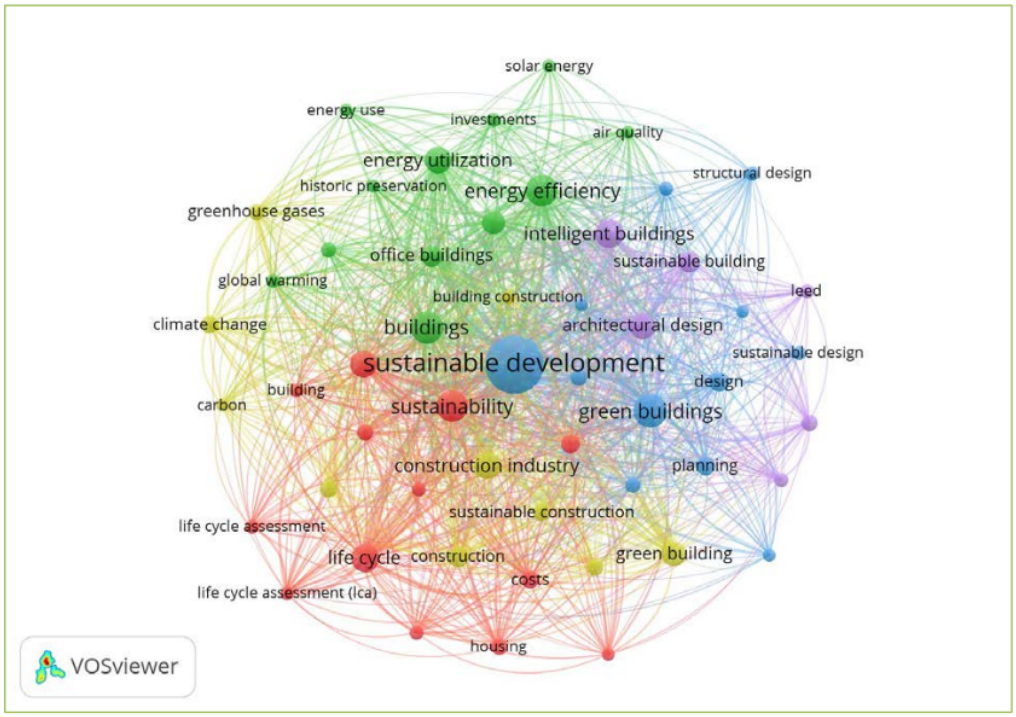

Figure 8. Keyword – Network Visualization

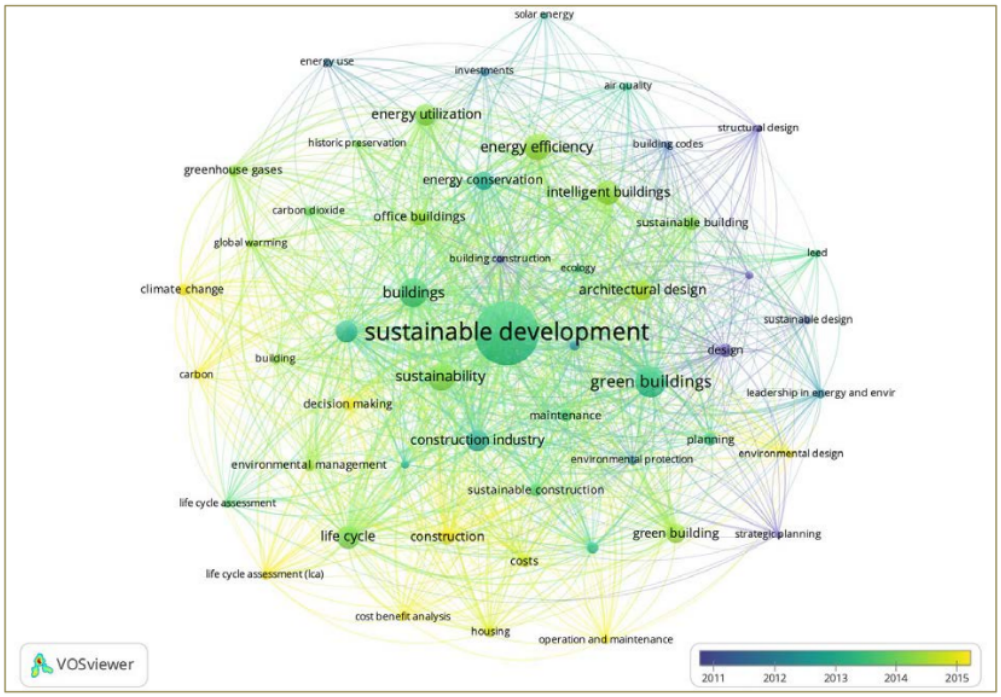

Figure 9. Keyword – Overlay Visualization

Figure 9 shows the development of keywords within the period of 1999 – 2019. In the Early Years (1999 – 2012), major research areas were around design, sustainable design, building construction, structural design, investment, strategic planning, environmental protection, and energy use. In the middle period (2012 – 2014), many studies on sustainable development, construction industry, energy efficiency, and planning were conducted. Meanwhile, in the last years (2014 – 2019), the research areas began to move towards life cycle assessment, climate change, carbon, housing, operation, and management.

In this study, the main areas of research are divided by 3 groups organized by the number of occurrences of the keywords (**Table 5**). The group consists of Group 1 which is a category of keywords classified as often used with Occurrence level ≥ 50. Group 2 is a medium category with occurrence level of keywords 50> x> 25. Group 3 covers keywords which falls into the category of rarely used, namely keywords with occurrences 26> x> 19.

Group 1 (frequent category) consists of 16 keywords, including sustainable development, green buildings, sustainability, energy efficiency, intelligent buildings, life cycle, industrial construction, environmental impact, energy utilization, architectural design, energy conservation, office buildings, construction, and sustainable building. Group 2 (medium category) comprises keywords that are commonly used in the literature, which include design, maintenance, planning, sustainable construction, climate change, costs, environmental management, building materials, housing, environmental protection, investments, and life cycle assessment. In Group 3 (rare category), the top 3 keywords include cost benefit analysis, global warming, building codes, building construction, environmental sustainability, sustainable design, environmental design, structural design, water quality, carbon, ecology, operation and maintenance, energy use, historic preservation, societies and institutions, solar energy, and strategic planning.

Table 5. Keyword Grouping

No	Keyword	Occurrences (> 50)	Total Link Strength	No	Keyword	Occurrences (50 > X > 25)	Total Link Strength	No	Keyword	Occurrences (26 > X > 19)	Total Link Strength
1	sustainable development	396	1853	17	design	49	269	35	cost benefit analysis	25	175
2	green buildings	140	805	18	maintenance	43	203	36	global warming	25	155
3	buildings	126	784	19	planning	41	213	37	building codes	24	142
4	sustainability	119	539	20	sustainable construction	40	207	38	building construction	24	144
5	energy efficiency	115	683	21	climate change	37	180	39	environmental sustainability	24	126
6	intelligent buildings	101	602	22	costs	37	257	40	leed	24	122
7	life cycle	92	586	23	environmental management	37	205	41	life cycle assessment	24	147
8	construction industry	90	564	24	decision making	35	234	42	sustainable design	24	77
9	environmental impact	87	501	25	greenhouse gases	35	245	43	environmental design	23	142
10	energy utilization	86	527	26	project management	35	217	44	structural design	23	113
11	architectural design	78	495	27	building materials	33	193	45	air quality	22	117
12	green building	74	380	28	housing	32	182	46	carbon	22	168
13	energy conservation	68	379	29	leadership in energy and environmental designs	32	190	47	ecology	22	96
14	office buildings	56	295	30	carbon dioxide	30	181	48	operation and maintenance	22	124
15	construction	54	381	31	environmental protection	27	137	49	energy use	21	86
16	sustainable building	52	343	32	building	26	135	50	historic preservation	21	125
				33	investments	26	143	51	societies and institutions	21	87
				34	life cycle assessment (lca)	26	200	52	solar energy	20	70
								53	strategic planning	20	96

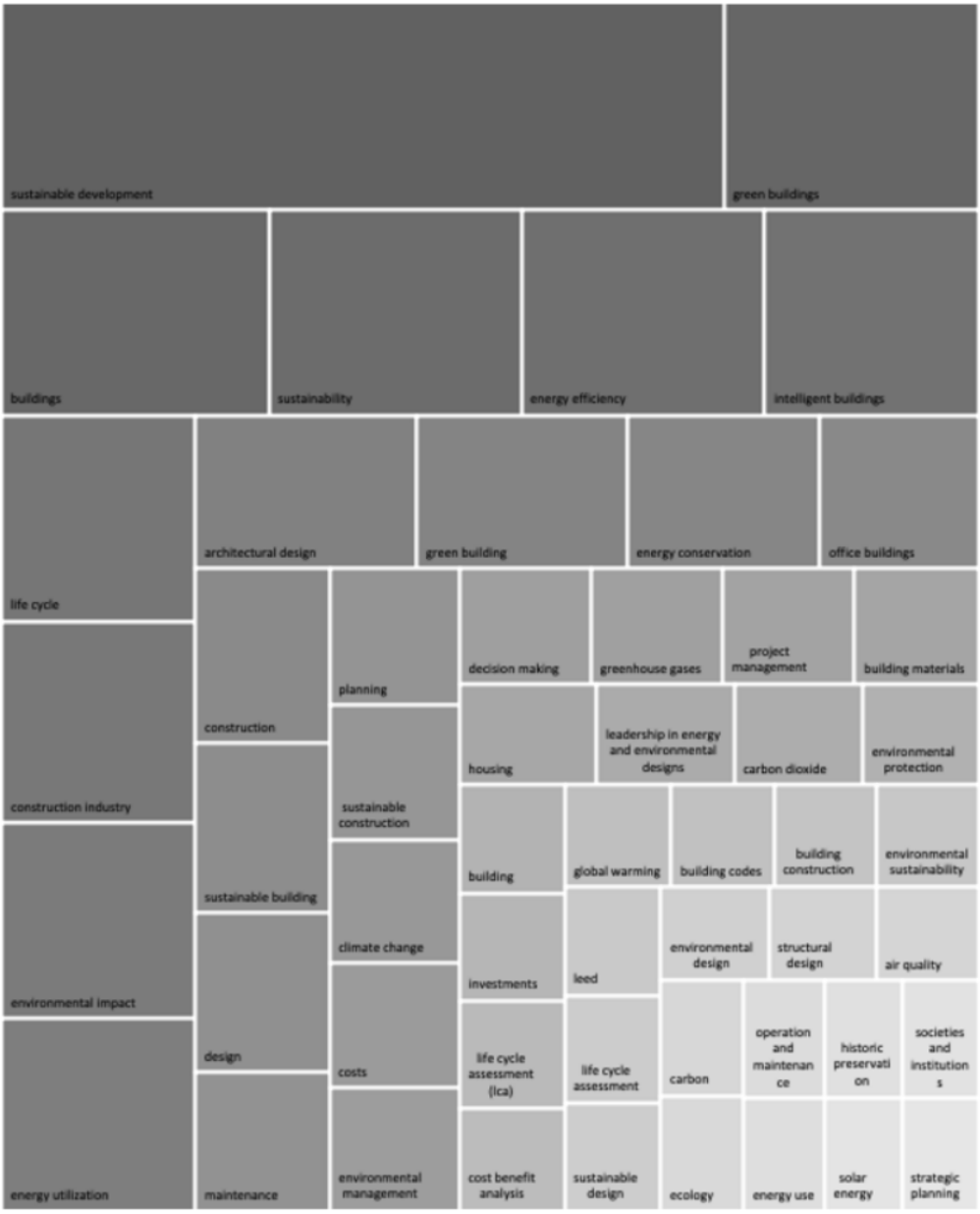

Figure 10. Treemap Main Research Area

Figure 10 displays the Treemap of main research areas. The main research areas that receive a sizeable and growing portion in discussing the operation and maintenance phases of sustainable green buildings include sustainable development, green buildings, buildings, sustainability, energy efficiency, and intelligent building. Meanwhile, research areas that are underdeveloped or get a small proportion in the period of observation include strategic planning, societies and institutions, operations and maintenance, energy use, and ecology.

Based on the division of the group and the Treemap, information on the categorization of keywords is the basis for the main research area, where the proportion of research keywords is seen based on the level of frequency of use (frequent, medium, rarely) by researchers in conducting their studies. This is one of the functions of

this analysis where the combination of keyword categorization gives an opportunity to encourage the presence of new studies to complement existing studies, so that research in this field can continue to develop and the gaps can be seen and filled properly.

4. Conclusions

Management of operational phases and sustainable maintenance of green buildings can guarantee and improve the performance of green buildings as planned. From the results of science mapping, 746 publications are found in the period of 1999 - 2019. The types of publications that have a large contribution come from Articles (43.2%), conference papers (43.0%), and conference reviews (4.3%) with the 3 most influential sources are the Journal of Green Building (25 documents), Advance Material Research (24 documents), Applied Mechanics and Materials (21 documents).

The mapping results reveal that 82 countries have contributed to research related to the operation phase and maintenance of sustainable green buildings. The United States (221 publications), China (84 publications), and Malaysia (52 publications) are 3 countries that have the largest and the most influential contributions in this field compared to other countries.

Based on the aspect of authors with the highest number of contributions, the 3 authors with the highest number of documents are Perini, K. (6 documents), Wang, Y. (6 documents), and Chew, M.Y.L. (5 documents). Meanwhile, based on the number of citations, the 3 authors with the highest number of citations are Zhang, X. (300 citations), Shen, L. (284 citations), and Wu, Y. (191 citations).

From 1999-2019, Sustainable construction-The role of environmental assessment tools (Ding, 2008), The moderating effects of institutional pressures on emergent green supply chain practices and performance (Zhu and Sarkis, 2007), and Balancing priorities: Decision-making in sustainable supply chain management (Wu and Pagell, 2011) are the 3 most cited publications and references in the world.

So far, the major areas of study have been dominated by research in the field of engineering (37.8%), environmental science (17.6%), energy (11.6%), and social science (11.1%). Meanwhile, other fields of study have contributions below 10%, such as Business, Management and Accounting 7.2%, Computer Science 5.3%, Materials Science 4.3%, Earth and Planetary Sciences 3.1%, and Decision Sciences 2.1%.

The main research area is identified through the keywords used. During the period of 1999 - 2012, the main research areas were design, sustainable design, building construction, structural design, investment, strategic planning, environmental protection, and energy use. During 2012-2014, the main research areas were related to sustainable development, construction industry, energy efficiency, and planning. Meanwhile, in the 2014-2019 period, the main study areas were life cycle assessments, climate change, carbon, housing, operations and management.

If the main research area is reviewed from keyword occurrences, the top 3 keywords found in Group 1 (frequent categories) consist of sustainable development, green buildings, and buildings in general, keywords in Group 2 (medium category) consist of design, maintenance, and planning, and keywords in Group 3 (rare category) consist of cost-benefit analysis, global warming, and building codes.

During the period 1999 – 2019, research area that is considered as experiencing significant development is the area that discusses sustainable development, green buildings, buildings, sustainability and energy efficiency and intelligent building. Meanwhile, the less developed research area is an area that examines strategic planning, societies and institutions, operation and maintenance, energy use, and ecology.

This study offers holistic knowledge development of papers that have relevance to the operation and maintenance phase of green buildings to ensure sustainable building performance. The results obtained are expected to increase knowledge and future researchers can identify and address the gap of the research area that is deemed to be done further studies to complete the existing research literature. This study has some limitations, although testing and analysis have been completed. Among them are the depth of discussions which is limited by space and the use of data sources that only use Scopus. This study does not map papers from other sources which are relevant to the topic discussed.

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