



A BIBLIOMETRIC ANALYSIS OF GREEN BUILDINGS

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Abstract: studies on green building have become a significant area of consideration by researchers in recent time. Currently, bibliometrics analysis increasingly plays a significant role in combining previous studies' outcomes to effectively advance the current information to develop a line of study and result-oriented understanding. Though numerous studies have been reported on green building, limited research has explored the publication trends in this area of sustainability. Therefore, the objective of this study was to fill the void by conducting a bibliometrics analysis of publication trends in green building. The Web of Science database was hunted for publications from 2012 to 2022 with “green building” in the heading. Microsoft Excel 2016, VOSviewer, R Bibliometrix and Biblioshiny packages were deployed for the statistical analysis of published research articles. A total of 36,915 published documents were identified in the Web of Science database for this ten years study period (2012 – 2022). The analyses disclosed that the annual scientific production growth rate stood at 16.53% with the highest number of 1057 articles in 2021. Y Wang and Y Zhang were the two top authors in term of production in green building publications with 96 and 76 published articles respectively and had the most intense authors' collaboration network. Sustainability was the leading journal in publications on green building studies with a total of 958 published articles followed by the Journal of Cleaner Production with 669 articles. This study can help researchers in the construction industry obtain a comprehensive understanding of the state-of-the-art of green building research.

Keywords: Green building, bibliometric analysis, sustainable environment, publication trend, Web of Science

1.0 Introduction

The problem of ozone layer depletion, global warming, high emission, climate change coupled with the challenges of high investment and ever-increasing pollution associated with the traditional construction industry required an immediate attention of all stakeholders in the construction industry in order to have a sustainable built environment (Zhang et al., 2019; Chen et al., 2022). The construction industry is the largest energy consumer, consuming 40% of the world's energy and emitting 30% of the world's greenhouse gases (Si et al., 2016). The advantage of green building cannot be over-emphasized as it provides a natural and harmonious building form, a healthy, comfortable, serene and efficient living space with the usage of minimum resources, sustaining the environment and reducing environmental degradation and pollution throughout the life cycle of the building (Zhang et al., 2019). It is all of these and many more that make research on green building to become a notable area and an area of consideration by researchers in recent time, thus studies on green building are significant.

Green building also known as green construction or sustainable building refers to both a structure and the application of processes that are environmentally responsible and resource-efficient throughout a building's life cycle; from planning to design, construction, operation, maintenance, renovation, and demolition (US-EPA, 2006). This requires close cooperation of the contractors, the architects, the engineers, and the clients at all project stages (Yan & Stellios, 2006). The green building practice expands and compliments the classical building design concerns of economy, utility, durability and comfort (US-EPA, 2006). To achieve all of the “3 Ps”, these are the three dimensions of sustainability, that is, planet, people and profit, these “3 Ps”, are to be put into consideration throughout the entire supply chain (Solaimani and Sedighi, 2019).

Moreover, several studies have been researching green building globally since its inception. It is worthy to note that many researchers have carried out research on green building such as, technology (Liu et al., 2014); management (Yang & Zou, 2014); performance (Nilashi, et al., 2015); design (Jalaei & Jrade, 2015); certification (Avis & Nils, 2015) effectiveness (Hou et al., 2017); rating tools (Illakoon et al., 2017); cost prediction (Ade-Ojo & Ogunsemi, 2019); awareness (Ade-Ojo & Awodele, 2020); amongst others. Currently, bibliometric analysis increasingly plays a significant role in combining these previous studies' outcomes to effectively advance the current information to develop a line of study and result-oriented understanding. However, bibliometrics studies on green building are scanty and only few have performed to the best of our abilities in evaluating published patterns on the subject matter. Based on the search emanated from this study, more than 63,869 documents associated with green building have been printed in the literature (Web of Science). Studies emanating from such investigation have provided information about the informed nature of such research and discovered breaches.

The termed bibliometrics analysis is a statistical approach deployed to evaluate the essential evolving inclinations and features of a specified study subject built on the printed studies (Li et al., 2020). Bibliometrics and visualization have been conveyed as an essential way to detect evolving concepts in the construction industry, and it is an imperative technique of scientific research evaluation. This observation is correct considering the situation of the present age, where multiple amounts of information is being exchanged among stakeholders in construction industry (Zhang, 2019).

Furthermore, bibliometrics is usually used in various disciplines to appraise scientific research quantitatively and qualitatively (Deng, 2020). Therefore, to systematically divulge associates within the green building family, our study deployed bibliometrics and visualization approaches to analyze green building-linked publications and citations, countries, and author impact. Based on the evidence gathered through the research, and to the best of our knowledge, this is the first bibliometric study on trends in green building research covering up to year 2022 in the world; 5365 published articles were repossessed and statistically analyzed in the present bibliometric analysis. Findings from this study brought to light the green building studies' hot spots and can benefit the development of a national and institutional research strategy. Additionally, the resulting data or evidence from the visualizations can be used to study the scientific history of investigation outputs in a definite discipline and recognize the potential future investigation path and prospects for collaboration (Roth et al., 2017).

2.0 Data Search and Research Methodology

2.1. Data Search

Data used for this study were retrieved from Web of Science (WoS) database. Web of Science (WoS) was chosen because presently it is the world's largest and most comprehensive database of information resources. It contains over 11,000 authoritative academic journals that significantly impact the environmental sciences, engineering, applied and natural sciences, medical and biomedical sciences etc. We explored the Web of Science™ core collection within the WoS database as a data source for this study. The document type is the article, the search method is a title search, and the language is all languages. The keyword "green building" was used as a topic term to search documents that contained this word in the title or keyword. A total of 63,869 documents were found from the database, while a total of 49,927 documents published from 2012 to 2022 were found from the database, with the following types of documents: article (36,915; 73.94%), proceedings (10,038; 20.11%), review article (2,805; 5.62%), early access (730; 1.46%), letter (95; 1.58%), editorial (429; 0.86%), meeting abstract (101; 0.20%), book chapter (988; 1.98%), correction (62; 0.12%), letter (49; 0.10%), book review (41; 0.08%), news item (29; 0.06%), data paper (27; 0.05%), others (40; 0.08%). Hence, we chose articles for the final analysis because articles contain a description of complete research and results. Data around these articles and the total annual citations for each article were downloaded. Comprehensive document lists thereafter were exported as BibTeX.

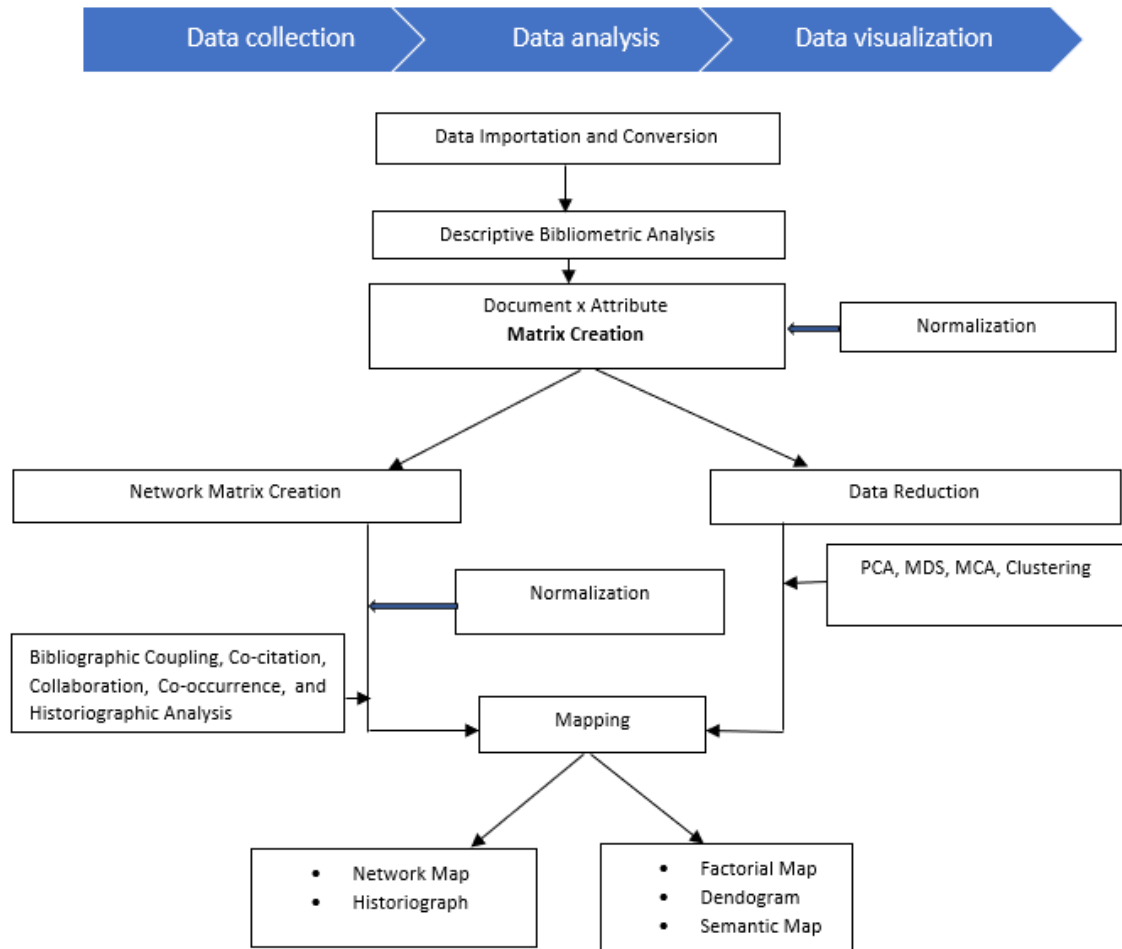


Figure 1. Bibliometrics processing of information and science mapping

Adapted from Ogunsakin et al., 2022

In order to ensure that the extracted data were properly analyzed and the needed results gotten, five important steps that allow quantitative and qualitative analysis used for a bibliometric analysis were considered, these are, data importation and conversion, descriptive bibliometric analysis, matrix creation, normalization and mapping.

2.2. Research Methodology

Bibliometrics analyses allow us to find a vast array of perception from an averagely comprehensive study. Bibliometrics tool in R package is designed to be used in quantitative scientometrics and informetrics (Aria and Cuccurullo, 2017). The tool provided various measures for the importation of bibliographic data from various database such as Social Science Citation Index (SSCI), Science Citation Index Expanded (SCI-EXPANDED), PubMed, Scopus, Clarivate Analytics Web of Science, MedLine, Digital Science Dimensions, Lens, and Cochrane Library. In addition, the bibliometric packages allow for classification and analyzing vast quantities of historical data from research spanned over a specified period to acquire metadata from the database. Following the importation of the documents, data pre-processing and bibliometric analysis on the sources, authors, citations, scientific collaboration and keywords analyses were performed and the graphs obtained were then visualized. The VOSviewer package of R language was applied to visualize the collaboration network of high-producing countries and authors in green building research (Van and Waltman, 2013). The command `vos.path = ""`, `type = "VOSviewer"`, `size = T`, `delete; multiple = T` has been used to call the VOSviewer software application and generate cooperative maps for both countries and authors. The visualization maps were created with the help of VOSviewer 1.6.17 (Centre for Science and Technology Studies, Leiden University) to analyze and visualize any relationships among authors, countries, and the terms used in the papers (Van and Waltman, 2013).

3.0 Results and Discussion

A total of 63,869 documents were identified from the database as published documents since inception of the concept of green building. When it was limited to cover the scope of this study, that is, ten (10) years span, 2012 – 2022, a total of 49,927 documents were gotten and out of this, 36,915 were identified as published articles, these were categorized and a total of 5,365 were under environmental sciences and further restricted to published articles in English Language. Eight articles not published in English Language were then removed. This was done by restricting the results to English Language only during the research. Finally, 5,357 relevant papers were eligible for the final bibliometric analysis. This was further categorized in descending order as, articles (3,960; 73.94%), proceedings (1,077; 20.11%), review articles (301; 5.62%), book chapters (106; 1.98%), letters (85; 1.58%), early access (78; 1.46%), editorial (46; 0.86%), meeting abstracts (11; 0.20%), corrections (6; 0.12%), letters (5; 0.10%), others (14; 0.27%).

3.1 Annual scientific production

This is shows the trends of research within a year, that is, publication year trend, based on the statistics from our data analysis, it shows that from the time of collection of articles about published articles on green building, a total of 3,960 articles were published within the study period. Fewer articles were published in this area at the beginning of the study period; this is because the study on green building was just gathering momentum.

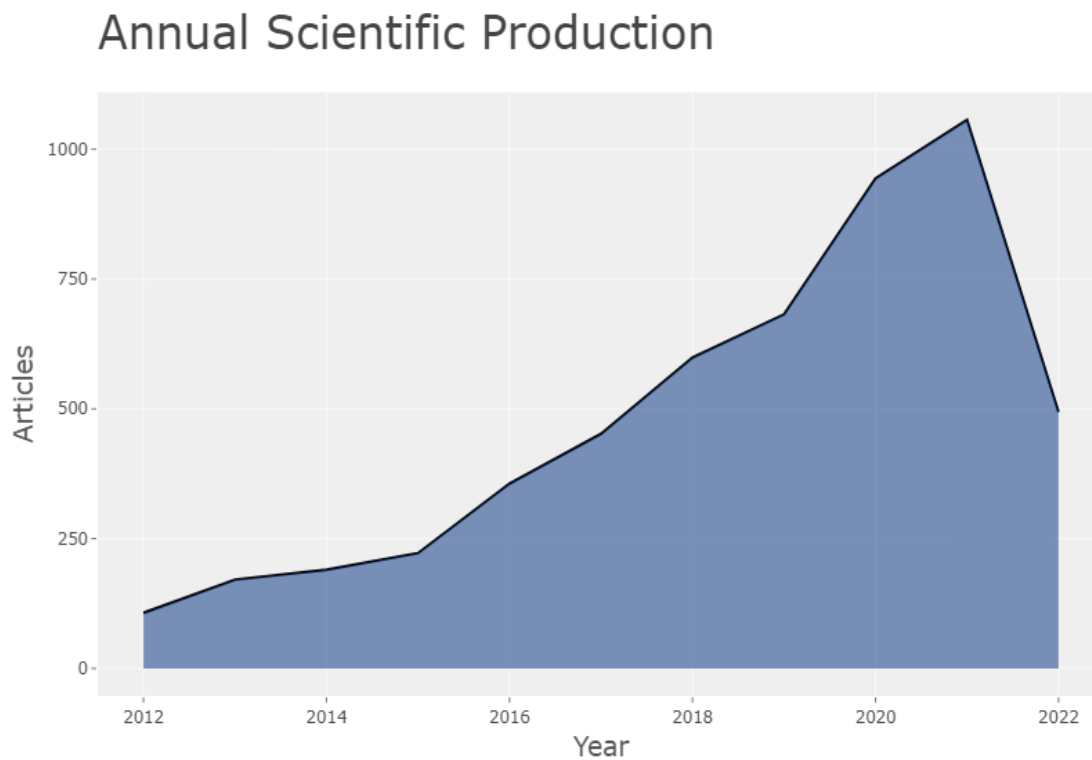


Figure 2. Annual scientific production of literature on green building

It is worthy to note that from 2012 to 2015, the number of published articles on green building increase steadily; the implication of this was that, the research on green building attracted minimum attention of most researchers within this period. However, the published articles on green building increased drastically in 2016 – 2020 (Figure 2), this indicates that green building has attracted the attention of many scholars from various countries. Between 2020 and 2021, which can be described as the active high-performance period, recorded a sharp increase, reaching a maximum of 1,057 in 2021. Though the number of publication for 2022 was 494 as at May, 2022 when the data were extracted the projected figure for the whole year of 2022 will be 1,186, which is higher than that of 2021. This shows an upward trend within the years under review and this in agreement with other authors in separate and similar studies such as Zhao et al., 2016; Zhang et al., 2019; Li et al., 2021 and Chen et al., 2022 have reported.

3.2. Top authors' production over time and their relevance

Considering the number of papers published (Figure 3) the top 10 authors were Wang Y, Zhang Y, Zhang X, Llu Y, Wang J, Zhang J, Wang X, Li Y, Li J, and Llu X with 96, 76, 75, 68, 65, 63, 62, 59, 54, and 48 articles, respectively. The Chinese scholar, Wang, Y. is the first influential author regarding green building in document numbers with h-index and g-index of 21, and 36, respectively. Most of his reported papers were published in high-impact factor journals of high quality.

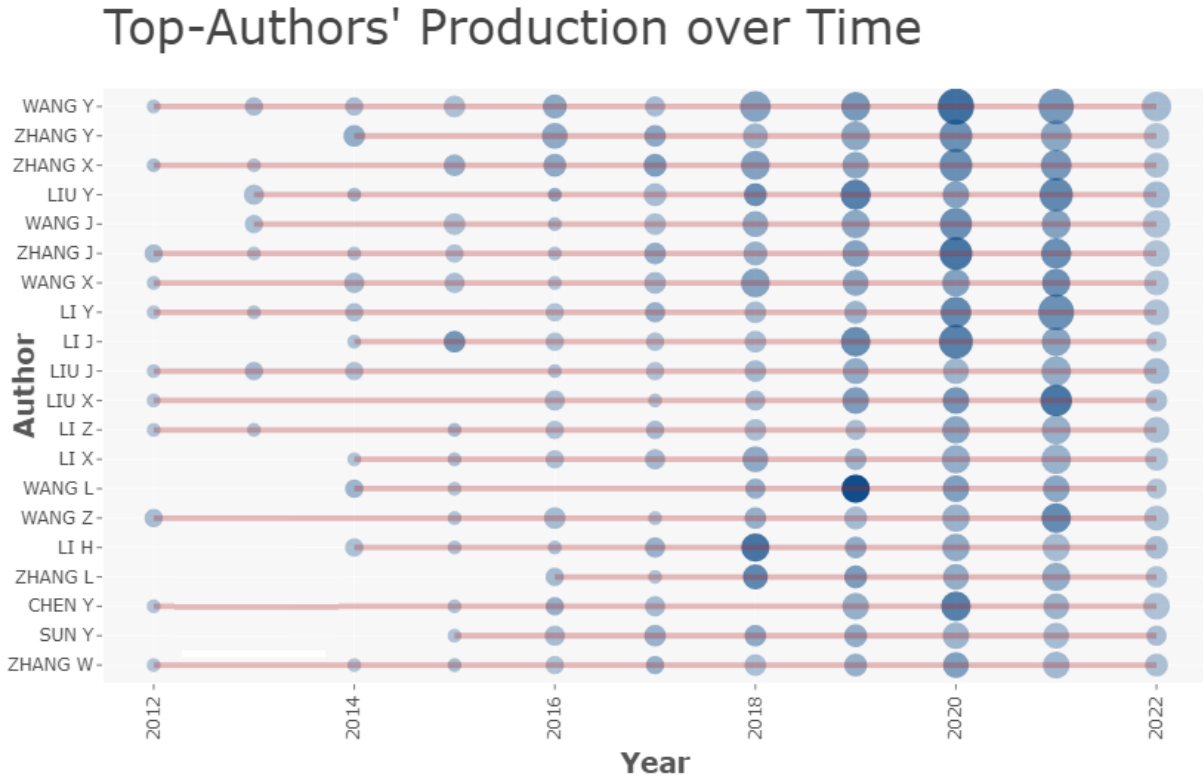


Figure 3. Top-authors' production over time in green building

Interestingly, Wang Y obtained the highest number of published articles and the highest frequency peak of average citations per item in 2020. Zhang Y is another leading outstanding researcher when it comes to research on green building. The author has 76 articles; h-index and g-index of 20 and 34, respectively. Most of the reported papers from this author also were published in high-impact factor journals of high quality.

3.3 Academic Collaboration Network

A collaborative network is a network that shows a link among authors and co-authors in particular field of study. Collaborations of authors are part of the strength that accelerates expertise and discussion, it widens the vision of a particular subject area and this is also applicable to green building. It is worthy to note that, there are collaborations between the authors at multiple levels on green building. VOSviewer was used to visualize the graph from the R studio software interface. Figure 4 shows node, which signifies the authors, the size of the node signifies the number of articles, the lines denote the strength of collaboration between the authors, and each color signifies a cluster (group of items with comparable attributes within a network) (Xie et al., 2020). The network is positioned on Wang Y, Zhang Y, Zhang X, Zhang J, Wang J and Llu, respectively. The network represented by Wang Y and Zhang Y has a high clustering density, and the authors have a significant influence in the field of green building.



Figure 4. Authors' collaboration network in green building publication

Besides, Zhang Y and Zhang J are influential authors in the subject area of green building. Wang's h-index and g-index values are 21 and 36, respectively. Wang Y and co-workers did a collaborative network to bring together the relevant data from around Asia Countries to focus on the increase in green building reports. The collaborative effort led to the combination of data from ten Asia countries, which indicated that there is high increase and distinctive interest in green building.

3.4 Productive Journals in Green Building

The research articles were analyzed based on journal sources during 2012 – 2022 for researchers to identify a reliable reference and when searching for journals to publish their research manuscripts.

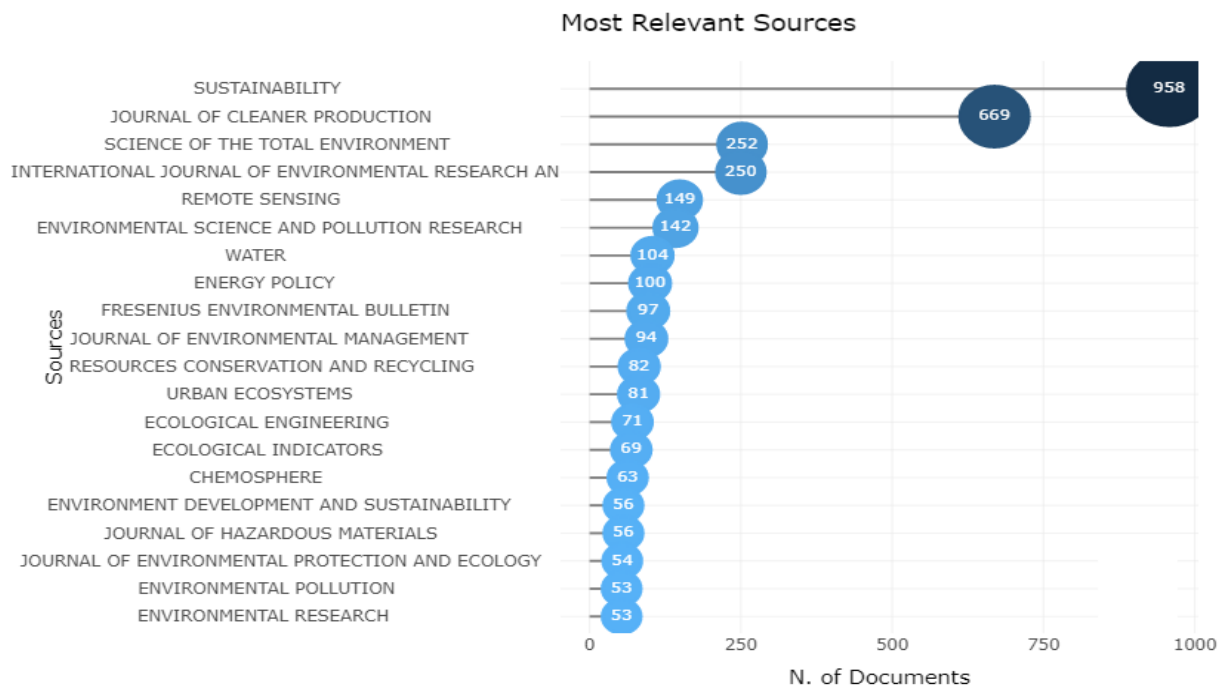


Figure 5. Productive journals in green building

The top 20 journals with high numbers of published green building-related articles were presented in Figure 5. Among the journals, Sustainability published the most (958), followed by the Journal of Cleaner Production

(669), Science of the Total Environment (252) and International Journal of Environmental Research and Public Health (250). Other core journals include Remote Sensing, Environmental Science and Pollution Research, Water and Energy Policy. The study of green building may be concluded to include multidisciplinary research, such as environmental pollution, urban ecosystem, built environment, chemosphere, energy policy, resources conservation and recycling, remote sensing and environmental science.

4.0 Future Perspective

Research in green building in recent times has drawn the attention of many scholars. Bibliometrics analyses of research trends in this area give a broad view of area of coverage in green building in terms of strength and limitations. Though the research team emphasized on the core areas of bibliometric analysis such as annual scientific production, top authors' production and their relevance over time, academic collaboration network and productive journals. It is however worthy to note that carrying out Bibliometrics analysis on green building in exhaustive details will require covering every aspect of the analysis and this is recommended for future consideration.

5.0 Conclusions

The current study conducted on green building between 2012 and 2022 through bibliometric analysis provides a quantitative representation of studies conducted and data gathered in the past and present, bridging the gap historical gaps and forecasting the future on green building thereby providing valuable insights for building research agenda and policymakers could use the results to strengthen investment policies in green building research and development.

6.0 Recommendations

The following are the recommendations:

- Awareness about green building
- Education/Advocacy about green building
- Enactment and enforcement of laws about green building

References

- Ade-Ojo, C. O. and Awodele, O. A. (2020). Awareness of green building pre-requisites for skill development among built-industry professionals in Nigeria. In book: *The Construction Industry in the 4th Industrial Revolution* pp. 188 – 196. doi:10.1007/978-3-030-26528-1 19.
- Ade-Ojo, C. O. and Ogunsemi, D. R. (2019). Cost prediction for affordable housing in Nigeria. In *Greening Affordable Housing*. e-Book 1st Edition ISBN = 9781315103556 pp.17 CRC Press
- Aria, M.; Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* 11, 959 – 975.
- Avis, D. and Nils, K. (2015). Greencertification and building performance: Implications for tangibles and intangibles. *The Journal of Portfolio Management.* doi:10.3905/jpm.2015.41.6.151; 1 -15
- Deng, Z.; Chen, J.; Wang, T. (2020). Bibliometric and visualization analysis of human coronaviruses: Prospects and implications for COVID-19 research. *Front. Cell. Infect. Microbiol.* 10, 529.
- Deng, Z.; Wang, H.; Chen, Z.; Wang, T. (2020). Bibliometric analysis of dendritic epidermal T cell (DETC) research from 1983 to 2019. *Front. Immunol.* 11, 259.
- Ekundayo, T. C. and Okoh, A. I. (2018). A global bibliometric analysis of Plesiomonas-related research (1990–2017). *PLoS ONE* 13, e0207655.
- "Green Building - US EPA". www.epa.gov. Archived from the original on 2006-09-22. Retrieved 2022-06-20.
- Huo, X., Yu, A.T.W., Wu, Z. (2017). A comparative analysis of site planning and design among green building rating tools. *Journal of Cleaner Production*, 147: 352-359.
- Hwang, B.-G., Tan, J.S. (2012). Green building project management: obstacles and solutions for sustainable development. *Sustainable Development*, 20(5): 335 - 349.
- Ilhan, B., Yaman, H. (2016) Green building assessment tool (GBAT) for integrated BIM-based design decisions. *Automation in Construction*, 70: 26 - 37.
- Illankoon, I.M.C.S., Tam, V.W.Y., Le, K.N., et al. (2017) Key credit criteria among international green building rating tools. *Journal of Cleaner Production* 164: 209-220.
- Jalaei, F., Jade, A. (2015) Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings. *Sustainable Cities and Society*, 18: 95 - 107.
- Li, C.; Ojeda-Thies, C.; Renz, N.; Margaryan, D.; Perka, C.; Trampuz, A. (2020). The global state of clinical research and trends in periprosthetic joint infection: A bibliometric analysis. *Int. J. Infect. Dis.* 96, 696 – 709.
- Liu, Y., Guo, X., Hu, F. (2014). Cost-benefit analysis on green building energy efficiency technology application: A case in China. *Energy and Buildings*, 82: 37 - 46.
- Nilashi, M., Zakaria, R., Ibrahim, O., et al. (2015) A knowledge-based expert system for assessing the performance level of green buildings. *Knowledge-Based Systems*, 86: 194 - 209.
- Ogunsakin, R. E., Ebenezer O. and Ginindza, T. G. (2022). A Bibliometric Analysis of the Literature on Norovirus Disease from 1991–2021 *Int. J. Environ. Res. Public Health*

19, 2508. <https://doi.org/10.3390/ijerph19052508>

- Roth, G.A.; Johnson, C.; Abajobir, A.; Abd-Allah, F.; Abera, S.F.; Abyu, G.; Ahmed, M.; Aksut, B.; Alam, T.; Alam, K. (2017). Global, regional, and national burden of cardiovascular diseases for 10 causes, 1990 to 2015. *J. Am. Coll. Cardiol.* 70, 1–25.
- Si, J., Marjanovic-Halburd, L. and Nasiri, F. (2016). Assessment of building-integrated green technologies: A review and case study on applications of Multi-Criteria Decision Making (MCDM) method. *Sustainable Cities and Society*, 27: 106 - 115.
- Singh, A., Syal, M. and Grady, S.C. (2010). Effects of Green Buildings on Employee Health and Productivity. *American Journal of Public Health*, 100 (9): 1665 - 1668.
- Solaimani, S. and Sedighi, M. (2019). Toward a holistic view on Lean sustainable construction: a literature review. *Journal of Cleaner Production*, DOI: 10.1016/j.jclepro.2019.119213
- U.S. Environmental Protection Agency. (October 28, 2009). Green Building Basic Information. Retrieved June 22, 2022 from <http://www.epa.gov/greenbuilding/pubs/about.htm> Archived 2006-09-22 at the Wayback Machine
- Van Eck, N.J. and Waltman, L. (2013). VOSviewer manual. Leiden Univeristeit (1) 1 – 53.
- Wei, W., Ramalho, O., Mandin, C. (2015). Indoor air quality requirements in green building certifications. *Building and Environment*, 92: 10 - 19.
- Xi, J. A., Min, W., Graham, D.Y., Estes, M.K. (1992). Expression, Self-Assembly, and Antigenicity of the Norwalk Virus Capsid Protein. *J. Virol.* 66:6527 – 6532.
- Xie, H.; Zhang, Y.; Wu, Z.; Lv, T. (2020). A bibliometric analysis on land degradation: Current status, development, and future directions. *Land* (9): 28.
- Yan Ji and Stellios Plainiotis (2006). Design for Sustainability. Beijing: China Architecture and Building Press. ISBN 7-112-08390-7
- Yang, R.J., Zou, P.X.W. (2014) Stakeholder-associated risks and their interactions in complex green building projects: A social network model. *Build and Environment* 73: 208 - 222.
- Zhao, X. , Zuo, J., Wu, G. and Huang, C. (2019). A bibliometric review of green building research 2000 – 2016 *Architectural Science Review* Vol. 62 (1) 74 - 88
- Zhang , X., Song, L. and Min, H.(2019). The state-of-the-art of green building research (2010-2019): A bibliometric review 2019 *IOP Conf. Ser.: Earth Environ. Sci.* 376 012025 doi:10.1088/1755-1315/376/1/012025