A theoretical mapping of green roofs on building for sustainable constructions

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Abstract. In 2019, the results of the national GHG inventory calculation showed a GHG emission level of 1,866,552 Gg CO2e in each industrial sector. This poses a significant challenge in the era of globalization. If construction continues with high carbon usage, climate change conditions in the coming years will likely lead to global warming of more than 1.5°C. One of the proposed agendas in the Indonesia Construction 2030 document is the promotion of sustainable development through the application of environmentally friendly building concepts. This paper aims to map the studies conducted on Green Roofs within the past 10 years and study their application in Sustainable Construction in Indonesia. The mixed method approach was used in this research. A total of 864 articles were gathered from the Scopus database, and a bibliometric analysis was conducted using the VOSviewer® application. The results indicate that the number of publications between 2012 and 2023, indexed by Scopus, was highest in 2020, with 110 publications. China emerged as the largest contributor in terms of publications. The most productive authors were Cabeza L. F. and Shushunova N., who produced 12 articles. The development of publications based on co-words resulted in three clusters. The application of green roofs in Sustainable Construction in Indonesia has already commenced, with notable examples such as the PT Dahana Campus and the University of Indonesia Library. These projects have demonstrated numerous benefits.

1 Introduction

The increasing concentration of greenhouse gases in the Earth's atmosphere has had a profound impact on climate change, leading to significant changes in people's lives. These changes are characterized by more frequent extreme weather events, such as heavy rainfall, rising temperatures (global warming), increased water volume due to melting polar ice caps, and reduced water resources. To address these challenges, the United Nations Framework Convention on Climate Change (UNFCCC) was established. Climate change is primarily caused by human activities that alter the composition of the global atmosphere, as well as natural climate variability over comparable periods. According to the Greenhouse Gas Inventory and Monitoring, Verification Reporting in 2020, Indonesia has set a target of reducing greenhouse gas emissions by 29% (unconditional) to 41% (conditional) compared to the Business as Usual (BAU) scenario by 2030, as outlined in the Nationally Determined Contributions (NDC) document. Specifically, the emission reduction target for 2030, based on the NDC, is 834 million tons of CO2e for the unconditional target (CM1) and 1,081 million tons of CO2e for the conditional target (CM2). The results of the national GHG inventory calculation in 2019 revealed that the total GHG emission level amounted to 1,866,552 Gg CO2e. The emissions were categorized as follows:

1) Energy accounted for 638,808 Gg CO2e,
2) Industrial Processes and Product Use accounted for 60,175 Gg CO2e,
3) Agriculture accounted for 108,598 Gg CO2e,
4) Forestry and Peat Fire accounted for 924,853 Gg CO2e, and
5) Waste accounted for 134,119 Gg CO2e. The achievement of GHG emission reduction in 2019 was 68.99 million tons of CO2e at the national level.

The emergence of the COVID-19 pandemic in 2020 had a significant impact on Indonesia's economic growth rate. However, the implementation of activity restrictions, such as the requirement for people to work from home (WFH) during certain times and in specific regions, resulted in reduced emissions across all sectors. It is important to note that as we anticipate the post-COVID-19 period, efforts to boost economic growth may lead to an increase in overall carbon production. Continuing development with high carbon usage poses a risk of exacerbating climate change conditions in the coming years, potentially leading to a temperature increase of more than 1.5°C (global warming). Therefore, it is crucial to prioritize low-carbon development strategies to effectively reduce greenhouse gas emissions. One of the proposed agendas in the Indonesian Construction 2030 document is to promote sustainable construction practices. This includes measures to conserve materials, reduce the generation of residual waste, and facilitate post-construction building

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maintenance. By embracing sustainable practices, the construction industry can contribute to mitigating environmental impacts and fostering a greener future [1].

The goal of sustainable development is to achieve sustainable, environmentally friendly, and high-performance buildings. One effective strategy for achieving these objectives is the adoption of Green Roof technology. Green Roofs serve various functions, including enhancing public comfort, reducing the need for cooling and heating, mitigating air pollution, and improving air quality, among others. They also act as a rainwater conservation method, particularly valuable in areas with limited water catchment, which was evident during the widespread floods experienced in early 2021. However, despite the benefits, the application of Green Roofs in Indonesia, especially in certain areas prone to frequent flooding, has been limited. Green Roofs can significantly reduce the amount of water entering drainage channels, thereby helping to prevent flooding. Moreover, the concept of Green Roofs can be combined with sensor technology to automate plant watering processes. In 2016, Indonesia experienced a notable increase in its environmental performance index, scoring 21.49 points higher compared to 2014. This index encompasses various components, including clean air quality, species preservation, indoor air quality, hazardous chemical management, urban waste management, nuclear safety, preservation of fertile land, agricultural land degradation, recycling rates, adaptation, vulnerability, and resilience to climate change. This achievement can serve as an asset for Indonesia in promoting the widespread adoption of Green Roofs within the construction sector. However, in terms of research and publications on Green Roofs, Indonesia has only produced 15 publications between 2012 and 2023, as per the data obtained from the Scopus database. This indicates that there is still limited research output on Green Roofs in Indonesia, highlighting the need for further exploration and investigation in this field.

This study aims to map the research conducted on Green Roofs within the past 10 years and explore their application in Sustainable Construction in Indonesia. Green Roof research offers a range of benefits for different stakeholders, including building owners and the government, as it provides economic advantages. By researching Green Roofs, stakeholders can capitalize on these benefits and develop innovative technologies and practices that optimize the utilization of Green Roofs in urban environments.

2 Literature review

2.1 Definition of green construction

The implementation of Green Construction is highly embraced by many countries today due to its positive impact on the development of environmentally friendly construction practices. In Indonesia, the construction industry is also experiencing rapid growth, encompassing the construction of buildings, bridges, water structures, and roads. As a result, the application of Green Construction is warmly welcomed in Indonesia, exemplified by the issuance of Minister of Public Works and Public Housing Regulation Number 21 of 2021, which focuses on Green Building Performance Assessment. Green Construction is an integral part of Green Building, and its successful implementation requires proper management to achieve sustainable construction standards. The typical stages involved in a construction project include design or planning, procurement, operation, and post-development maintenance. In the context of "Green" buildings, these stages encompass the pre-design stage, design stage, bid stage, construction stage, and occupancy stage [2]. Green Construction entails the planning and management of construction projects through contract documents to minimize the environmental impact of the construction process. The concept of Green Construction encompasses several aspects, such as construction project planning and scheduling, material conservation, appropriate land use, construction waste management, material storage, creation of an environmentally friendly work environment, and the use of eco-friendly construction equipment [3]. Furthermore, Green Construction involves the practice of building structures while adhering to environmental considerations and resource efficiency throughout the building's lifecycle, spanning from site planning, construction, operation, maintenance, and renovation, to deconstruction. It emphasizes the efficient utilization of natural resources and energy, to minimize waste generated by construction projects while maintaining the quality of the building [4]. Based on the information provided, it can be concluded that Green Construction encompasses a series of development activities that aim to utilize natural resources and energy efficiency while prioritizing environmental friendliness. The objective is to minimize the generation of harmful gases and excessive construction waste, all while maintaining the quality of construction and producing environmentally friendly building products. The following outlines the process of Green Construction:

1. Green construction implementation method.

   Before commencing a construction project, it is essential to determine the appropriate implementation method. The construction implementation method plays a key role in transforming a plan into a physical building. It comprises procedures, techniques, and core activities within the construction management system. The chosen implementation method should be adjusted to the environmental conditions to avoid any detrimental effects [5].

2. Optimization of equipment usage.

   During the construction project, various resources are utilized to achieve the desired outcome. Equipment costs typically account for 7-15% of the total project cost. Construction equipment refers to tools or machinery employed for mechanical construction work. Therefore, maximizing the efficient utilization of heavy equipment during the project implementation stage can lead to improved efficiency, effectiveness, and desired outcomes [6].

3. Implementation of construction waste management.

   Construction waste refers to leftover materials that can no longer be utilized in construction activities. It includes materials from both development and demolition projects, such as concrete, stone, brick, plaster, and other discarded items. Construction waste has significant negative impacts on the environment. Proper management of construction waste is crucial. Three considerations should be taken into account when implementing waste management:

   1) Environmentally and human-friendly building design;
   2) Construction implementation; and
   3) Fostering a green construction mindset among project workers. This approach can help minimize the negative environmental impact and improve people's lives [7].

4. Application of water conservation in construction implementation.

   Water conservation measures are employed to reduce unnecessary usage of clean water, enhance recycling systems, and promote the reuse of rainwater or wastewater [8].

2.2 Definition of green roof

The application of green roofs has been implemented in various locations worldwide, including Singapore, Japan, and other developed countries. From a technical perspective, the use of green roofs can influence building design in several ways, such as load considerations, accommodating space for green roof layers, and drainage systems, and addressing wastewater issues for plants [9]. A green roof consists of five main layers: vegetation layer, soil layer (substrate/growing media), filter layer, drainage layer, and waterproof membrane. The concept of green roofs has gained traction in Indonesia in recent years. It is derived from the principle of sustainability, which emphasizes the interaction between Earth's resources and human cultural and economic systems, as well as adaptability to changing environmental conditions. Apart from enhancing aesthetics and a harmonious connection with nature [10], the purpose of implementing green roofs includes rainwater absorption, providing an insulation zone, creating habitats for wildlife, mitigating air and noise pollution, and reducing the impact of global warming. Green roofs are also known as eco-roofs, rooftop greenery, vegetated roofs, and living roofs [9]. Additionally, green roofs offer benefits in water catchment areas by attenuating rainwater runoff, reducing noise and air pollution, and preserving wildlife and biodiversity. The application of green roofs contributes to creating visually appealing and comfortable cityscapes, fostering healthier cities, providing living spaces and recreational areas for people, offering opportunities for quality time, improving water and air quality, constructing environmentally friendly buildings, reducing roof maintenance costs, and mitigating the effects of ultraviolet radiation and extreme temperature changes around buildings.

Based on their role, green roofs are classified into three types [11] (Fig. 1 and Tables 1-2):

1) Intensive green roofs. These roofs have a planting media layer with a thickness of more than 20 cm. They use fertile soil and are suitable for locations like campuses or performance halls where various types of vegetation can be grown. Intensive green roofs are commonly applied to houses and buildings.
2) Extensive green roofs. These roofs have a planting media layer with a thickness of less than 15 cm. They do not require highly fertile soil and are typically covered with grass. Due to their thin layer, extensive green roofs are not intended for foot traffic.
3) Brown or biodiverse roofs. These roofs are intentionally designed to support the growth of wild plants. They aim to create a natural and ecological roof ecosystem. In addition to soil and plants, biodiverse roofs incorporate sand, rocks, and other elements. They provide habitats for insects and animals, promoting biodiversity and natural balance. The planting medium for brown roofs consists of a thin layer of soil supplemented with sand and rocks.

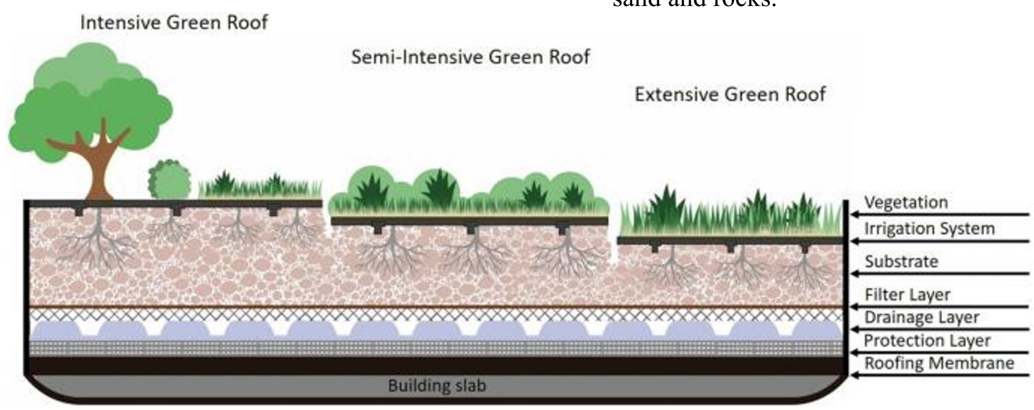

Fig. 1. Longitudinal sections of each green roof type [12].

Table 1. Features of green roof types.

Roof Type	Intensive	Semi-Intensive	Extensive
Height	> 20cm	12-25 cm	6-20 cm
Weight	200-500 kg/m^2	120-200 kg/m^2	60-150 kg/m^2
Vegetation	Trees, Herbaceous Plants, Shrubs, Coppices, Grasses	Shrubs, Coppices, Grass, Herbaceous Plants	Grass
Drainage	Separate layer	Separate layer	No separate layer
Irrigation	Required	Required	Required
Accessibility	Often accessible	Partially accessible	Often inaccessible
Maintenance	Regularly	Periodically	Rarely

Table 2. Economic benefits and barriers of green roofs.

Economic Benefits of Green Roof	Disadvantages of Green Roofs from an Economic Perspective
Reduce UsageEnergy	High Construction Cost
Improving Thermal Insulation in Reinforcement	High maintenance costs,especially with intensive green roofs or when irrigation required
Reduced roof maintenance costs due to extended lifespan resilience	Complex construction
Reduce the amount of rainwater wasted on urban infrastructure	Risk of failure
Increase the market price and selling price of buildings	Costly integration of existingbuildings when structural adjustments are madeas required
Improving the surface buildings that can be used	

The construction of a green roof typically involves several layers, including a concrete floor plate, waterproof membrane, drain mat, filter cloth, growing medium, and vegetation. The concrete floor plate serves as the base or structural element of the roof. The waterproof membrane is applied as a layer to ensure the roof's waterproofing. A drain mat is used to facilitate water flow from the irrigation system on the green roof. The filter cloth acts as a separator between the drain mat and the growing medium. The growing medium provides the planting substrate for vegetation to thrive. Finally, the top layer consists of the vegetation itself, such as plants, grass, flowers, or trees [13]. Several key characteristics of vegetation influence the heat transfer on green roofs, including plant height, leaf area index, fractional coverage, albedo (reflectivity), and stomatal resistance [14]. According to the Guidelines for the Provision of Green Open Space Utilization in Urban Areas issued by the Ministry of Public Works in 2008, the criteria for vegetation used in building roof gardens and potted plants include the following:

a) Plants should have shallow root systems to thrive in pots or planters;
b) They should be relatively resistant to water shortages;
c) Their root and stem growth should not interfere with building structures;
d) They should be able to withstand and thrive in high ambient temperatures;
e) They should be easy to maintain.

Fig. 2 illustrates the common types of vegetation used in green roofs.

Fig. 2. Plantation options of various designs of green roofs [15].

2.3 Definition of sustainable construction

The link between sustainable construction and sustainable development lies in the integration of a healthy working environment, work efficiency, and quality of life through efficient design processes, sustainable procurement, and sustainable construction implementation [16]. The commitment, knowledge, and involvement of various stakeholders in the construction industry are crucial to producing projects that reflect significant efforts toward achieving a greener environment [16]. Furthermore, it is necessary to establish specific requirements aimed at minimizing barriers to the implementation of sustainable construction on a national level. This is essential for successfully adopting sustainable construction practices.

The commitment, knowledge, and involvement of various stakeholders in the construction industry are essential to produce projects that reflect significant efforts toward achieving a greener environment [16]. Additionally, there is a need to develop requirements that minimize barriers in national construction to successfully implement sustainable construction.

In principle, the development of various infrastructures should be based on local building technologies and the ecological demands of nature. Sustainable development encompasses four principles of ecologically sustainable development:

1) Using natural raw materials at a rating that aligns with the pace at which nature can generate replacements.
2) Establishing a system that maximizes the utilization of renewable energy.
3) Allowing for the utilization of edible by-products or by-products that can be used as raw materials for the production of other materials.
4) Promoting an increase in functional customization and biological diversity.

The implementation of sustainable development needs to consider five aspects [2]:

1) Implement measures for plant and ecosystem protection.
2) Plan and implement occupational health and safety programs.
3) Efficiently utilize natural resources and minimize waste during the construction or demolition stage of the building by implementing a construction waste management plan.
4) Provide training for subcontractors on environmentally focused construction practices and safety programs.
5) Minimize the negative impact of previous development activities.

The government has issued Ministry Regulation PUPR No. 5 of 2015, which pertains to the implementation of sustainable construction. Other regulations associated with sustainable construction include Law No. 5 of 2015 on the implementation of sustainable construction, Law No. 18 of 2013 on the prevention and eradication of forest destruction, Law No. 26 of 2007 on spatial planning, and Act No. 41 of 1999 on forestry. These regulations are interconnected and contribute to the framework of sustainable construction.

To plan and achieve sustainable development, the project team needs to work collectively and consider the following aspects:

a) Improving the material transfer and storage system to minimize construction material waste;
b) Recycling materials such as topsoil, asphalt, and concrete for use in new buildings;
c) Establishing requirements for product and material installation procedures to address air quality concerns;
d) Providing comprehensive training to subcontractors on construction waste management;
e) Monitoring moisture levels during the construction phase; (f) e
f) Ensuring soil hardness at the work site to prevent erosion and sedimentation; and
g) Minimizing the impact of construction activities, such as compaction and tree damage, at the work site.

2.4 Scope and structure of the paper

To establish a shared understanding of the concept addressed in this paper, "A Theoretical Mapping of Green Roofs on Buildings for Sustainable Constructions" presents an extensive examination of publications related to Green Roofs on buildings to achieve sustainable construction. The study utilizes the Scopus database and VosViewer application to analyze publications based on criteria such as publication year, country, keywords, and the number of researchers involved. Additionally, a research review is conducted to explore the application of Green Roofs specifically in Indonesia.

3 Research method

This paper employs quantitative and qualitative methods, including mixed methods, to analyze articles about Green Roof. The quantitative analysis examines the distribution of Green Roof publications, taking into account factors such as time, authors, countries, research institutions, subject categories, and published journals. The qualitative analysis involves importing several bibliometric records into a bibliometric tool for visualization analysis, including co-authorship networks, country and institution networks, co-occurring subject category networks, co-occurring keyword networks, journal co-citation networks, author co-citation networks, and document co-citation networks. Bibliometric analysis is utilized to explore and analyze various bibliographic data in related articles. The process of preparing this paper involves three stages:

1. Data collection comprising articles and publications relevant to green roof for sustainable construction,
2. Quantitative analysis through bibliometric analysis, and
3. Qualitative analysis to comprehensively discuss the obtained results.

3.1 Quantitative analysis

This research utilizes international publication data in the field of instrumentation obtained from the Scopus database (www.scopus.com). Scopus was chosen due to its status as one of the largest databases of abstracts and citations from the peer-reviewed research literature, comprising over 22,000 titles from more than 5,000 international publishers. Data collection involved searching for publications in Scopus using the keywords "green construction" and "green roof," focusing on article titles, abstracts, and keywords from 2012 to 2023. Only publications from the past 10 years, specifically from 2012 to 2023, were considered. A total of 864 research publications were obtained and will be utilized in the subsequent analysis. Microsoft Excel was used to analyze the data, including the number of publications per year, journals containing articles in the field of instrumentation, authors, author origins, and subjects. The development trend of international publications in the field of instrumentation was examined using VOSviewer.

Bibliometric analysis is a quantitative method used to explore and analyze bibliographic data from scientific articles. Its purpose is to provide an overview of the literature on a specific topic. Through this analysis, one can examine the performance and patterns of research conducted by various authors in different journals, countries, and institutions, as well as identify and observe the relationships between these studies. VOSviewer software was employed for bibliometric analysis in this study. VOSviewer is a visualization application that facilitates large-scale network analysis by utilizing natural language processing methods and text mining techniques to present comprehensive bibliometric maps in an easily interpretable manner. The software encompasses various bibliometric techniques, such as co-authorship, co-occurrence, citations, bibliographic merging, and co-citation analysis.

Data obtained from the Scopus database in the form of CSV files were imported into VOSviewer software to create a publication network based on direct citations. The network map is constructed using a distance-based approach, where the proximity between nodes indicates the degree of relatedness. The color of the network represents the concentration of citations, with red indicating the highest concentration. The bibliometric analysis was conducted based on this network map.

3.2 Qualitative analysis

A qualitative analysis was undertaken to gain a comprehensive overview of green roofs for sustainable construction. The objective of this qualitative analysis is not to generate new theories, but rather to identify the findings from various studies and identify any existing gaps. A review of several relevant published articles was conducted to obtain a broad understanding of green roof research conducted in the past decade, as well as their relevance to sustainable construction in Indonesia.

4 Results

4.1 Mapping of green roof studies conducted over 10 years

4.1.1 Publication development by year of publication

The analysis of publications on Green Roof over a span of 10 years, from 2012 to 2023, sourced from the Scopus database, reveals a notable increase in the number of publications. Specifically, there was a significant rise from 73 publication articles in 2018 to 96 publication articles in 2019. The highest growth in publications related to Green Construction and Green Roof, as indexed by Scopus, occurred in 2020, with a total of 110 publications (12.75% growth). Further details regarding the growth of international publications are exhibited in Table 3.

Table 3. Number of publications within 10 years.

Year	Number of Publication	Percentage
2012	47	5.45%
2013	60	6.95%
2014	74	8.57%
2015	46	5.33%
2016	61	7.07%
2017	74	8.57%
2018	73	8.46%
2019	96	11.12%
2020	110	12.75%
2021	90	10.43%
2022	108	12.51%
2023	24	2.78%

4.1.2 Publication development by country

Based on the published data obtained from Scopus regarding Green Construction and Green Roofs, the findings indicate that China has the highest number of articles published in this field, with 161 articles (19.90%). This is followed by the United States (US) with 100 articles (12.36%), and Italy with 48 articles (5.93%). The data also demonstrates that research on Green Construction and Green Roofs has been conducted in numerous countries worldwide, as presented in Table 4.

Table 4. Number of publications by country.

Country	Number of Publication	Percentage
Slovakia	10	1.24%
Portugal	10	1.24%
Sweden	11	1.36%
Germany	11	1.36%
Hong Kong	12	1.48%
Taiwan	14	1.73%
Austria	14	1.73%
Turkey	15	1.85%
Indonesia	15	1.85%
Czech Republic	15	1.85%
France	20	2.47%
Poland	21	2.60%
Iran	22	2.72%
South Korea	22	2.72%
Brazil	22	2.72%
Greece	24	2.97%
Malaysia	30	3.71%
Canada	30	3.71%
Russian Federation	30	3.71%
India	34	4.20%
United Kingdom	38	4.70%
Spain	39	4.82%
Australia	41	5.07%
Italy	48	5.93%
United States	100	12.36%
China	161	19.90%

The network of countries or regions illustrates the connections between countries or the contributions made by each country in the field of Green Roof research. The resulting network (Fig. 3) comprises 13 clusters and 173 links, with a total link strength of 241. Based on the network, it is evident that out of the 83 countries mentioned in all the documents, only 67 countries are interconnected. This information is valuable for readers to understand that over the past 10 years, Green Roof has been widely discussed and has seen consistent growth. Furthermore, it highlights China as a notable example of successful Green Roof implementation, particularly for countries like Indonesia that are still in the process of adopting such practices.

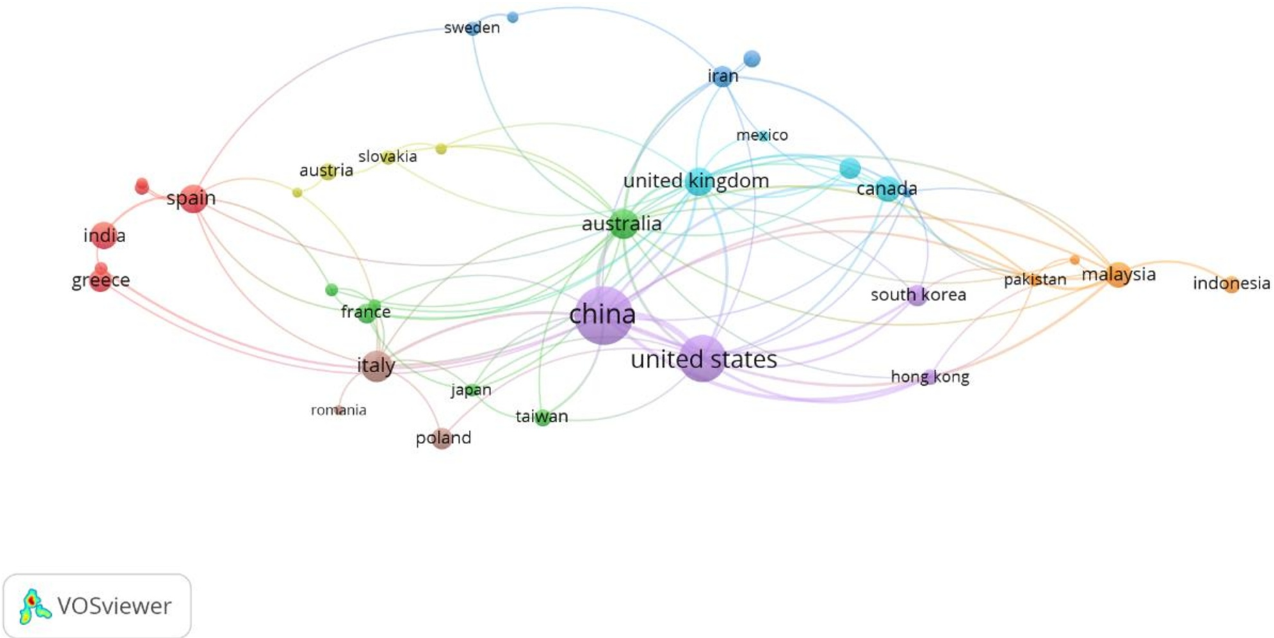

Fig. 3. Network of countries.

4.1.3 Publication development by keyword

Fig. 4 show the research publications from 2012 to 2023, categorized using Scopus-indexed keywords, can be grouped into three clusters. Cluster 1 (shown in red) includes the fields of green roofs, the construction industry, greenhouse gases, energy efficiency, green buildings, environmental impact, maintenance, urban heat island, and atmospheric temperature. Cluster 2 (shown in green) encompasses the fields of plant science, extensive green roofs, green space, irrigation, water retention, conservation of natural resources, facility design, and construction. Cluster 3 (shown in blue) focuses on the fields of drainage, water supply, stormwater management, and low-impact development.

4.1.4 Publication development based on the number of researchers

The productivity of the top 10 researchers indexed by Scopus from 2012 to 2023 demonstrates a diverse range of output, with publication counts ranging from 7 to 12, as presented in Table 5. According to Table 5, the researcher with the highest productivity is Cabeza, L. F. and Shushunova, N., each contributing 12 articles (12.90%), followed by Perez, G. and Papafotiou, M., with 11 articles (11.83%).

4.2 Application of green roofs in sustainable construction in Indonesia

Fig. 5 show the intensity of the yellow color indicates the number of publications in the field of instrumentation. Indonesia is depicted in green color, representing a total contribution of 15 publications out of 864 publications from all countries. This indicates that Indonesia has published a relatively small amount of research related to Green Roof.

However, the application of the green roof concept in building projects in Indonesia has been implemented in specific locations such as the University of Indonesia library (Fig. 6) and the Dahana Campus (Fig. 7) [17]. The following are some pictures showcasing the application of Green Roof in Indonesia:

1) Research results on the application of green construction and green roofs in Indonesia indicated that green construction, as part of sustainable construction, has an impact on building operation, the design process, and construction experience [5].
2) The green roof is a construction concept that involves adding layers to the roof to plant vegetation. Green roofs offer various sustainable environmental benefits, including improved air and water quality, functioning as rainwater catchment areas, room temperature cooling, enhanced ecological building practices, reduced

roof maintenance costs, and long-term durability when constructed properly [17].

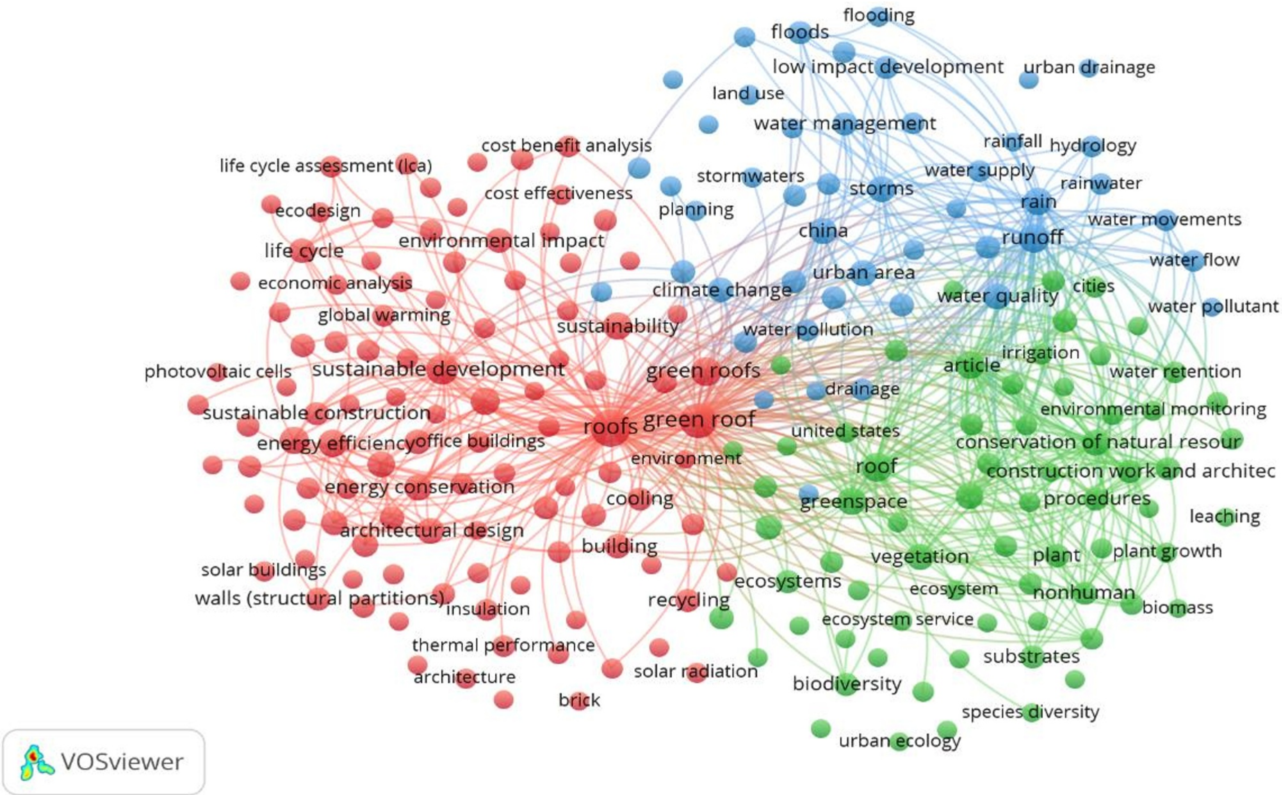

Fig. 4. Network of keyword co-occurrence.

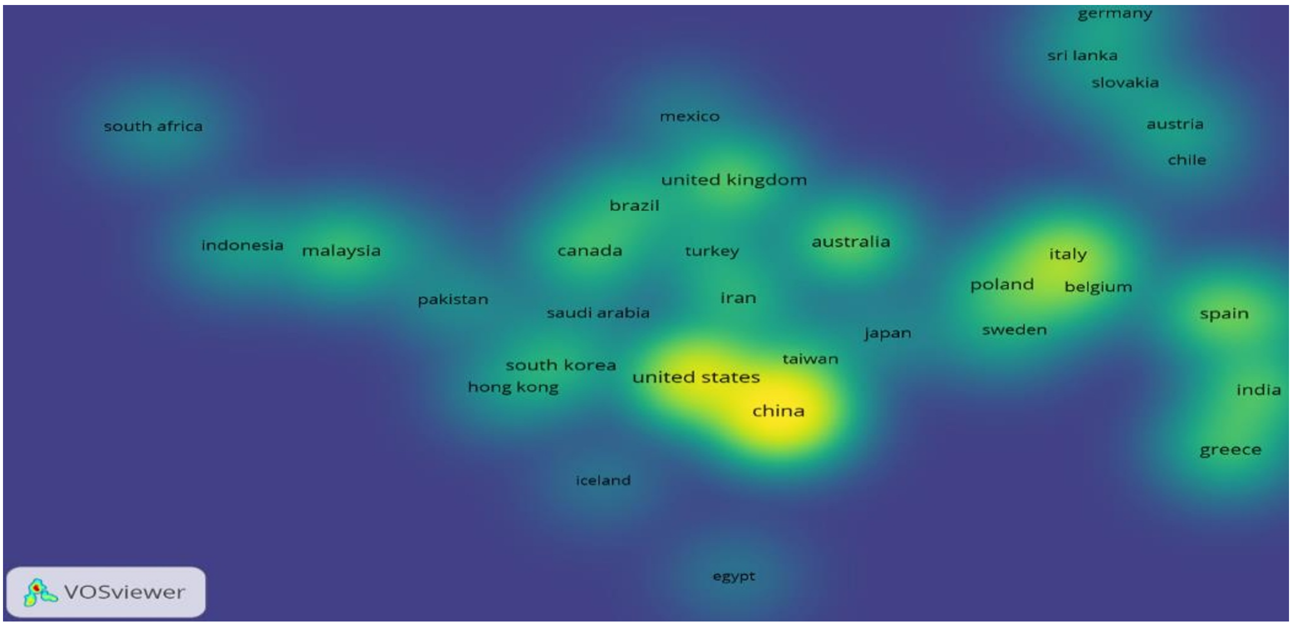

Fig. 5. Density visualization.

Fig. 6. The University of Indonesia library, Depok [17].

Fig. 6. PT Dahana Campus [17].

3) Green roofs bring a range of benefits, such as reduced building energy consumption, mitigation of the urban heat effect, improved air pollution, effective water management, enhanced sound insulation, and ecological preservation. Green roofs contribute to the development of more sustainable buildings and cities. However, the successful integration of green roofs requires consideration of specific climatic conditions and building characteristics. Economic aspects related to the life cycle costs of green roofs are also discussed, along with policies and incentive programs promoting green roofs worldwide [15].
4) An application of Green Construction through a Roof Garden, covering a land area of 416,380 m2, yields ecological benefits such as energy savings of up to 25 OHs (typically used), reduction of air pollutants by 8,956 kg to 89,563 kg, provision of habitat for 597,088 plants, and absorption of rainwater totaling 5,105,102 liters per year. Economic benefits include the production of 1,378 kg of mochi rice. Aesthetically, it reduces noise levels from 10 dB to 40 dB and contributes to the creation of 203 aesthetic areas within the city. Socially, it provides an additional 203 community spaces within the designated area block [18].
5) Green roofs have been proven to offer numerous benefits. In tropical climates, they contribute to energy savings by reducing heat transfer from the roof, thereby enhancing building user comfort, and reducing energy costs. Green roofs also help mitigate air pollution. In terms of water conservation, green roofs excel in capturing rainwater and preventing its wasteful runoff. Factors that influence water retention on a green roof include rainfall intensity and volume, the time elapsed since the last rainfall event, and roof slope and depth. The quality of runoff water from green roofs is influenced by factors such as vegetation type, fertilizer use, rainwater pH, and planting media [14].

Based on observations and studies conducted on two roof models, the conventional roof exhibited a maximum temperature of 39.7°C, while the plant roof recorded a maximum temperature of 30.7°C when the ambient temperature was 40.1°C. Furthermore, the plant roof demonstrated an annual energy consumption reduction of 1652.042 kJ (51.4%) compared to conventional roofs. These findings indicate that the plant roof building model minimizes roof temperature fluctuations and reduces overall building energy consumption compared to conventional roofs [19].

Improving air quality on green roofs involves the absorption of chemical pollutants, leading to a decrease in sulfur dioxide (SO_2), ammonia (NH_3), nitrogen dioxide (NO_2), ozone (O_3), and carbon monoxide (CO) levels [20]. Green roofs reduce temperature, pH, sulfate, and ammonia, enhancing air quality [21].

4.3 Discussion

Based on the mapping and analysis of existing literature, the development of publications on the application of Green Roof over the last 10 years (2012-2023) demonstrates a notable increase. Specifically, there was a significant surge from 73 published articles in previous years to 96 articles in 2019. The peak of publication activity occurred in 2020 with 110 articles. China emerged as the country with the highest number of published articles on Green Roof, with 161 articles, followed by the United States (100 articles) and Italy (48 articles). The research publications from 2012 to 2023, analyzed based on Scopus-indexed keywords, formed three distinct clusters. Cluster 1 (red) comprises topics related to green roofs, the construction industry, greenhouse gases, energy efficiency, green buildings, environmental impact, maintenance, urban heat island, and atmospheric temperature. Cluster 2 (green) includes fields such as plant science, extensive green roofs, green space, irrigation, water retention, conservation of natural resources, facility design, and construction. Cluster 3 (blue) focuses on drainage, water supply, stormwater management, and low-impact development. Regarding researcher productivity, Cabeza L.F. and Shushunova N. lead with a total of 12 articles, followed by Perez G. and Papafotiou M. with 11 articles. While publications related to green roofs in Indonesia remain limited, with only 15 publications out of 864, the application of green roofs in sustainable construction has begun in certain projects such as PT Dahana Campus and the University of Indonesia Library in Depok. These applications offer potential sustainable solutions to address environmental challenges faced by Indonesian cities, including heat reduction in buildings, increased sunlight reflection, mitigation of rainwater runoff, improved urban air quality resulting from industrial activity, and decreased greenhouse gas emissions. However, implementation challenges persist, including a lack of awareness, high installation costs, and limited availability of plant species suitable for local climates and site conditions.

5 Conclusion

Based on the aforementioned results and discussions, the following conclusions can be drawn, over the course of 10 years (2012-2023), the highest number of Scopus-indexed publications was observed in 2020, with a total of 110 publications. China emerged as the leading contributor in terms of publication output. Among the authors, Cabeza L.F. and Shushunova N. demonstrated the highest productivity, having produced 12 articles. The analysis of co-occurring keywords (co-words) resulted in the formation of three distinct clusters. These clusters highlight the objectives of sustainable development, focusing on the creation of sustainable, eco-friendly, and high-performance buildings. Green Construction, particularly Green Roofs, is one of the strategies and applications employed in sustainable development to achieve environmental friendliness. Green Roof offers numerous benefits, including the reduction of heat absorption in buildings, an increased reflection of sunlight into the atmosphere, mitigation of rainwater runoff to prevent flooding, improvement of urban air quality, and reduction of greenhouse gas emissions. The implementation of green roofs contributes to the development of more sustainable buildings and cities. Notably, green roof applications have been successfully implemented in various locations in developed countries. There have also been notable implementations in Indonesia, such as at the PT Dahana Campus and the University of Indonesia Library. These initiatives have demonstrated the manifold benefits of green roofs.

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