

Nature-Based Solutions and Materials Promoting Net-Zero Construction in South Africa: Trends and Insights from a Bibliometric Review

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Abstract

Buildings contribute 40% of global greenhouse gas emissions, with materials like cement, steel, and aluminium significantly adding to the carbon footprint. The worldwide goal to achieve net-zero emissions from the built environment can be achieved through Nature-based Solutions. NbS leverage ecosystems and their innate services to tackle pressing sustainability challenges, including climate change, energy consumption, energy poverty, and decarbonisation. This study examines the role of NbS and sustainable materials in advancing net-zero construction, emphasising their potential to reshape the industry's traditional approach to environmental and societal challenges. This bibliometric study, conducted using Elsevier Scopus, retrieved 51 documents and later filtered to 30 relevant studies, using the keywords "nature OR based AND solutions AND materials AND net AND zero AND construction." VOS viewer text-mining tool was employed to analyse the data, through cluster analysis identified key themes such as "Innovative Strategies for Decarbonisation and Circular Economy," "Sustainable Building Materials and Carbon Management," "Energy Efficiency and Decision-Making in Sustainable Architectural Design," "Zero-Carbon Strategies in Construction and Housing," and "Embodied Carbon and Sustainability in Construction Supply Chains." The analysis revealed the critical role of nature-based solutions in reducing carbon emissions, optimising supply chains, and enhancing energy efficiency. However, gaps persist in integrating life cycle analysis with nature-based materials and addressing regional disparities in adoption. Limitations include reliance on the Scopus database and quantitative data, excluding qualitative insights for a comprehensive research perspective. This study provides a foundation for advancing sustainable practices and contributes to the growing discourse on environmentally conscious construction strategies.

Keywords: Carbon Footprint, Nature-based Solutions (NbS), Net-Zero Construction, Sustainable Materials, Sustainability.

1. Introduction

Current trends of rapid population increase bring with them an alarming rate of energy demands. The construction industry significantly contributes to global greenhouse gas emissions, accounting for nearly 40% of energy-related emissions worldwide (Mathur *et al.*, 2021). As the most prevalent greenhouse gas (GHG), carbon dioxide (CO₂) emissions have become a growing concern for governments worldwide. In recent years, major carbon-emitting nations have formulated strategies and roadmaps to reduce their CO₂ emissions, aiming to achieve a carbon-neutral future (Xiao *et al.*, 2023). The construction industry also recognises the need to shift from a traditional linear economy to a circular economy, which offers a more sustainable and restorative approach (Otasowie *et al.*, 2024). This reality has driven researchers and practitioners to explore innovative pathways toward achieving net-zero construction (Frota De Albuquerque Landi *et al.*, 2023; Matthews, 2024; Päätaalo *et al.*, 2024). Central to this effort is the integration of nature-based solutions (NbS) and sustainable materials, which promise to revolutionise building practices by reducing carbon footprints and promoting circular economies (Labaran *et al.*, 2024; Saint *et al.*, 2023). This study employs a

bibliometric analysis to investigate the role of nature-based solutions in advancing net-zero construction and using Elsevier Scopus as the primary database. VOS viewer text-mining software (version 16) was employed to identify and classify the emerging themes from sequencing cluster analysis in research, including innovative decarbonisation strategies, sustainable material use, energy efficiency, zero-carbon construction methods, and the role of embodied carbon in supply chains. The contribution of this study that sets it apart is its bibliometric approach to uncovering gaps and opportunities within the current body of knowledge. While prior studies have explored aspects of sustainable construction and net-zero targets (Archila *et al.*, 2023; Labaran *et al.*, 2024), this work uniquely highlights the interplay between nature-based solutions and net-zero buildings. The originality of this study lies in its focus on synthesising diverse themes into a coherent framework that underpins net-zero construction efforts. This study further contributes to the growing discourse on sustainable construction practices, underscoring the critical importance of aligning innovative, nature-based solutions with global decarbonisation goals, offering actionable insights for stakeholders aiming to transform the built environment into a more sustainable and resilient industry.

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2. Literature Review

Nature-based solutions (NbS) are sustainable design strategies that leverage natural processes to address environmental, social, and economic challenges, including climate change mitigation and adaptation (Cohen-Shacham *et al.*, 2016). In the context of net-zero carbon buildings, NbS incorporates green infrastructure, passive design strategies, biophilic architecture, and ecosystem-based approaches to enhance energy efficiency, carbon sequestration, and climate resilience (Raymond *et al.*, 2017). Nature-based Solutions (NbS) have gained recognition in environmental sciences and construction, offering sustainable strategies to achieve net-zero emission goals. By leveraging natural processes and ecosystems, NbS promotes the development of sustainable infrastructure, enhancing energy efficiency, reducing resource consumption, and mitigating climate impacts. (Chen *et al.*, 2024).

Net-zero energy buildings provide a propitious approach to decarbonisation by reducing energy consumption and enhancing renewable energy integration (Hadba *et al.*, 2024; Matthews, 2024). As net-zero targets become more stringent, NbS provides a cost-effective and regenerative pathway to achieving sustainability goals in the construction industry (Seddon *et al.*, 2020). Examples include green roofs, fog harvesting, and renewable materials like clay, timber and cypress, which not only improve air quality and reduce urban heat but also support renewable energy integration (Hadba *et al.*, 2024; Matthews, 2024; Perera *et al.*, 2022; Saint *et al.*, 2023). Net-zero energy buildings, defined as structures with zero net energy or carbon consumption, exemplify how NbS can transform the construction industry by reducing environmental footprints and aligning with decarbonisation goals (Ahmed *et al.*, 2022).

Recent studies reveal that NbS have gathered enough momentum using other related terms such as “biomimicry”, “biophilic”, and “nature-inspired” (AlAli *et al.*, 2023; Moreira Da Silva *et al.*, 2024). Oguntona and Aigbavboa (2023) highlighted the substantial role of nature-inspired solutions in combating climate change. Incorporating features such as green roofs and walls enhances cities' capacity for carbon sequestration, effectively reducing greenhouse gas emissions. Similarly, Singh and Ru (2022) demonstrated that these solutions align with clean energy goals by improving energy efficiency in buildings, decreasing energy consumption, and reducing reliance on non-renewable energy sources. Moreover, urban green initiatives promote sustainable consumption patterns and help minimise the ecological footprint of urban areas.

Additionally, Azari *et al.* (2024) reveal that building envelopes adapt to environmental changes and are also

essential for managing heat, air, and moisture exchange between a structure's interior and exterior. Their efficient design and implementation can significantly reduce energy use and carbon emissions over the building's lifecycle. In regions like South Africa, where construction significantly contributes to greenhouse gas emissions (23 per cent) (Simpeh & Smallwood, 2021), adopting NbS is crucial for mitigating environmental impacts and addressing energy poverty. (Dosumu and Aigbavboa, 2021). A systematic review of current literature on NbS and net-zero construction can thus inform innovative frameworks and strategies, advancing the development of resilient, sustainable urban environments.

3. Research Methodology

The primary objective of this study was to explore the role of NbS and sustainable materials in advancing net-zero construction. This was accomplished using a bibliometric approach to identify and map core knowledge domains and co-occurring keywords, uncovering research trends and gaps. Bibliometric analysis employs science mapping tools to visualise the physical aspects of scientific research and domains while elucidating the structural composition of their disciplines (Waltman *et al.*, 2010). As highlighted by Akinlolu *et al.* (2022), bibliometric analysis provides a quantitative and comprehensive approach for examining existing literature, surpassing the limitations of manual reviews. For this research, the bibliometric analysis followed a four-step process outlined by Aliu and Aigbavboa (2023). The data for this study were sourced from the Scopus database, renowned for its extensive coverage and high-quality literature resources. As one of the largest abstract and citation databases, Scopus provides a vast collection of peer-reviewed books, book chapters, journals, and conference proceedings, surpassing other databases like Clarivate Web of Science and Google Scholar in scope and reliability (Aghimien *et al.*, 2019; Aliu & Aigbavboa, 2023). In the Scopus database catalogue, the following retrieval schema was entered: "nature OR based AND solutions AND materials AND net AND zero AND construction." "TITLE-ABS-KEY" indicated either a conference paper or journal article title, abstract, and keywords.

The period for this study search was 2014–2024, and using the above keywords, 51 documents were retrieved. The review period for this bibliometric study was limited to 2014–2024 to ensure the inclusion of contemporary and high-impact research on Nature-Based Solutions (NbS) in achieving net-zero carbon buildings. Accordingly, academic publications on NBS and net-zero buildings gained momentum from 2014 onward, driven by advancements in green infrastructure, biophilic design, and regenerative materials. In contrast, earlier studies lacked a strong focus on net-zero carbon buildings due to their recent

emergence in policy frameworks, certification standards (e.g., LEED Zero, EDGE Zero Carbon), and research funding priorities (Frantzeskaki *et al.*, 2019; Lützkendorf *et al.*, 2015; Seddon *et al.*, 2020). Also, bibliometric analysis benefits from a well-defined time frame that captures relevant trends and emerging themes while ensuring data consistency (Donthu *et al.*, 2021). Therefore, by setting the review period from 2014 onwards, this study ensures the inclusion of recent and high-quality literature that reflects the latest technological advancements, policy shifts, and industry adoption of NbS in net-zero construction. The research design employed for the bibliometric analysis is shown in Figure 1.

adopted in construction literature reviews (Aghimien *et al.*, 2019; Akinlolu *et al.*, 2022; Aliu & Aigbavboa, 2023). Vosviewer analysed bibliometric networks based on several key metrics. These included: (1) the number of publications per document type, (2) publications by country, (3) publications by year, and (4) the co-occurrence of keywords. A final cluster analysis was done after the co-occurrence of keywords network map was generated. This structured methodology ensured a systematic and in-depth exploration of the literature on Nature-based Solutions and Sustainable materials in the built environment.

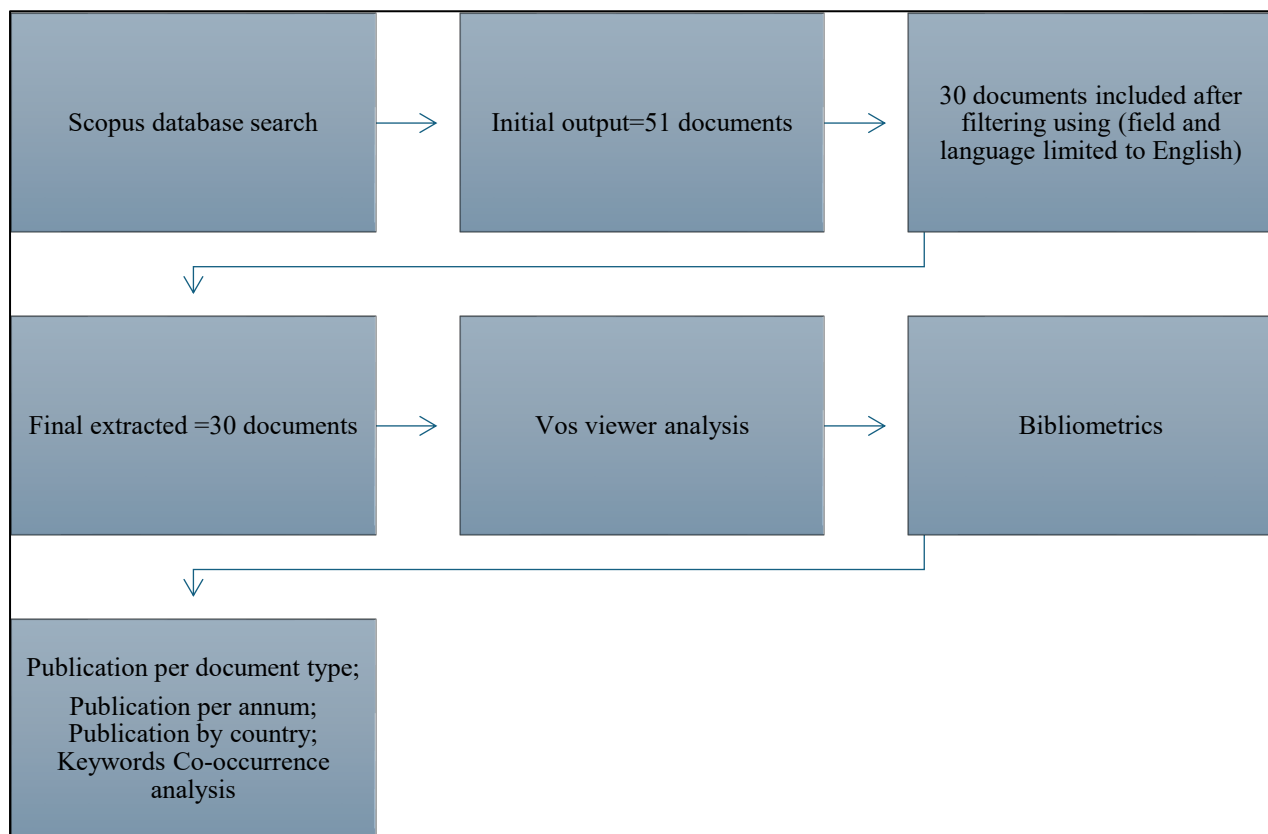


Figure 3: Research design Methodology

The results were refined using two parameters: field (Engineering, Energy, Materials Science, and Environmental Science) and language (English). This filtering process initially identified 31 documents. Following a manual screening, one document was excluded, resulting in a final set of 30 relevant documents for review. Visualisation tools such as CiteSpace, HiteSpace, VOSviewer, Gephi, and BibExcel are frequently used in bibliometric studies (Moral-Munoz *et al.*, 2019). This study utilised VOSviewer software to analyse statistical data from the source and generate a keyword co-occurrence map (Van Eck & Waltman, 2014). VOSviewer is widely

4. Findings and Discussion

4.1. Publications per annum and Document type

Results illustrate the annual publication trends on NbS and their influence on net-zero buildings from 2014 to 2024. Before 2014, no publications were recorded in this area. Between 2014 and 2019, research activity was minimal, with only four publications by 2019, reflecting slow initial growth. A decline occurred in 2021, with only one publication, but interest rallied in 2022. A notable surge followed in 2023, with the number of publications rising to seven, three more than

the previous year. By 2024, research momentum had significantly increased, culminating in 12 publications to date. This upward trend aligns with the growing recognition of NbS as a vital strategy for promoting efficient energy use and innovative approaches to climate action.

Previous studies anticipate continued expansion in this field as researchers increasingly focus on leveraging NbS to address environmental challenges and support sustainable construction practices (Hadba et al., 2024; Labaran et al., 2024; Matthews, 2024; Päätao et al., 2024). A total of 30 documents were analysed, comprising 15 journal articles, seven conference papers, five review papers, and three book chapters. The relatively low number of journal articles may be attributed to the rigorous peer-review process required for publication, which can limit the volume of accepted articles. Similarly, the number of conference papers is modest, despite their quicker publication timelines and higher volumes, often influenced by the relevance of conference themes. African countries could capitalise on conference platforms to boost research output in this area. Figure 2 illustrates the findings.

cited three times and did not meet the set threshold. This analysis reveals the uneven global research output, with certain countries significantly contributing to the literature, particularly in Europe and North America. At the same time, regions like Africa remain underrepresented despite the growing importance of NbS in addressing climate challenges and net-zero construction. Table 1 (see Appendix 1) provides the results of the top 5 countries discussed (Figure 3).

4.3. Analysis of Co-occurring Keywords and Cluster Themes

Keywords are meaningful in describing research content and concepts, particularly in studies on sustainable construction strategies. Using Scopus data and VOS viewer, a visualisation map was generated to reveal co-occurring keywords and research topic networks, where keyword proximity and similarity indicate the degree of co-occurrence (Van Eck & Waltman, 2014). A keyword co-occurrence analysis was thus achieved to uncover the core structure and thematic clusters within research on the impact of Nature-based Solutions (NbS) on net-zero construction. Utilising VOS viewer software, a network was generated from 395 keywords, with 55 keywords

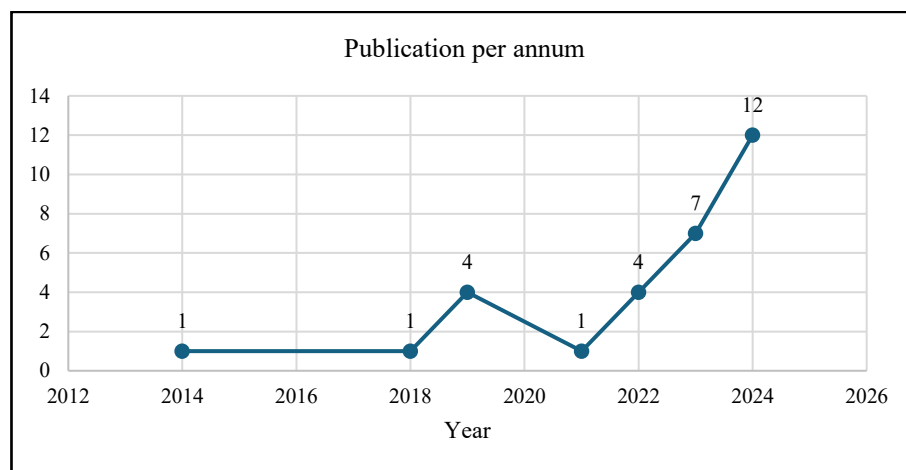


Figure 4: Publication per annum

4.2. Publication by Country

These findings highlight the global distribution of publications on Nature-based Solutions (NbS) in net-zero buildings, showcasing the number of documents and citations by country. Data, analysed using a VOS viewer with a minimum threshold of two publications per country, reveal 14 countries (depicted in the world map, Figure 3 in Appendix 1) with research outputs. The United Kingdom leads with 10 publications and 33 citations. Australia follows with five publications and 12 citations, while the United States and Finland each have four publications, accumulating 70 and 75 citations, respectively. Italy and India also recorded four publications, 75 and three citations, respectively. South Africa, by contrast, had only one publication,

meeting the threshold of at least two co-occurrences. It was realised that some keywords repeated, emphasising their importance across multiple thematic clusters in literature. This analysis identified six prominent keyword clusters, as visualised in the network map presented in Figure 4.

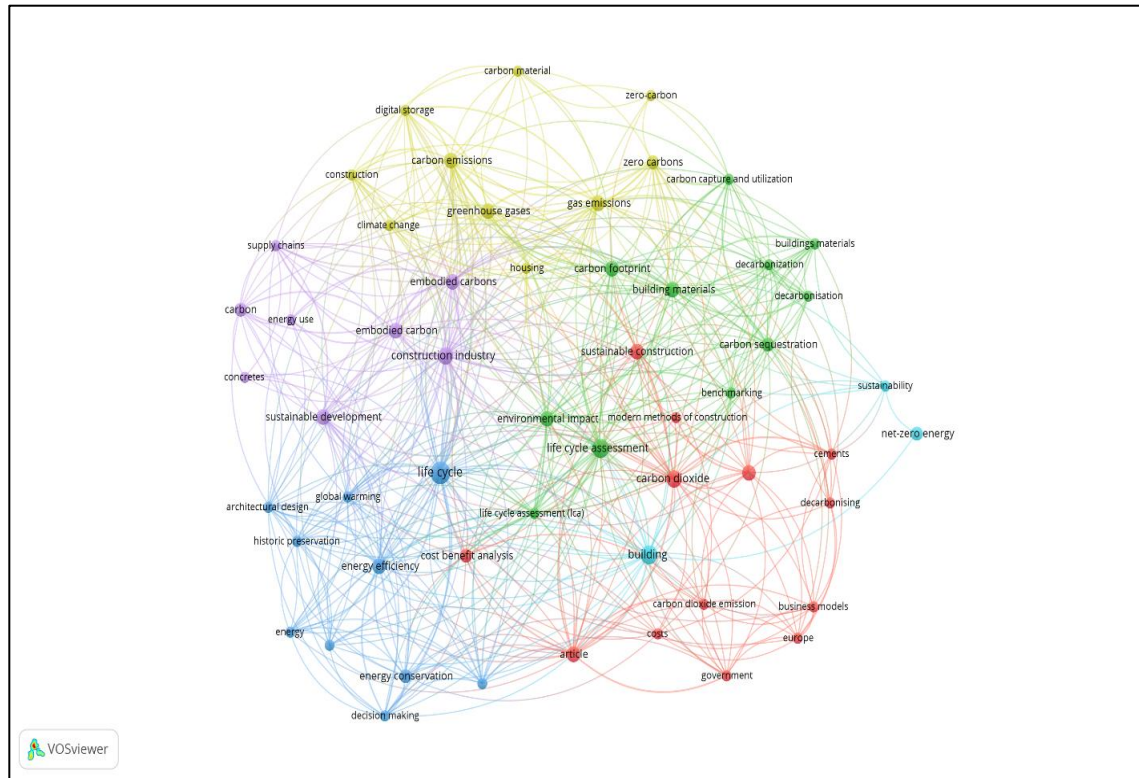


Figure 5: Network visualisation of Co-occurring Keywords

Cluster 1: Innovative Strategies for Decarbonisation and Circular Economy in Net-Zero Construction. The first cluster contains 13 keywords, and it makes up the red region of the map. The keywords were: article, business models, carbon dioxide, carbon dioxide emissions, cement, circular economy, cost-benefit analysis, decarbonising, costs, modern methods of construction, sustainability and sustainable construction. This theme underscores research on the role of nature-based solutions in reducing carbon dioxide emissions and integrating circular economy principles into construction (Archila *et al.*, 2023; Chakraborty, 2023; Perera *et al.*, 2022). Materials like low-carbon cement and modern construction methods can help achieve decarbonisation while addressing cost-benefit analysis concerns (Ahmadi *et al.*, 2024; Frota De Albuquerque Landi *et al.*, 2023; Khalid *et al.*, 2023). Furthermore, these studies highlight that exploring business models aligned with sustainable development ensures cost-effective and environmentally conscious practices towards Net-Zero Construction.

Cluster 2: Sustainable Building Materials and Carbon Management in Construction. Cluster 2, represented by green in the visualisation, comprises 11 keywords, which are benchmarking, building materials, carbon capture and utilisation, carbon footprint, carbon sequestration, decarbonisation, environmental impacts, and life cycle assessment. Research works by (Ekanayake *et al.*, 2024; Hu, 2019; Saint *et al.*, 2023) indicate that life cycle assessment and carbon footprint

analysis are critical in understanding the environmental impact of building materials. Carbon capture, utilisation, and sequestration technologies can be leveraged to enhance material sustainability (Archila *et al.*, 2023; Gallego Dávila & Aagesen, 2024). Integrating nature-based materials into construction processes supports decarbonisation and reduces long-term environmental impacts.

Cluster 3: Energy Efficiency and Decision-Making in Sustainable Architectural Design. The third cluster is made up of the blue region with 10 keywords: architectural design, decision making, energy, energy conservation, energy efficiency, feasibility study, global warming, historic preservation, life cycle, and life cycle analysis. Energy conservation and efficiency are integral to achieving net-zero construction goals, as highlighted in several studies (Azari *et al.*, 2024; Ehsan & Maryam, 2022). Nature-based solutions in architectural design, such as passive solar design and green roofs, can reduce energy use (Hu, 2019; Labaran *et al.*, 2024). Additionally, decision-making informed by feasibility studies and life cycle analysis ensures that design choices align with global warming mitigation and historic preservation (Frischknecht *et al.*, 2019).

Cluster 4: Cluster 4 highlights the theme "Zero-Carbon Strategies in Construction and Housing" with 10 keywords in the yellow region on the map. The keywords include carbon emissions, carbon material, climate change, construction, digital storage, gas emissions, greenhouse gases, housing, zero carbon, and

zero-carbon. This theme reveals studies that have focused on the reduction of greenhouse gas emissions through innovative materials and digital storage solutions in construction (Matthews, 2024; Pisini *et al.*, 2024; Saint *et al.*, 2023). Nature-based housing materials and designs can minimise energy use and promote zero-carbon living and the well-being of inhabitants. Sustainable strategies in construction align with climate change goals and support global net-zero initiatives through strategies such as NbS.

Cluster 5: The fifth cluster, representing the purple section of the map, has eight keywords: carbon, concretes, construction industry, embodied carbon, supply chains, sustainable development, and is themed "Embodied Carbon and Sustainability in Construction Supply Chains." Embodied carbon in construction materials is a significant contributor to overall emissions. Using sustainable materials and optimising supply chains can reduce the environmental footprint (Ahmadi *et al.*, 2024; Azari *et al.*, 2024; Weber *et al.*, 2022). Nature-based solutions provide alternatives that prioritise energy efficiency and sustainable development within the construction industry (McGarry *et al.*, 2022).

Cluster 6: Net-Zero Energy Buildings for Sustainability. The last cluster is represented by the turquoise region with three keywords: buildings, net-zero energy and sustainability. The theme highlights research conducted on revealing the importance of integrating nature-based solutions in building designs to achieve net-zero energy performance (Byrne *et al.*, 2019; Villarruz, 2019). Technologies like energy-efficient materials and renewable energy systems ensure sustainability, as indicated in studies by Ahmadi *et al.* (2024) and Azari *et al.* (2024). Nature-based solutions and strategies not only reduce carbon emissions but also enhance long-term resilience and environmental harmony towards achieving a Net-Zero Construction industry.

5. Conclusion and Further Research

This study demonstrates the growing prominence of Nature-based Solutions (NbS) in achieving net-zero construction, particularly within Europe and North America. Research has demonstrated that incorporating nature-inspired strategies significantly contributes to reducing energy consumption, carbon emissions, and resource depletion while enhancing resilience to climate change. The analysis highlights NbS as a critical approach for reducing carbon emissions, optimising supply chains, and enhancing energy efficiency.

A keyword co-occurrence analysis identified six key research themes emerging in this field from 2014 to the present. However, the review also revealed significant gaps, including lower conference paper publications, the limited integration of life cycle analysis with nature-based materials and pronounced regional disparities in research output and adoption, particularly in Africa, where only South Africa featured in the results. Addressing these disparities through policy support, localised research and capacity building is critical to advancing net-zero buildings and broader sustainability goals. This indicates that research in this area remains nascent in many developing regions. The study's reliance on the Scopus database and its focus on quantitative literature analysis present limitations, which may overlook relevant work in other databases or non-English publications. Future research should prioritise exploring the practical applications of NbS in diverse contexts, assessing their scalability in achieving net-zero construction, and addressing the gaps in underrepresented regions. Expanding the scope to include multiple databases and multilingual sources will provide a more comprehensive understanding of this evolving field.

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Appendix 1

Table 1: Publication by Country (Top 5 countries)

Country	Number of documents	Citations
United Kingdom	10	33
Australia	5	12
United States of America	4	70
Finland	4	75
Italy	3	75
India	3	7

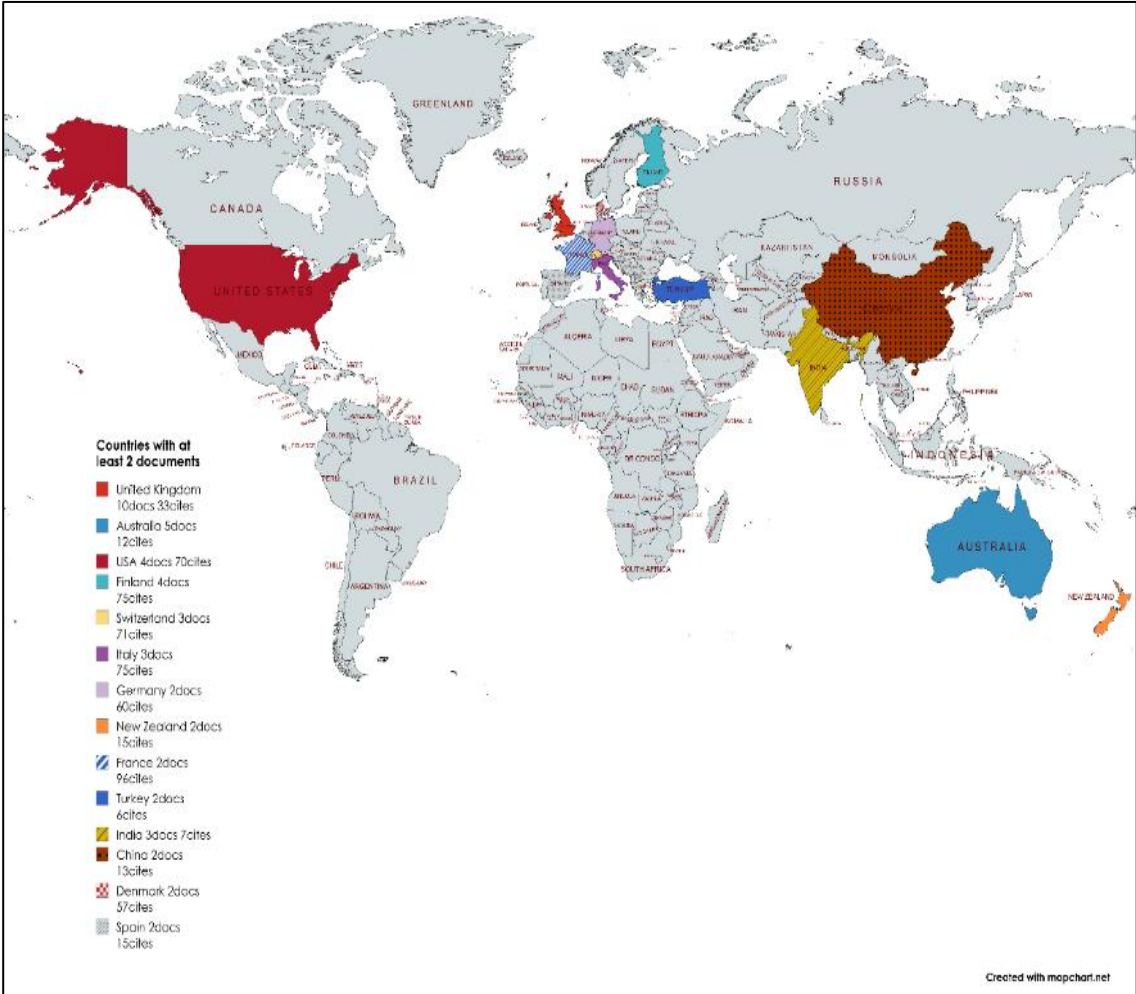


Figure 6: Map showing the number of publications per country