

DEZVOLTARE DURABILĂ PRIN CLĂDIRI VERZI: ANALIZĂ BIBLIOMETRICĂ ACTUALIZATĂ A LITERATURII ÎN DOMENIU

SUSTAINABLE DEVELOPMENT THROUGH GREEN BUILDINGS: UPDATED BIBLIOMETRIC ANALYSIS OF THE LITERATURE IN THE FIELD

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Green buildings (GBs) aim to improve the characteristic performance of buildings throughout their entire life cycle, to conserve resources and increase the comfort of residents. The theme of GBs is very specific to the field of construction. However, a relevant, current analysis of the specialized literature in the field, to evaluate the scientific impact and citations, is missing. This study aims to identify and analyze already published scientific papers. In this context, the Scopus database was comprehensively explored. Therefore, the records and citations of the 8612 identified manuscripts were imported into VOSviewer to perform this bibliometric analysis. Most of the manuscripts were published after 2010. The publications were mainly focused on terminology characteristics of sustainable development (i.e. sustainability, GBs, construction). The publication share increased every year. The main contributors to this area are the United States of America, China, Italy, and the United Kingdom. The most prolific journals were Energy and Buildings, Sustainability, Building and Environment and Journal of Cleaner Production. Temporal analysis of citation patterns revealed an intense growth of scientific interest, focusing especially on green/sustainable buildings especially in the recent period. Romania is only at the beginning of approaching this topic, the first work being published only in 2003 and oscillations in the publication tendency being observed.

Clădirile verzi au scopul de a îmbunătăți performanțele caracteristice construcțiilor de-a lungul întregului ciclu de viață, de a conserva resursele și de a crește confortul locuitorilor. Tema clădirilor verzi este specifică domeniului construcțiilor. Lipsește însă o analiză relevantă, actuală, a literaturii de specialitate în domeniu, în vederea evaluării impactului științific și a citărilor. Acest studiu își propune să identifice și să analizeze lucrările științifice publicate. În acest context, baza de date Scopus a fost explorată cuprinzător. Prin urmare, înregistrările și citările celor 8612 manuscrise identificate au fost importate în VOSviewer pentru a efectua această analiză bibliometrică. Cele mai multe dintre manuscrise au fost publicate după 2010. Publicațiile au fost focusate în principal pe terminologia caracteristică dezvoltării durabile (i.e. sustenabilitate, clădiri verzi, construcții, etc.). Cota de publicare a crescut cu fiecare an. Principalii contribuitori ai acestui domeniu sunt Statele Unite ale Americii, China, Italia și Regatul Unit. Cele mai prolifiche reviste au fost Energy and Buildings, Sustainability, Building and Environment și Journal of Cleaner Production. Analiza temporală a modelelor de citare a relevat o creștere intensă a interesului științific, concentrându-se în special pe clădirile verzi/durabile, mai ales în ultima perioadă. România este abia la începutul abordării acestei topici, prima lucrare fiind publicată abia în 2003 și observându-se oscilații în tendința de publicare.

Keywords: Green buildings; sustainability; constructions; energy performance; bibliometric analysis

1. Introduction

The field of constructions, regardless of their type (e.g., industrial, civil, etc.) occupies a major place when it comes to the development and evolution of a country. In contrast, this industry plays a significant negative role related to global accentuated climate changes and environmental pollution, with construction activities generating significant emissions of greenhouse gases and other environmental pollutants [1]. Published data show that the construction sector has a major impact in terms of world consumption of raw materials (e.g.,

40% stone and sand, between 25-70% natural wood, 16% water) [2,3] and it must be added a consumption of > 30% of the global energy, necessary for the operation of the buildings [4,5]. Moreover, the construction sector worldwide is influenced by building materials (i.e., steel, cement, wood, stone, masonry etc.) [6]. The most impactful environmental issues of these materials are the energy consumption and the carbon dioxide emission. Cement is one of the top-energy consuming material of all construction processes, being available in several types (i.e., normal strength concrete, plain concrete, reinforced

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concrete, prestressed concrete, precast concrete, air entrained concrete, polymer concrete, shotcrete concrete, vacuum concrete, limecrete, roller compacted concrete, glass concrete etc.) [7].

Due to certain disadvantages of the standard cement, supplementary cementitious materials have received considerable scientific interest. Furthermore, because solid wastes, including used glass are not biodegradable, they contribute significantly to major environmental issues [8]. Recycling used glass is a sustainable strategy to decrease environmental challenges, conserve energy during the recycling operations, and preserve natural resources. An environmentally sustainable approach to address energy-intensive and pollution challenges is to partially substitute conventional Portland cement (OPC) with recycled solid waste materials or industrial byproducts [9]. The use of energy-efficient, low-carbon manufacturing techniques, geopolymers [10], unique cement formulations, carbon negative cements, recycled wood, are several technological innovations that may counteract the current environmental concerns [11,12].

Additional results are more severe, stating that the construction industry consumes 40% of total energy production, 32% of both non-renewable and renewable resources, 40% of all raw materials, 12-16% of all available water, 25% of all wood, producing 30-40% of total solid waste and emitting 35-40% of CO₂, which has led to an increase in global awareness of the importance of sustainability in the construction industry [13]. These statistics reveal the large amounts of waste generated by traditional constructions throughout their life cycle, which inevitably contribute to the pollution of the environment [5,14]. Due to these findings, individuals become increasingly aware of the importance of sustainability in the construction industry [13]. Therefore, the last decade has generated a growing interest in "green" construction concepts and practices, increasing the demand for sustainable / green buildings (GBs).

A GB refers to constructions that consider and minimize its impact on the environment, and therefore on human health, using smaller amounts of water and energy than a non-GB, with a high level of indoor air quality. In addition, GB achieves a balance throughout its life cycle, between the impact of the different types of construction materials from which the building, furniture and other endowments are made. Consequently, the implementation of the GB offers both beneficial effects on the environment and economic / social benefits on the construction industry. In 2013, these benefits were summarized and it have been presented numerous parameters related to climate change, CO₂ and other pollutants, renewable natural resources, improving public health, well-being and comfort of the population, alleviating poverty / increasing incomes / reducing

costs, etc., demonstrating that GB is a real and current opportunity and necessity for the construction industry that can contribute to sustainable development by implementing solutions sustainable construction [15–17].

When designing sustainable buildings, many ecological, economic, and social aspects are considered and correlated with the impact of buildings on the habitat [18]. Thus, extensive formal / informal initiatives of the private industry, professional organizations, legislative decision-making forums, governments, etc. are involved. Such efforts have led to the development of improved energy [19] codes / names / regulations, the design and development of materials with low environmental impact, optimized design guides, energy and renewable resources, and the introduction of the concept of analyzing the consequences (during the entire life cycle of the building) of design options [20,21]

This study has been conducted for meeting the bibliographic needs of researchers interested in the topic. Thus, by consulting the present paper, future authors are targeted directly to the most prolific journals, and the most productive and relevant authors in the field of GBs. As the most cited articles are also highlighted, the most important information will be found more quickly and accurately. Therefore, this study is a time-saving approach of researchers focused on the subject, by making a bibliometric and visualization analysis of published information on GBs. The novelty of this topical analysis from the point of view of published literature lies precisely in the fact that this topic is incompletely and much less covered than other topics of interest (i.e., medicine, chemical compounds, pharmacology etc.).

2. Materials and Methods

A literature search was performed using the Scopus database, one of the largest abstract and citation databases. A number of 17862 documents were identified using the following search parameter: TITLE-ABS-KEY ({green building} OR {green buildings} OR {passive buildings} OR {resilient building} OR {resilient buildings} OR {sustainable building} OR {sustainable buildings} OR {zero energy building} OR {zero energy buildings} OR {low-energy buildings} OR {zero energy building} OR {energy efficient buildings} OR {zero-energy buildings} OR {nature inclusive building} OR {nature inclusive buildings}). Of the 17862 documents, 8971 are articles, 6507 conference papers, and 919 reviews, the others are included in other categories. Most of the documents are written in English (17434 documents), with Chinese (214 documents) and German (97 documents) being the next most-used languages. Most of the articles were included in the following Scopus subject areas "Engineering",

"Environmental Science", "Energy", and "Social Sciences". Other subject areas had under 2000 documents.

For this research, the document type was set to articles (which present original research on this topic and because the Reviews type papers presents data obtained by articles), written in English, thus restricting the number of included documents to 8612. A total of 16064 items were found. The inequality with the 8612 articles previously mentioned as being taken into account in this research is explained by the fact that an article falls into multiple subject areas. The bibliometric analysis was conducted utilizing the Scopus analyze results function and the VOSviewer software [22], the data being extracted using the "Export" function [23]. Moreover, the bibliometric analysis was conducted over two time periods: from 1980 to 2010 (1175 manuscripts), and from 2011 to 2022 (7437 manuscripts). The most productive countries, sources, authors, and most cited papers were identified for each period. The analysis period was divided into two, to gain a deeper understanding of the evolution of this subject. The data was split in this manner because prior to 2010, the number of articles published on this topic demonstrated a slower rate of growth. Therefore, after 2010, there was a significant increase in interest in this subject.

Scientific mapping studies were conducted to examine the collaboration networks between nations, a map of high-frequency terms, and a scientific map depicting the connections between these terms. In the network map of country co-authorship, the size of the nodes represents the number of papers published by a particular country. The thickness of the lines connecting two countries reflects the degree of collaboration between them, and their color indicates the cluster to which each country has been assigned. Generally, countries within the same cluster demonstrate a stronger

collaborative relationship. In the term occurrence bubble map, the size of each bubble corresponds to the number of occurrences of the term, and the color of the bubble reflects the average number of citations received by papers that include that word. In the network map of word co-occurrence, the node's size reflects the number of occurrences for that term. The thickness of the lines connecting two terms reflects the degree of co-occurrences; if the line is thicker, the two terms occur together in more manuscripts.

3. Results

3.1. The most productive countries in the field

During 1980-2010, a total of 59 countries published documents that matched the search criteria. 35 (59.32%) of the countries had at least five published documents. The United States was the most productive country, publishing 416 (35.40%) documents and having an average citation rate/document of 27.50. **Table 1** presents the top 10 most productive countries during this period. Even though The United States had a high number of published documents, countries like the United Kingdom and Canada (ranked 2nd and 3rd) had higher average citations/documents. The country with the highest average citation/document was China (57.17).

Between 2011-2022, China and the United States showed the most interest in this subject, publishing a total of 2385 articles. China has 1293 published articles with a total number of citations of 21237 (16.42 average citation/document), followed by the United States with 1092 articles but with a higher average citation/document of 22.62 (**Table 1**). Hong Kong has the highest average number of citations per article, followed by Italy. Australia, the United Kingdom, and Canada also have relatively high average citations per article.

Table 1

Top 10 prolific countries/ Top 10 cele mai prolifică țări							
Country	Articles No.	Citations No.	TLS	Country	Articles No.	Citations No.	TLS
1980-2010				2011-2022			
United States	416	10834	20	China	1293	21237	622
United Kingdom	94	4231	14	United States	1092	24702	439
Canada	76	4033	11	Italy	554	15141	183
Australia	39	1898	4	United Kingdom	475	10642	311
China	36	2058	7	Australia	432	10472	348
Germany	31	1388	2	India	400	4068	93
Netherlands	28	1057	4	Malaysia	387	3998	146
Hong Kong	25	1416	2	Spain	307	4779	150
India	22	225	1	Hong Kong	302	8899	227
Sweden	21	1180	5	Canada	256	6449	174

TLS, total link strength value attributed by VOSviewer to measure the degree of collaboration between two countries.

Table 2

Top 10 most prolific journals / Top 10 jurnale

Journal	No.	C	Average citation/doc.	Cite score	SNIP 2021	Publisher
1980-2010						
Journal of Green Building	91	1073	11.79	1.9	0.407	College Publications
Energy And Buildings	61	7422	121.67	11.5	2.069	Elsevier
ASHRAE Journal	47	475	10.11	0.7	0.382	American Society of Heating, Refrigerating and Air Conditioning Engineers
Building Research and Information	44	3014	68.5	8.9	1.901	Taylor & Francis
Building and Environment	43	4137	96.21	10.7	2.228	Elsevier
HPAC Heating, Piping, Air Conditioning Engineering	42	13	0.31	0.0 (2019)	0.000 (2019)	Penton Media, Inc.
WIT Transactions on Ecology And The Environment	29	74	2.55	0.8	0.210	WIT Press
Consulting-Specifying Engineer	25	6	0.24	0.1 (2020)	0.000 (2013)	Elsevier
Renewable Energy	23	1107	48.13	28.5	4.535	Elsevier
Engineered Systems	20	1	0.05	0.0 (2020)	0.000 (2021)	Business News Publishing Co.
2011-2022						
Energy And Buildings	476	19712	41.41	11.5	2.069	Elsevier
Sustainability (Switzerland)	404	4287	10.61	5.0	1.310	Multidisciplinary Digital Publishing Institute
Journal Of Cleaner Production	247	7908	32.02	15.8	2.444	Elsevier
Energies	243	2291	9.43	5.0	1.104	Multidisciplinary Digital Publishing Institute
Building And Environment	230	7889	34.30	10.7	2.228	Elsevier
Journal of Building Engineering	184	2949	16.03	6.4	2.147	Elsevier
Applied Energy	161	7722	47.96	20.4	2.652	Elsevier
Journal of Green Building	137	1026	7.49	1.9	0.407	College Publications
Sustainable Cities and Society	137	4078	29.77	14.4	2.539	Elsevier
Buildings	129	1161	9.00	3.8	1.372	Multidisciplinary Digital Publishing Institute

No., number of papers; C, citations; SNIP, source normalized impact per paper (a bibliometric indicator that measures the impact of a journal or publication); Cite Score is per 2021.

3.2. The most prolific journals

During 1980-2010, a total of 157 journals published documents that met the defined search criteria. As shown in **Table 2**, the most productive journals of this period are presented. The Journal of Green Building had the highest number of published documents for this time. However, based on the citation score provided by Scopus, the journal Renewable Energy stands out with a high average citation per document and a high citation score. For this period, the journal that had the highest average citation/document is Energy and Buildings, the 2nd journal in terms of published documents.

During 2011-2022, a total of 246 journals published documents that met the defined search criteria. Based on the information provided in **Table 2**, it appears that the journal "Energy and Buildings" had the highest number of published documents during the specified period, with a total of 476

documents. This journal also had a relatively high average citation rate per document, averaging 41.41 citations per document. The journal "Applied Energy" had the highest average citation rate per document, with an average of 47.96 citations per document. However, it should be noted that the number of published documents for this journal was lower than that of "Energy and Buildings," with a total of 161 documents.

3.3. Citations status

Between 1980-2010, a total of 1805 authors published documents, of which 15 (0.83%) had at least five published documents. Cole, R.J. from The University of British Columbia, Vancouver, Canada, had the highest number of published documents (13) and a high average citation per document (59.23). His most highly cited article, "Evaluating user experience in green buildings in relation to

Table 3

The most influential 5 scientific articles/each period / *Cele mai de impact 5 articole/fiecare perioadă*

First author [Ref.]	Titles	Year	Source title	Citations
1998-2010				
Meyer, C. [25]	The greening of the concrete industry	2009	Cement and Concrete Composites	919
Sartori, I. [26]	Energy use in the life cycle of conventional and low-energy buildings: A review article	2007	Energy and Buildings	904
Ding, G.K.C. [27]	Sustainable construction-The role of environmental assessment tools	2008	Journal of Environmental Management	755
Reinhart, C.F. [28]	Dynamic daylight performance metrics for sustainable building design	2006	Journal of Illuminating Engineering Society of North America	495
Wang, W. [29]	Applying multi-objective genetic algorithms in green building design optimization	2005	Building and Environment	524
2011-2022				
Marszal, A.J. [30]	Zero Energy Building - A review of definitions and calculation methodologies	2011	Energy and Buildings	782
Scrivener, K.L. [31]	Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry	2018	Cement and Concrete Research	734
Cao, X. [32]	Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade	2016	Energy and Buildings	611
Sartori, I. [33]	Net zero energy buildings: A consistent definition framework	2012	Energy and Buildings	587
Menezes, A.C. [34]	Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap	2012	Applied Energy	515

workplace culture and context," [24] was published in the journal *Facilities* and had 69 citations, with a citation score of 3.7 in 2021.

The most influential paper of this period was published by Meyer, C. from Columbia University, New York, United States. The article is titled "The greening of the concrete industry" and was published in *Cement and Concrete Composites* (cite score for 2021 of 13.3) in 2009 [25]. Data analysis reveals that the most influential papers tended to be published towards the end of the studied period [26–28]. The earliest publication among the presented items is "Applying multi-objective genetic algorithms in green building design optimization," which was published in 2005 in the journal *Building and Environment* [29]. Among the presented authors, Zmeureanu, Radu G. from the Centre for Zero Energy Building Studies in Montreal, Canada, had the highest average citation per document (162.80). During the 1980-2010 period, 1175 documents were published. The most influential publications corresponding to the periods evaluated are included in **Table 3**.

The most influential paper between 2011-2022 was published by Marszal-Pomianowska A. from Aalborg University, Aalborg, Denmark, the article being titled "Zero Energy Building - A review of definitions and calculation methodologies" [30]. Of the most influential publications in terms of citations during the period under review, "Eco-efficient cements: Potential economically viable solutions for a low-CO₂-based cement materials industry,"

published in 2018 in the journal *Cement and Concrete Research* by Scrivener et al., is the most timely [31]. Most of the documents that are included in the list were published towards the beginning of the analyzed period [32–34].

Considering the most prolific authors of period 2011-2022, Tam V.W.Y. from the Western Sydney University, Penrith, Australia, was the most active author. Her most cited work (150 citations), as the second author, is titled "Key credit criteria among international green building rating tools" [35] and was published in 2017 in the *Journal of Cleaner Production*. Ranked second in number of papers is Gou Z., affiliated to Wuhan University, Wuhan, China. His most cited article is titled "Are green buildings more satisfactory and comfortable?" [36] and was published in 2013 in the journal *Habitat International*.

Based on the average citation/document, ranked first is Attia S., with an average citation per document of 50.31, followed by Lau S.S.Y. with an average citation per document of 48.5, and Sun Y. with an average citation per document of 36.39. Attia S. is affiliated to the Université de Liège, Liege, Belgium. His most cited work is titled "Assessing gaps and needs for integrating building performance optimization tools in net zero energy buildings design" [37] and was published in 2013, in the journal *Energy and Buildings*. A total of 7437 documents meeting the specified criteria were published.

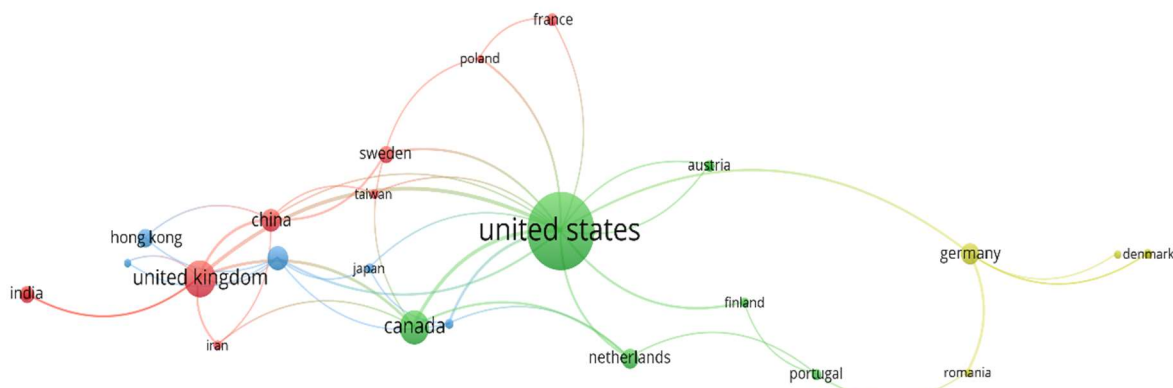


Fig. 1 - Network map of the country co-authorship (1980–2010) / Harta rețelei de co-autori / țări (1980-2010)

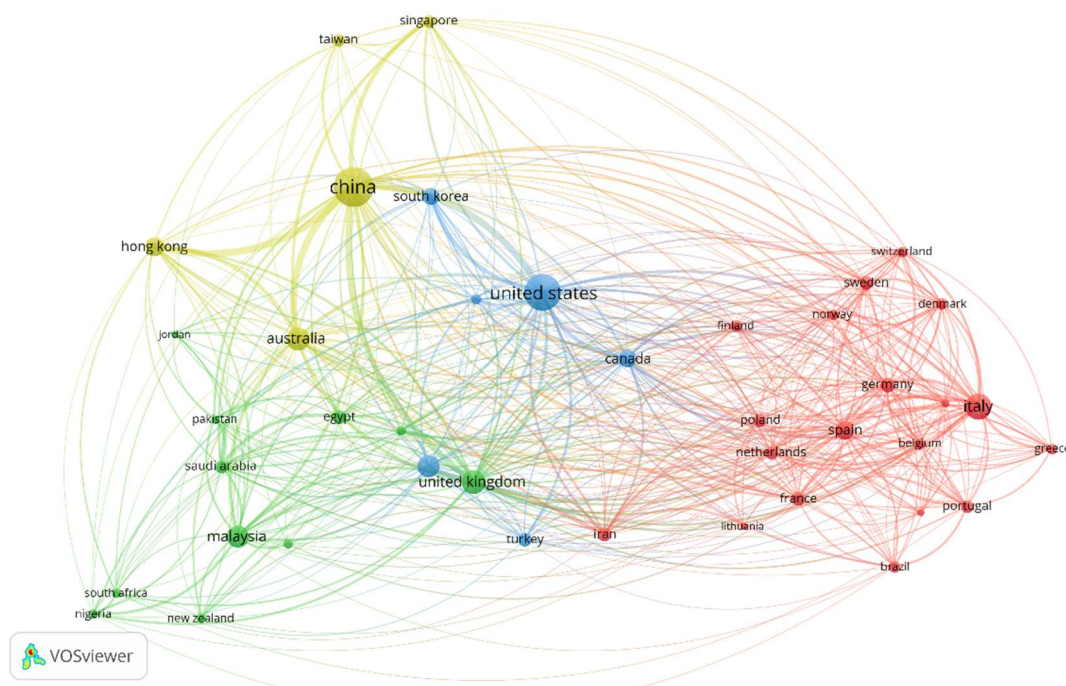


Fig. 2 - Network map of the country co-authorship (2011–2022). / Harta rețelei de co-autori / țări (2011-2022)

3.4. Network map of the country co-authorship

The network map of country co-authorship for 1980-2010 is presented in the **Figure 1**. The minimum required documents for a country to be represented was set to 5. There are 27 countries represented in the network map of country co-authorship. These countries are grouped into clusters. The red cluster contains 10 countries, the green cluster contains 7 countries, the blue cluster contains 5 countries, and the yellow cluster also contains 5 countries. Based on the information provided in the figure, it appears that the countries that have a strong collaborative relationship are The United States with the United Kingdom and with Canada, the United Kingdom with China and Canada, and Germany with Romania.

For 2010-2022, a network map illustrating the co-authorship relationships between countries is presented in **Figure 2**. The minimum number of

documents required for a country to be included in the analysis was set at 50. A total of 41 countries met this criterion and are depicted in the network map, which is divided into four clusters. The red cluster includes 19 countries, the green cluster includes 11 countries, the blue cluster includes 6 countries, and the yellow cluster includes 5 countries. The analysis reveals that China has strong collaborative relationships with the United States, the United Kingdom, Australia, and Hong Kong. Additionally, the United States has strong collaborative relationships with Canada, South Korea, and the United Kingdom.

3.5. Term map and network map of term co-occurrence

For 1980-2010, based on the information provided in **Figure 3**, it appears that the term "sustainable development" has the highest occurrence rate, with an average of 47.54 citations

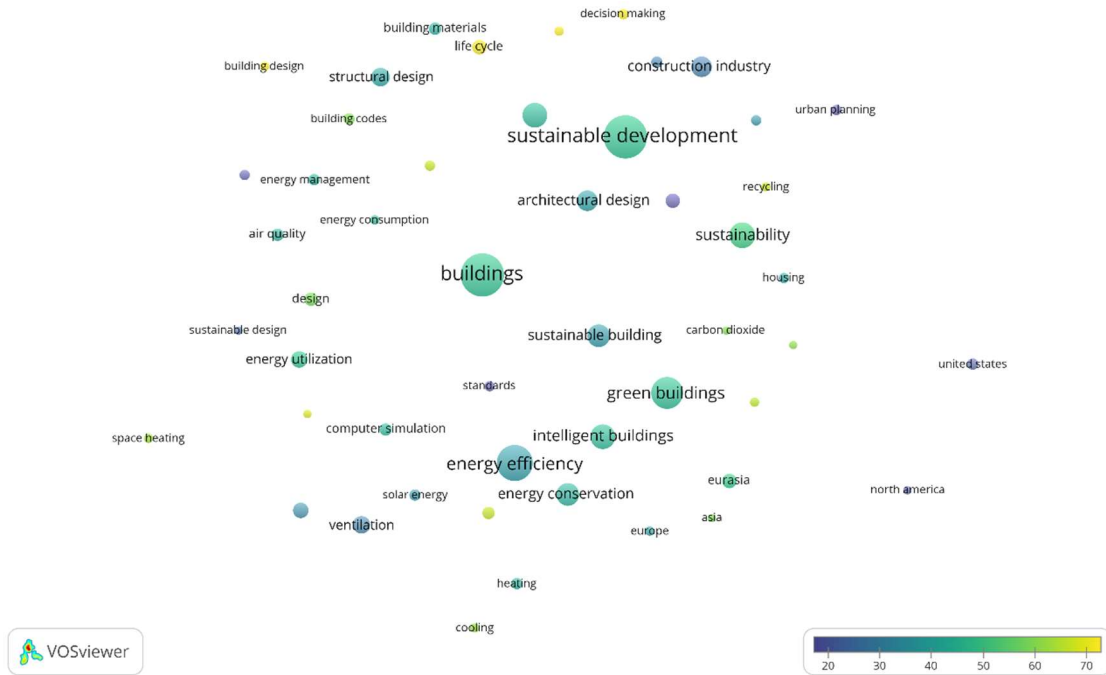


Fig. 3 - Bubble map of high frequency terms (1980-2010) / Harta cu bule a termenilor cei mai frecvenți (1980-2010)

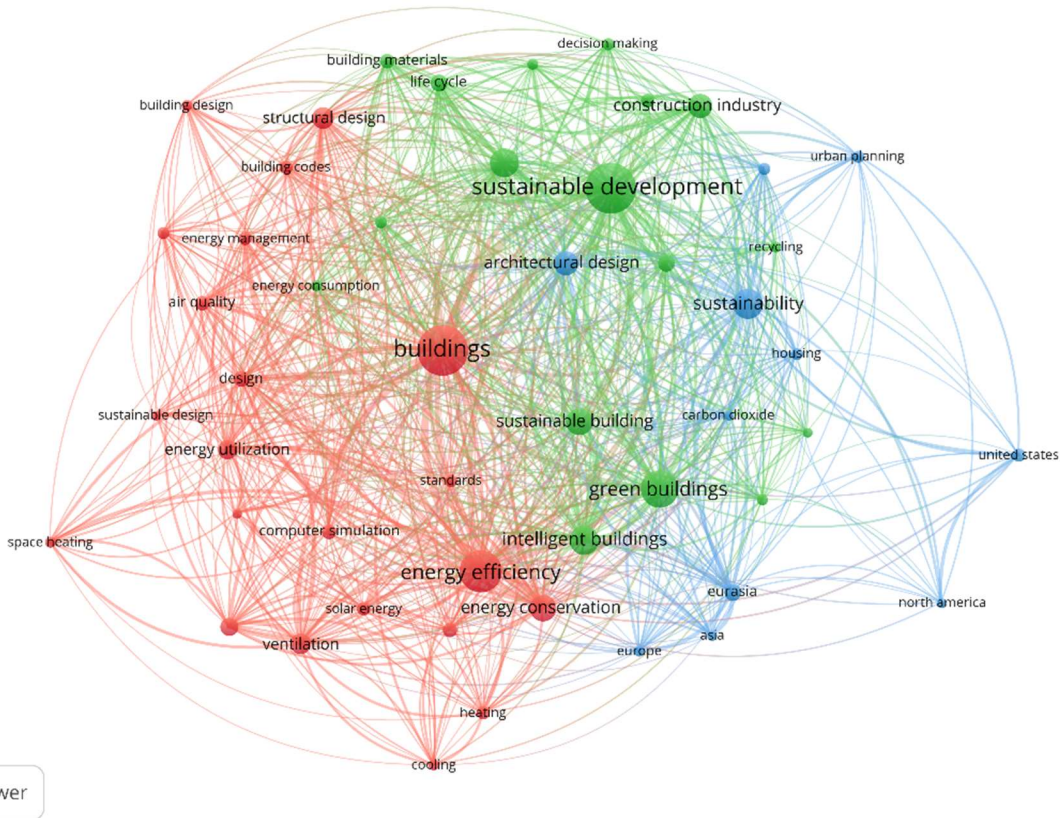


Fig. 4 - Co-occurrence network map of keywords (1980-2010) / Harta rețelei de co-ocurență a cuvintelor cheie (1980-2010)

per document. This is followed by "buildings" and "energy efficiency," which have occurrence rates of 240 and 189, respectively, and average citation rates of 47.36 and 35.89 per document. "Green buildings" also has a relatively high occurrence rate of 161, with an average citation rate of 46.27

per document. The words represented with yellow have a high average citation/document and are represented by strategic planning (27, 85.48), life cycle (51, 80.47), decision making (32, 76.47), building design (29, 71.24), other words having under 70 average citations/document. There are

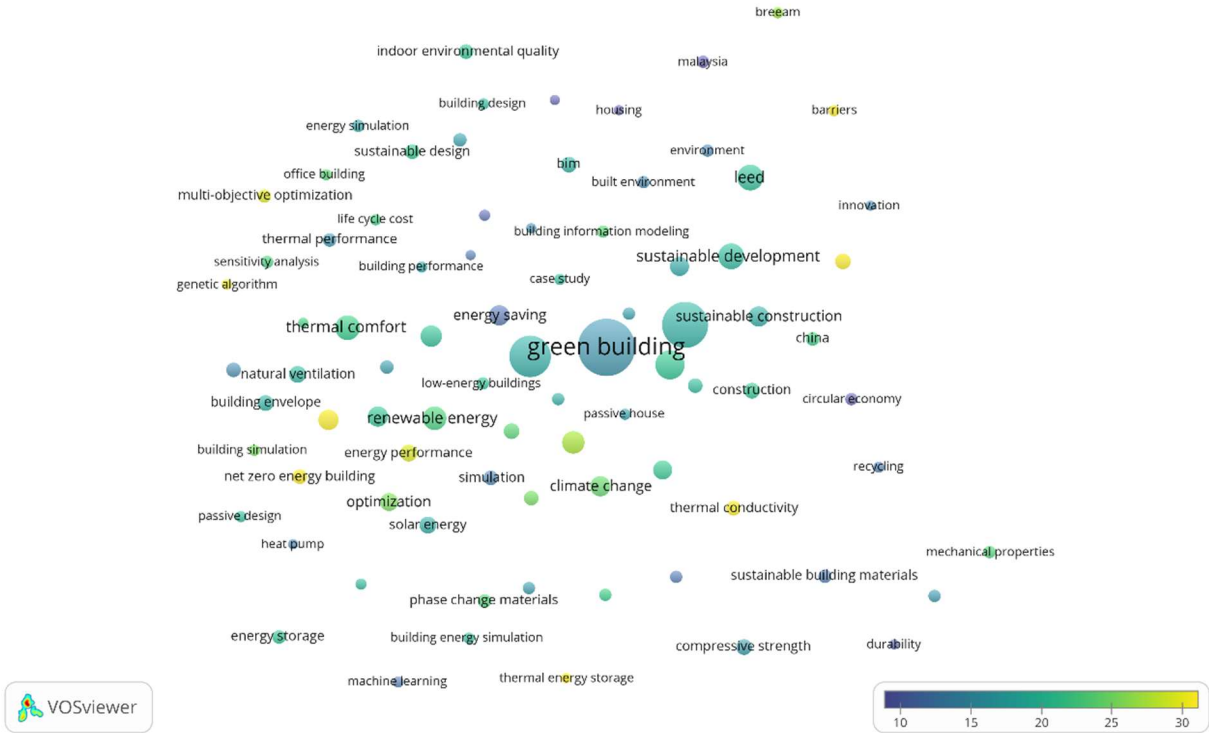


Fig. 5 - Bubble map of high frequency terms (2011–2022) / *Harta cu bule a termenilor cei mai frecvenți (2011-2022)*

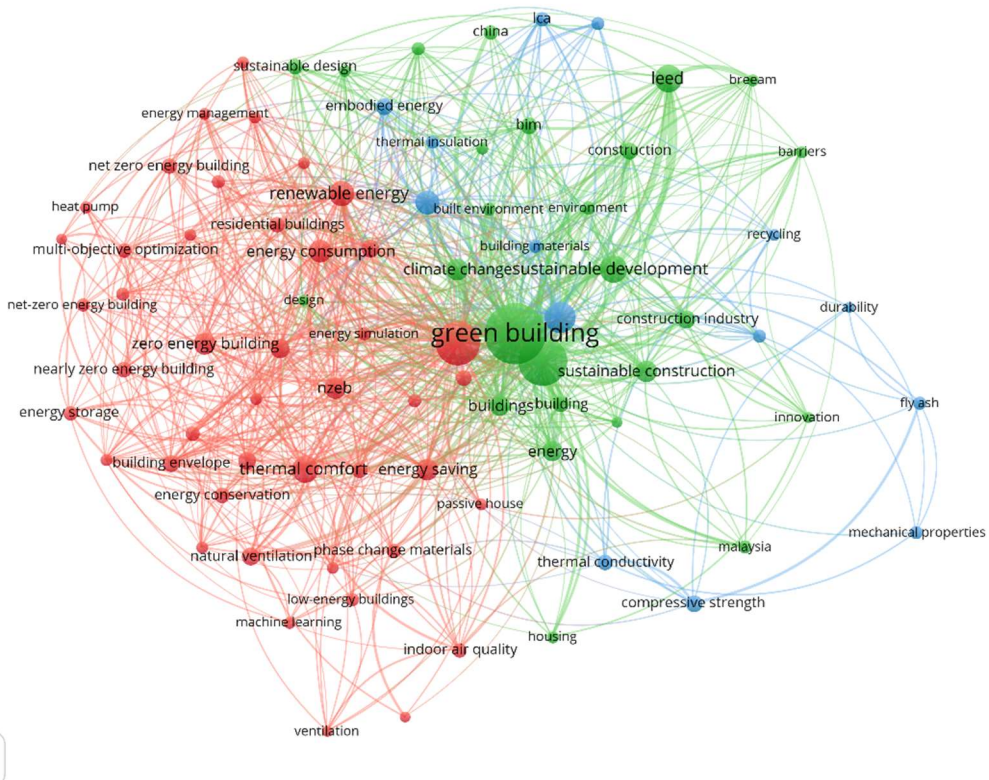


Fig. 6 - Co-occurrence network map of keywords (2011-2022) / *Harta rețelei de co-ocurență a cuvintelor cheie (2011-2022)*

also references to various geographical locations, such as Asia (26, 57.15), Eurasia (50, 49.40), Europe (28, 37.57), North America (26, 22.00), and

the United States (36, 22.75). The color bar legend indicates the average citations per document. **Figure 4** presents the network map of keywords co-

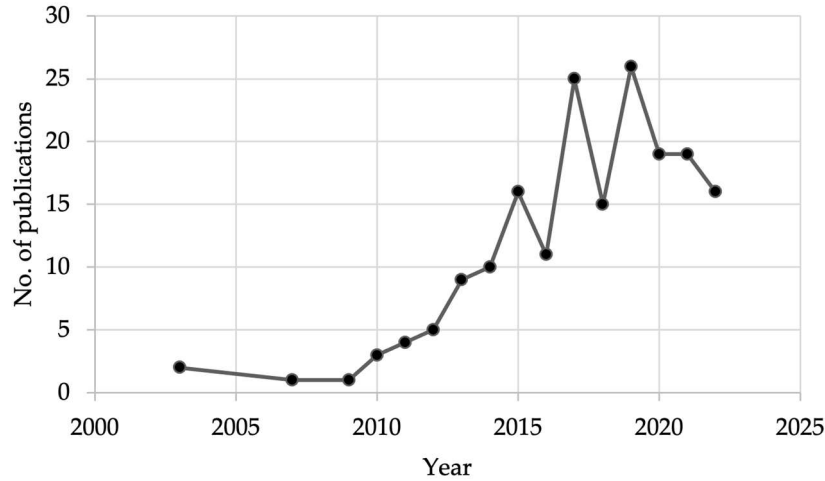


Fig. 7 - The trend of publications with Romanian authors / *Trendul publicațiilor cu autori români*

Table 4

Data regarding the first five highest cited publications on green building, with Romanian authors
Date privind cele mai citate cinci publicații despre clădiri verzi, cu autori din România

First author [Ref.]	Title	Year	Journal
Attia, S. [39]	Overview and future challenges of nearly zero energy buildings (nZEB) design in Southern Europe	2017	Energy and Buildings
Diaconu, B.M. [40]	Novel concept of composite phase change material wall system for year-round thermal energy savings	2010	Energy and Buildings
Popescu, D. [41]	Impact of energy efficiency measures on the economic value of buildings	2012	Applied Energy
Soreanu, G. [42]	Botanical biofiltration of indoor gaseous pollutants - A mini-review	2013	Chemical Engineering Journal
Ionescu, C [43]	The historical evolution of the energy efficient buildings	2015	Renewable and Sustainable Energy Reviews

occurrence. The red cluster contains the most terms (22), followed by the green cluster with 17 terms and the blue cluster with 11 terms. The following words have a high co-occurrence: "Buildings" with "sustainable development", "energy efficiency", "green buildings"; "Sustainable development" with "intelligent buildings", "sustainable building", "sustainability", "green buildings".

Between 2010-2022, based on the information provided in the **Figure 5**, it appears that the term "green building" has the highest occurrence rate (853), with an average of 15.15 citations per document. The next terms with high occurrences are "sustainability" (561, 18.55), and "energy efficiency" (451 occurrences, 18.10 average citations per document). **Figure 6** presents the network map of word co-occurrence. The red cluster contains 44 terms, followed by the green cluster with 15 terms, the blue cluster with 15 terms, and the yellow cluster with 10 terms. The following words have a high co-occurrence: "Green Building" with "sustainability", "energy efficiency", "leed", and "sustainable development"; "Sustainability" with "construction", "buildings", "leed", and "environment".

3.6. Green building publications related to Romanian authors

According to current research, starting only from 2003, authors affiliated with Romania published a total of 182 documents of different types (original article, review, etc.). Of these, 97 are categorized in Engineering, 55 in Energy, and 45 in Environmental Science. All the remaining categories have under 40 assigned documents. Bădescu V., associated with the Romanian Academy, Bucharest, was the first Romanian author to publish an article that fits the search parameters. The article was published in Energy and Buildings (CiteScore 11.5) "Renewable energy for passive house heating: Part I. Building description" [38]. As seen in **Figure 7**, there is a clear trend of increasing interest in this subject among Romanian academics, with the highest number of publications being recorded in 2019. However, it appears that this interest has decreased in subsequent years.

Table 4 presents main information for the first five highest cited documents published by/with Romanian authors [39-43]. The most influential paper of this period was published by Attia S.

(Université de Liège, Liege, Belgium). Even though he is not a Romanian national, the paper's authorship includes significant contributions from Romanian authors Baracu T., Bădescu V. and Crutescu R. [39].

With an average citation rate per document of 2.44, Moga L.M. from the Technical University of Cluj-Napoca, Romania stands out among the most prolific authors, as having the most papers published; the most cited document by this author has 13 citations "Nano insulation materials for application in nZEB" [44]. Crutescu R. from Spiru Haret University in Bucharest, Romania, shows an impressive average citation rate per document (49.40). In addition, Bădescu V. presents a high citation rate per document (46.33). The last two mentioned authors participated in the writing of the most-cited paper [39], also affiliated to Romania (first author Attia S.).

4. Discussions

In terms of published articles and citations, it has been observed a significant variation between countries in both datasets. In the first period, the United States had the highest number of articles (416) with 10834 citations, while in the second period, China had the highest number of articles (1293) with 21237 citations. While in the first period, the countries with a higher average citation rate are represented by China, Sweden, and Canada, in the second period, countries with a high average citation/ document are represented by Italy, Canada, and Australia. Overall, the largest number of publications belong to the United States, followed by China, Italy, and the United Kingdom.

The assessment of the most prolific journals in the field analyzed the number of articles published in various journals to determine which ones were the most productive. This type of information may be relevant to authors in the field when selecting which journal to submit their research to. However, it is crucial to remember that a journal's quality is not always reflected in the number of papers it publishes. When assessing the relative worth of a journal, additional parameters should be considered.

The citation analysis of the publications presents the most cited works in the field of GBs. These works cover a range of topics, including the role of environmental assessment tools, the use of multi-objective genetic algorithms in design optimization, the performance of recycled aggregate concrete, the development of a GB assessment tool for developing countries, and the impact of climate change on residential building energy requirements. Other topics addressed in these works include the effect of material choice on the total energy need and recycling potential of a building, and the social and psychological barriers to GBs. Also, evaluating the most prolific authors can provide valuable

insights for future authors seeking potential collaborators for their research.

The structure and dynamics of a scientific field can be understood by utilizing science mapping analysis. The network map of country co-authorship highlights the countries from which authors have a strong collaborative relationship in both periods. Analyzing these maps, we can conclude that the research on GBs is of high interest worldwide. Furthermore, authors often collaborate with other authors from different countries. The term map analyzes the topics with high occurrence levels and the terms included in highly cited articles. The network map of term co-occurrence depicts the relationship between these terms.

The example of Romania demonstrates that this field of sustainable constructions is still in its development. Concern for everything that means a healthy living environment (GBs) must be one of the primary directions of the policies promoted by the governments and relevant ministries.

Taking into account that in most developed countries the interest in sustainable development is much more pronounced than in less developed countries, and that policies in this sense are much better developed and applied accordingly, it is expected that in the next period the number of publications in the field to grow especially in countries where the legal framework regarding sustainable development policies is clearly described and outlined. Moreover, the implementation of these green materials also requires the appropriate funds, sustainable development not being cheap; therefore, such development will be much more within the reach of countries that have substantial funds.

Bibliometric studies are subject to certain limitations that are largely a result of the analysis method employed. One such limitation is the restriction to documents written in English. Another limitation is the inability to thoroughly review every journal included in the analysis, which may result in the inclusion of false positives. Despite these limitations, bibliometric analyses offer several advantages, including objectivity, as the findings are not influenced by the personal biases of the authors, and the ability to evaluate a large number of papers, providing a broad overview of the topic.

5. Conclusions

To provide a comprehensive view of GBs, the current study examined 8612 Scopus indexed papers, using bibliometric analysis and science mapping technologies. Two time periods were bibliometrically analyzed, starting with the year when the first manuscripts on GBs were published. 1175 manuscripts were published between 1980-2010, while 7437 documents were published between 2011- 2022. For each period, the most

productive countries, journals, authors, and the most cited papers were identified. The present study employed network maps to illustrate the connections between various bits of knowledge, including the interactions between countries in the writing of articles. To further explore the most popular themes within this field and their relationships, term map analysis and network map of term co-occurrence were utilized. These tools provided insight into the structure and dynamics of the research landscape and identified potential areas for further investigation. By using bibliometric analysis associated with a specialized software, this study of GBs research provides a quantitative assessment of reports and studies conducted so far, merging chronological gaps, projecting the prospect of GBs, and providing a useful tool for researchers interested in this topic correlated with the disadvantages of the use of conventional technologies that affect the environment.

Considering the increasing interest in environmental protection and ecofriendly materials, it is expected that the following trends will show that the number of research / publications in the GB field will increase exponentially, being obvious the correlation between the theoretical knowledge, technological development with practical implications, financial abilities, and solid policies/legal framework related to sustainable development.

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