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Review

Qualitative and Quantitative Scientometric Analysis of Bioclimatic Retrofitting in Commercial Buildings from 2008 to 2022

Ali Heidari * and Francesca Olivieri

Departamento de Construcción y Tecnología Arquitectónicas, Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid, Av. Juan de Herrera 4, 28040 Madrid, Spain; francesca.olivieri@upm.es
* Correspondence: ali.heidari@alumnos.upm.es; Tel.: +34-644709777

Abstract: The present study offers a thorough scientometric analysis of the practice of bioclimatic retrofitting in commercial buildings, which is considered a crucial approach for mitigating energy consumption and addressing the challenges posed by climate change. Since Scopus offers advanced tools for literature search and analysis, its database was used to acquire bibliographic data for nearly 400 published papers using a bibliometric search, a scientometric methodology, and an in-depth qualitative analysis. The scientometric procedure utilizes various quantitative dimensions, such as the number of intermediate citations, occurrences, average publication year, and general connection power. A retrospective examination of research publication patterns spanning 2008 to May 2022 has unveiled an upward trajectory in scholarly investigations pertaining to commercial buildings during this 15-year period. Nevertheless, research on the topics of bioclimatic design, retrofitting strategies, and green building practices in the context of commercial buildings exhibits a more gradual incline, displaying an almost linear trend between the years 2016 and 2020. Additionally, the study provides qualitative perspectives on the research environment. The paper delineates various focal points of research within the field, encompassing thermal comfort in the context of energy management and climate control, ventilation systems, sustainable development as it pertains to architectural designs and green buildings, retrofitting strategies in commercial buildings to enhance energy efficiency, the interplay between carbon dioxide levels and energy resources, the utilization of solar energy, the relationship between energy conservation and atmospheric temperature, and the application of building energy simulation techniques.

Keywords: bioclimatic retrofitting; energy conservation; commercial buildings; scientometric review; bibliometric

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1. Introduction

Buildings consume energy throughout their operational lifespan. The operational phase of a building's life cycle plays a crucial role in energy consumption. The key features encompassed within a building's infrastructure include heating, ventilation, air conditioning (HVAC), lighting, and appliances [1]. According to empirical data, the energy consumption attributed to buildings and their associated activities throughout their life cycle accounts for over 40% of the total global energy demand [2]. Approximately 50% of the total energy consumption is allocated to heating, ventilation, and cooling (HVAC) systems [3].

The energy consumption in question pertains to carbon dioxide emissions, which have exhibited an annual growth rate of 6.83% over the previous decade. The rate of growth of this phenomenon is increasing, as evidenced by the total emissions of 881 megatons (Mt CO_2) reported in 2018. In the realm of existing structures, mercantile edifices are presently the most widely employed buildings, as determined by their overall performance [4].

Hence, the imperative to mitigate carbon dioxide emissions resulting from the utilization of fossil fuels to generate energy for pre-existing commercial structures has become a crucial matter of policy and design for governments globally [2]. Consequently, a considerable body of research, investment, technological advancements, and regulatory efforts are directed toward reducing energy consumption in HVAC systems through the implementation of sustainable building practices [3].

According to the definition provided by the US Environmental Protection Agency (2012), green construction refers to the practice of designing and implementing environmentally responsible structures and processes while also ensuring the efficient utilization of resources throughout the entire life cycle. A Green Building (GB) can also be referred to as a High-Performance Building or a Sustainable Building. There are two distinct categories of GB design, namely new design (ND), which pertains to the construction of new buildings, and reinforcement design (RD), which focuses on enhancing the structural integrity of existing buildings [5]. Studies have demonstrated that the energy consumption of newly constructed buildings often exceeds the initial projections made during the design phase, despite the utilization of architectural elements such as Green Building practices. This disparity is frequently denoted as the "performance gap" [3].

A study conducted in 2013 [6] examined the annual energy consumption per unit area (square meter or square foot) of building infrastructure in a sample of 953 properties located in New York City. The researcher observed a lack of substantial energy conservation in LEED-certified buildings compared to non-LEED-certified buildings. LEED, which stands for Leadership in Energy and Environmental Design, is a widely recognized certification standard for environmentally friendly construction established by the US Green Building Council [6].

In a study conducted in 2014, a comprehensive analysis was carried out on 51 buildings that were previously classified as "high performance" in the United States, Europe, and Asia [7]. It is noteworthy that a considerable proportion, roughly 50%, of the structures examined failed to comply with the ASHRAE Standard 90.1-2004 Energy Standards, as established by the American Society of Heating, Retrofitting, and Air Conditioning Engineers [8].

A separate study conducted in 2019 [9] examined the operational efficiency of green buildings, with a particular focus on China and the United States. A comprehensive review of the literature identified a total of 106 studies that included substantial quantitative data analysis. A comparison was conducted between the energy intensity of 121 high-performance certified buildings from the United States and 31 buildings from China. According to the study, there has been a marginal improvement in the overall performance of the building.

In conjunction with the considerable energy consumption exhibited by contemporary commercial buildings constructed in accordance with the Green Building Rules, as previously delineated, a more disconcerting reality pertains to the majority of commercial buildings in prominent urban centers worldwide, which were erected prior to the advent of energy efficiency measures and are currently 20 to 30 years old. The primary issue at hand pertains to the fact that the majority of these structures are anticipated to be in use until the year 2050. Hence, as a result of their elevated energy consumption, current commercial buildings exert added strain on the emission of carbon dioxide derived from fossil fuel sources [10].

Due to its perceived comparative advantages in terms of energy-saving potential, the construction sector occupies a prominent position in addressing global energy and environmental concerns, surpassing other sectors such as industry and transportation. The existing structure serves as the backbone of the construction sector, making it imperative to enhance its performance in order to ensure stability. Therefore, it is crucial to enhance the energy efficiency and environmental impact of existing commercial buildings in industrialized nations [1].

The recognition of sustainable retrofit strategies as the sole acceptable approach to mitigating energy consumption and carbon emissions in buildings is growing. According to the available data, sustainable retrofitting of commercial buildings has been found to result in a consistent reduction of approximately 75% [2]. One of the sustainable energy-efficient solutions is bioclimatic design [11], which emphasizes the various components of energy consumption in buildings. Hence, it is imperative to take into account the incorporation of design interventions rooted in standards of bioclimatic design when undertaking the retrofitting and sustainable operation of commercial buildings [2].

Bioclimatic architecture refers to the study of weather conditions in the field of architecture, with the aim of improving the well-being and comfort of building occupants. This is achieved through the implementation of passive energy processes, formal plan components, and heat transfer management technology [11].

Prior studies have proven valuable in elucidating the significance of bioclimatic architecture. In addition, they provide us with practical remedies for retrofitting commercial buildings. A study conducted in 2021 aimed to identify and prioritize the key factors involved in the selection of suitable repair and maintenance (R&M) procedures for commercial buildings (CB). This issue holds considerable significance for the construction industry, as well as the fields of architecture and engineering. The study encompasses a set of 16 measures that are categorized into five distinct areas. These areas consist of flexibility, technical skill, risks, maintenance costs, facilities, technology, and human resources. The Fuzzy Analytic Hierarchy Process (FAHP) technique was employed to determine the relative importance of various criteria, and it was determined that the maintenance cost criterion is more relevant than other criteria [12]. In 2021, a study was conducted in Egypt that focused on a commercial building located in Giza, serving as a representative case study for an urban area with a significant population. In order to mitigate energy consumption, decrease CO_2 emissions, and attain ecological equilibrium, the researcher employed an alga in the retrofitting of the building facade as a means to enhance its outer layer.

According to the researcher's findings, the utilization of algae in the building facade resulted in a notable decrease in electricity consumption, ranging from 45 to 50%, as well as a reduction in CO_2 emissions [13]. Research conducted in Saudi Arabia in 2021 examined the feasibility of retrofitting commercial buildings with the aim of enhancing energy efficiency and indoor air quality. The study examines various retrofitting alternatives in relation to energy conservation and financial costs. Based on the findings, the implemented retrofitting techniques resulted in a reduction of a building's energy consumption by 39%. The significance of enhancing indoor environmental quality has also been underscored, particularly in relation to aspects such as lighting, thermal comfort, the mitigation of pollutants, which encompasses PM10 (particulate matter), TSP (total suspended particulate), CO (Carbon Monoxide), SO_2 (Sulphur Dioxide), NO_2 (Nitrogen Dioxide), and VOCs (Volatile Organic Compounds), and noise management [1].

A 3D simulation study was conducted in 2017 using integrated environmental solutions software with the virtual environment. The findings of the study demonstrated the need of utilizing energy-efficient HVAC systems and techniques to reduce building energy consumption. The recommended strategies arising from the simulation analysis were as follows;

- Creating a full-height internal atrium. (Analyses showed that the effects of solar radiation inside the atrium of the building were significant).
- The proposed air conditioning system also includes a cold roof and a chilled beam system served by a centrifugal water chiller located in the basement. The building's eastern and western peripheral areas are operated by chilled beams, which are served by an air handling unit (AHU). The central areas are served by passive cold roofs perched on the perforated roof of the building. Outdoor air is supplied to the central areas through an AHU mounted on the roof. Relieved and reciprocating air is forced to flow through the atrium. Heat dissipation from the chiller is dissipated into the

atmosphere through cooling towers located in the factory room on the roof. It is also recommended that the building be carefully configured during the commissioning period, in addition to providing cold roof technology, high efficiency, and a low-energy chiller [14].

The year 2008 witnessed a notable paradigm shift in the international community's attention toward the concept of sustainability. In accordance with the declaration made by the United Nations, the year 2008 was designated as the International Year of Planet Earth, with a primary focus on highlighting the imperative of sustainable development [15]. During this particular era, there was a notable surge in scholarly attention towards investigating energy efficiency and sustainability, encompassing the field of bioclimatic retrofitting [16].

The period from 2008 to 2022 was characterized by notable progress in the field of technology, particularly in the domain of bioclimatic retrofitting. This period witnessed the emergence and enhancement of various tools and methodologies pertaining to this field [16]. Hence, this particular timeframe holds significant importance in comprehending the development and influence of these technologies.

During this period, numerous countries implemented policy changes aimed at enhancing energy efficiency and promoting sustainability [17]. Gaining an understanding of the prevailing research trends during this specific period can yield valuable insights into the potential ramifications of these policies.

The selection of a 15-year timeframe enables a thorough examination of the existing body of scholarly works. The temporal scope of this study allows for the identification of trends and patterns, while concurrently ensuring the contemporaneity and applicability of the obtained findings.

While some manual assessments of commercial buildings have been conducted, this is one of the first compound procedure qualitative scientometric study analyses linking bioclimatic retrofitting and energy savings in commercial buildings. It also aims to improve on previous manual assessments by resolving errors and filling in knowledge gaps.

The study's objectives are as follows: (i) to critically assess and recognize the maximum influence of issuing venues, papers in climatology retrofitting in commercial buildings, and study keywords utilizing science topography; (ii) to recognize the composition of scheming studies on climatology retrofitting; and (iii) to identify knowledge gaps in the bioclimatic retrofitting domain. The study results contribute to the expansion of existing knowledge by delivering an exhaustive review of the present condition of climatology retrofitting in commercial building studies, scheming study compositions and collections, and suggesting positions for prospective research. The research can also be used as a guide for practitioners looking to maximize the advantages of bioclimatic retrofitting and planning, as well as as a policy tool.

A Bioclimatic Retrofitting Approach

In the 1950s, Olgyay [18] identified bioclimatic concerns in architecture and, in the 1960s, established a design approach. This design process integrates building physics, climatology, and human physiology and has recently been considered a cornerstone for achieving more sustainable buildings and included within the building design professions in the framework of regionalism in architecture [2].

Vernacular architecture is the cornerstone of climatology construction [19]. Cruz et al. believe that this includes evaluating historical design in relation to the climate and culture of a place, as well as providing inactive alternatives to construction and architecture [20].

The interest in vernacular architecture has been prompted by instances when HVAC and lighting systems failed to solve cooling and lighting problems [20]. The technologies used are adapted to the bioclimatic conditions in the area, and the indigenous benefits are unique due to the location of the building. Thus, soil or wood is used as a building material in local architectural designs [19].

Vernacular structures take advantage of natural resources such as the sun and wind, and research has shown that they have superior thermal execution. As a result, vernacular architecture and bioclimatic architecture are inextricably linked [21].

Because low- and medium-scale buildings are simple to make climatically interactive, with the form and fabric of the building matched to human and climate elements to increase climate reaction, the research that led to the development of bioclimatic design regulations was mainly focused on these types of structures [2].

Large-scale buildings have largely been overlooked because of the complexity of the process, the dense urban fabric in which these structures are generally found, and the availability of inexpensive energy for cooling. Bioclimatic factors have been largely overlooked in design concepts for large-scale buildings, with a good internal environment being instead achieved by employing energetic mechanical systems to restore comfort. Most commercial buildings in major cities around the world were built before energy efficiency became a goal and are between 20 and 30 years old, and these buildings will be operational until 2050. Thus, bioclimatic retrofitting of existing commercial buildings to increase energy efficiency and the environment is important [2].

The bioclimatic retrofitting approach uses passive low-energy techniques that relate to and are borne by the site's climate and meteorological conditions. The approach focuses on providing high-quality passive changes in buildings through a high-performance envelope, form, and fabric [21]. This results in a building that is climate-responsive and environmentally interactive with reduced energy consumption in operation and embodiment. A bioclimatic retrofitting approach gives a clear triple bottom line. The most convincing justification for the bioclimatic retrofitting for high-rise buildings is perhaps an economic one: the savings from lower consumption can be as much as 30–60% of the overall energy costs of the building [2].

A further justification is that bioclimatic retrofitting affords a more human experience of a commercial building. Bioclimatic retrofitting promotes better natural ventilation and awareness of place, resulting in healthier internal environments and increasing overall business productivity. A further and essential justification is the ecological rationale. By using passive devices to achieve thermal comfort, climatically retrofitted buildings have lower total carbon dioxide emissions, lowering overall air pollution, and help minimize global warming [2].

The growing demand for energy-efficient structures has resulted in a significant upswing in scholarly investigations pertaining to the application of bioclimatic retrofitting, with a specific focus on commercial edifices. Despite the extensive body of research on this subject, there exists a dearth of comprehensive literature reviews that amalgamate the outcomes of these studies and discern areas of knowledge deficiency.

This study employs an innovative methodology to investigate the concept of bioclimatic retrofitting and its impact on energy conservation within the context of commercial buildings. This preliminary and extensive analysis of scientometric data in this field rectifies inaccuracies and fills in gaps in current knowledge. This paper presents a comprehensive framework aimed at achieving near-zero energy buildings, thereby contributing to global efforts to address the energy crisis. The present study undertakes an analysis of bioclimatic retrofitting in the context of commercial building research, thereby contributing to the existing body of global knowledge on this subject. The text provides an overview of research clusters and proposes potential avenues for future research. This study aims to assist professionals in optimizing the benefits of bioclimatic retrofitting and planning, while also providing valuable insights for the development and implementation of policies. Therefore, this holds significant value in the realm of construction engineering and architectural research and application.

2. Methods

The combined approach to periodic reviews was utilized to achieve the research's objectives. The combined approach to periodic reviews mixes qualitative and quantitative

information to produce conclusions that are more comprehensive than either quantitative or qualitative analyses could produce on their own [22]. The subjective bias associated with manual systematic reviews was also removed by this method [23]. The study methodologies and instruments employed in this research are described in this section. Subsections were established to provide a comprehensive explanation of the study methods used.

2.1. Scientometric Analysis and Review of Scientific Maps

In analyzing the massive amounts of data available in the bibliographic literature, scientific topography may help to show basic trends and patterns [24]. This technology emphasizes keywords in contrast to the manual assessment process, which emphasizes researchers, publication outlets, and countries, to be linked in a study domain [25]. Bibliographic data were analyzed using scientometric investigation, a quantitative scientific mapping process.

This procedure requires the presentation of thought trends and the sketching of structural patterns in a research topic to visualize and analyze a large number of publications [26].

Scientometrics has also been used in this research. With applications in various fields [19], scientometric analysis is one of the most widely utilized methodologies for research development analysis [27].

2.2. Science Mapping Software Selection

The map visualized in this study was created using the textualization tool VOSviewer 1.6.17 (Visualization of Similarities), expanded by Ludo Waltman and Nees Jan van Eck [28]. Open-source software has been selected because of its ease of use when displaying massive networks based on distance techniques [28].

The connections among journals, researchers, and individual articles within extensive networks are established through citations, bibliographic references, or shared authorship [29]. Studies of building control, construction management, public–private partnerships, building information modeling (BIM), and on-site construction have all made use of VOSviewer. As a result, to achieve the objectives of the study, VOSviewer is suitable.

2.3. Bibliographic Data Extraction

The selection of the Scopus database as the primary source of the literature for this study was based on multiple factors. Scopus provides extensive coverage across a wide array of academic disciplines. The database comprises a collection of over 22,000 titles sourced from more than 5000 publishers worldwide, thereby offering a diverse range of research materials. The selection of Scopus was influenced by the considerable importance placed on the quality of its content. Scopus exclusively incorporates publications from publishers that are widely recognized for their credibility and reliability. This rigorous selection process serves to uphold the integrity of the research by ensuring that it is derived from reputable and dependable sources. One additional benefit of Scopus that was taken into account is its capability for tracking citations. The comprehension of the influence of a specific piece of work and the interconnections among various works is essential for conducting scientometric analysis [30].

In addition, Scopus provides sophisticated tools for literature search and analysis. These tools facilitate the identification of trends, the discovery of pertinent studies, and the execution of a thorough literature review on the subject of bioclimatic retrofitting in commercial buildings.

Although Scopus is widely acknowledged as a valuable resource, it is important to note that it is not the sole database accessible for academic research. In addition to PubMed, Web of Science, and Google Scholar, there are several other databases that provide comprehensive repositories of scholarly literature. The selection of a database is contingent upon various factors, including the particular research discipline, the extent of the research endeavor, and the unique requirements of the researcher. Due to the inevitable occurrence

of duplicate publications when merging multiple databases, the decision was made to utilize a single database [31].

Scopus was selected in this instance due to its extensive coverage of the construction engineering and architecture domain, its high-quality content, and its sophisticated search and analysis capabilities. Nevertheless, it is acknowledged that the exclusive reliance on a solitary database could potentially constrain the thoroughness of the literature review, as certain pertinent studies may not be contained within the Scopus database. The aforementioned constraint has been duly considered in the study. Published journal articles, review papers, and conference proceedings were used to conduct the literature search. Zheng et al. believe that journal articles and review articles are preferred because they are reliable sources of information that are accurate and precise [32]. As a result, the source discussed above has been designated as a trustworthy resource for preparing a literature review [33].

As shown in Figure 1, the keyword "Commercial Buildings" was used to find publications. These keywords were derived from the titles of publications.

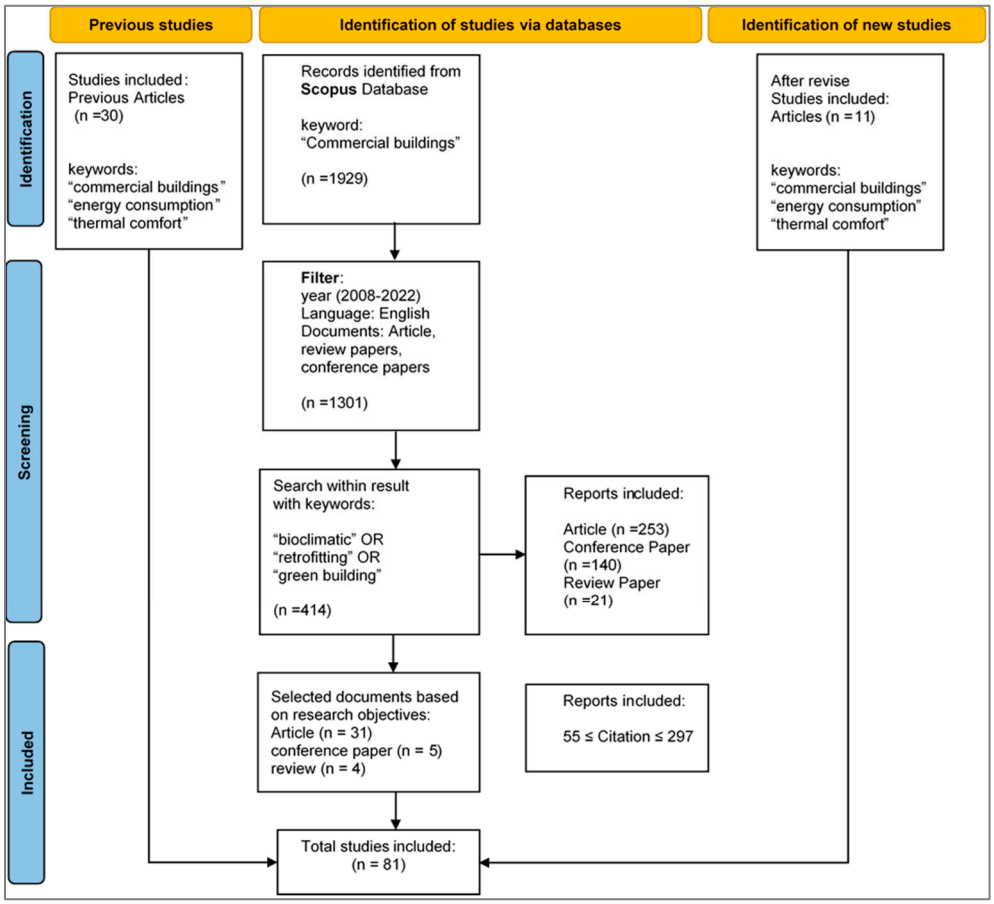


Figure 1. PRISMA [34] flow diagram for the systematic review process, which included searches of the Scopus database and previous studies.

The time frame for the search was 2008 through 2022. Furthermore, only papers in English were considered. There were 1301 publications in total.

The keywords "Retrofitting" OR "Bioclimatic" OR "Green Buildings" were used to further narrow these publications. These terms were chosen for their relevance to the subject of research. A total of 414 linked publications were obtained at the end of the refinements consisting of 253 journal articles, 140 conference papers, and 21 review papers. The catalog information was downloaded in CSV format (comma_separated values).

2.4. Scientometric Method

The downloaded bibliographic information was entered into the VOSviewer software (Figure 2). Network critique and visualization of those locations were performed. For network construction, network analysis including source investigation, citation investigation, keyword event investigation, and cluster investigation were used. Data congregation is an info-extracting process that uses similarity measurements to identify natural groupings in a multidimensional dataset [35]. Because it specifies and analyzes the connections among concepts and recognizes patterns, an essential part of the scientometric investigation is cluster analysis. Data related to research subject clusters are provided by VOSviewer. Objects of the same color belong to the same collection and are characterized by a mark in the keyword network investigation scheme. The relationship of the keyword to the distance between the circles is shown. Ultimately, tables and maps were prepared to show the networks and statistically describe their criteria.

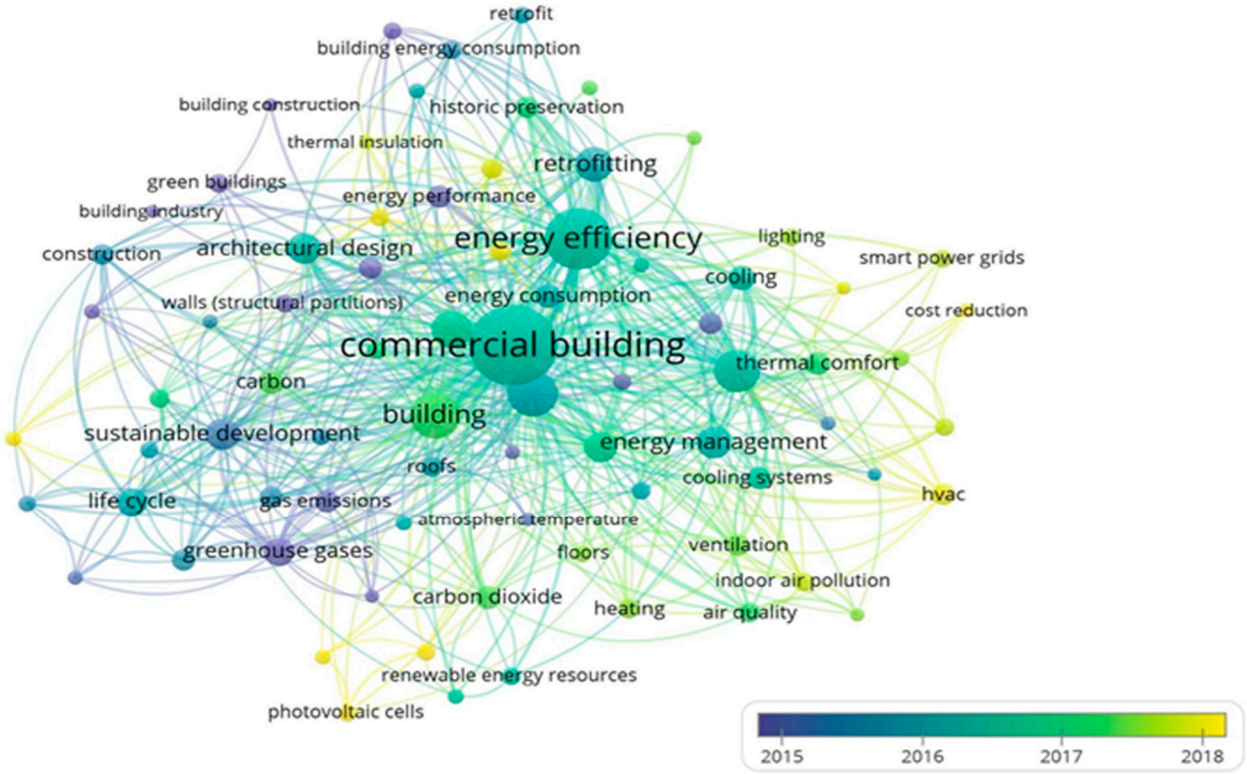


Figure 2. Overlay visualization map of co-occurring keywords (2008–2022).

3. Results and Discussion

3.1. Quantitative Analysis

A transition was made to a more data-driven process in the first quantitative analysis section. In this part, studies conducted in the field of commercial buildings over a 15-year period were statistically analyzed to find patterns and trends. During the period 2008 to 2022, a significant global shift towards sustainability took place. Scholars' focus was directed towards energy efficiency and bioclimatic retrofitting, resulting in significant advancements in technology. Policy adjustments were implemented in order to promote and support sustainability. Therefore, this 15-year timeframe is of great importance in understanding the development and influence of these technologies and policies [16].

This quantitative analysis could be utilized to ensure that the results of the qualitative analysis have quantitative significance and validity. The research was taken to a higher scientific and logical level by this quantification method. VOSviewer software was used in the second half of the study to display a scientific map of the investigations, and the results and discussion are presented here.

3.1.1. Publications per Year

Figure 3 depicts the annual number of commercial building-related publications from 2008 to 2022. The review was limited to articles with the keywords "bioclimatic", "retrofitting", and "green building".

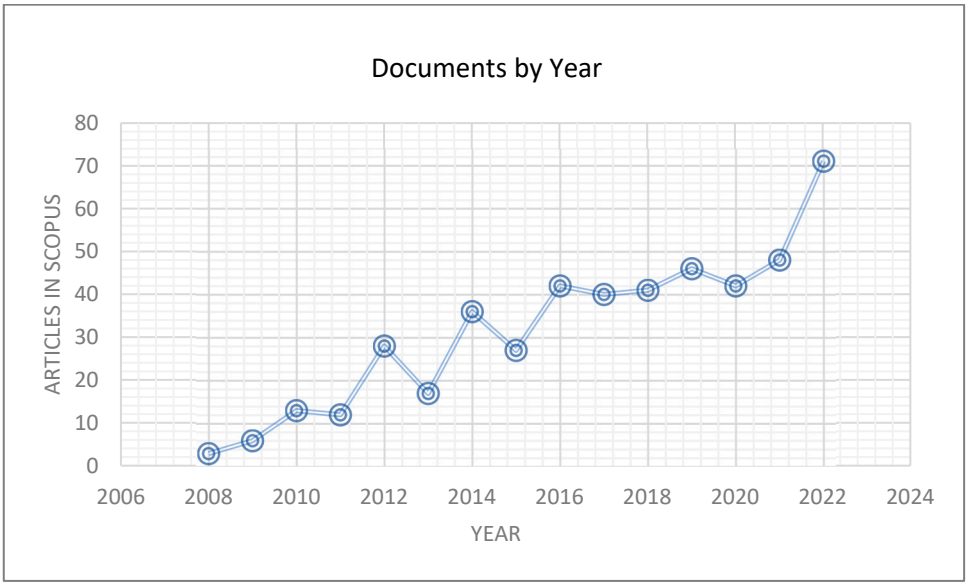


Figure 3. Number of publications per year.

The graph shows that the number of publications has been continuously increasing over the last 15 years, demonstrating a growing interest in commercial building research. However, the number of publications fell in 2020, owing to the significant impact of the coronavirus pandemic on research activity and academic publications. However, as seen in the graph, the slope begins to grow again in 2021, with the number of articles reaching a 15-year high in 2022. This growth in commercial building papers corresponds to the greater amount of research devoted to addressing these challenges in the twenty-first century, with the building industry being a major user of energy globally [2].

3.1.2. Publications per Document Source

The principal document sources for publishing academic contributions are journals. These journals give readers wells of material on a certain research topic, and they also supply authors with advice on where to publish their work [31].

Based on the data presented in the chart in Figure 4, it is apparent that the journal 'Energy and Buildings' has the highest number of articles, totaling 38, while 'Applied Energy' follows closely with 23 articles. The journals "Building and Environment" and "Energy" have made notable contributions to the field, with 14 and 12 articles, respectively. Additional noteworthy publishers in the field include 'Energies', 'IOP Conference Series Earth and Environmental Science', 'Energy Efficiency', 'Sustainability Switzerland', and The Journal of Architectural Engineering, each of which boasts a publication portfolio consisting of approximately 9 to 7 articles.

The chart in Figure 4 presents a visually accessible depiction of the allocation of articles across various publishers, effectively emphasizing the primary contributors within the respective domain. This information holds potential utility for researchers aiming to comprehend the scope of published literature within this field.

VOSviewer was used to obtain more data. The unit of analysis was "sources," and the type of analysis was "citation".

Table 1 shows 16 document sources after setting the minimum extraction to four documents. With 38 documents and 1264 citations, Energy and Buildings topped the list.

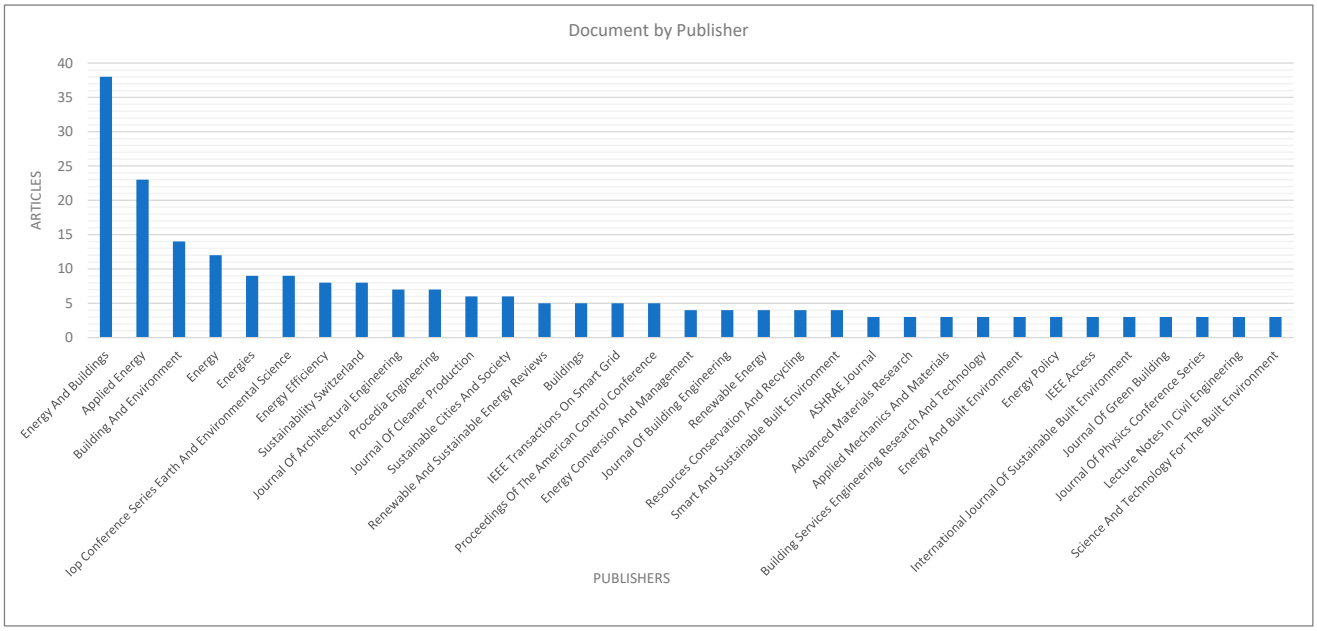


Figure 4. Research publishing trend 2008–2022.

Table 1. Summary of the number of publications per document source.

Document Source Title	No of Publications	Total Citations	Avg. Publication Year
Energy and Buildings	38	1264	2016
Applied Energy	23	949	2018
Building and Environment	14	485	2016
Energy	12	486	2018
Energies	9	77	2020
Energy Efficiency	8	223	2016
Procedia Engineering	7	84	2016
Architectural Engineering	6	53	2015
Cleaner Production	6	166	2019
Proceeding of American Control Conference	5	126	2016
Renewable and Sustainable Energy Reviews	5	374	2014
Building Engineering	4	33	2021
Renewable Energy	4	32	2019
IEEE Transactions on smart Grid	4	130	2017
Smart and Sustainable Built Environment	4	37	2018
Sustainable Cities and Society	4	128	2018

Energy and Buildings is a peer-reviewed international publication that publishes studies on how energy is used in buildings. This journal publishes cutting-edge research and tried-and-true methods for lowering building energy utilization and improving internal air quality. With an H-index of 184 and an impact factor of 5.879, the conclusion may not be surprising. The most significant publications from the results collected are Energy and Buildings and Applied Energy.

With an H-index of 212 and an impact factor of 9.746, Applied Energy acts as an association for information on invention, study, expansion, and corroboration in the fields of energy transformation and protection, energy efficiency, analysis, and optimization, energy processes, pollution reduction, and sustainable energy systems.

As a result, these two journals should be regarded the initial point of contact for everyone interested in bioclimatic architectural research.

3.1.3. Most Cited Publications

Scholars must identify the most referenced papers and their area of emphasis since they always identify with publications that have made a substantial contribution to the research community. To determine the influence of a piece of work, the total number of citations can be employed [21]. Setting the minimum number of citations at 55 produced a list of the 38 most-cited documents of the 414 identified by the search. Table 2 lists these documents.

Table 2. Quantitative summary of most-cited publications.

Article	Document Source Title	Citations
[36] Kneifel, J. (2010)	Energy and Buildings	297
[37] Balaji, B. et al. (2013)	Proceedings of the 11th ACM Conference on Embedded Networked Sensor	224
[38] Robinson, C. et al. (2017)	Applied Energy	185
[39] Lebinson, R., & Akbari, H. (2010)	Energy Efficiency	159
[40] Haq, M.A.U. et al. (2014)	Renewable and Sustainable Energy Reviews	158
[41] Onat, N.C. et al. (2014)	Building and Environment	117
[42] Hong, T. et al. (2015)	Applied Energy	112
[43] Lazos, D. et al. (2014)	Renewable and Sustainable Energy Reviews	112
[44] Zuo, J. et al. (2012)	Habitat International	98
[45] Liao, C., & Barooah, P. (2010)	Proceeding of American Control Conference	95
[46] Ma, M., & Cai, W. (2019)	Science of the Total Environment	94
[47] Ma, M. et al. (2019)	Cleaner Production	93
[48] Ma, M. et al. (2018)	Science of the Total Environment	92
[49] Dong, Y.H., & Ng, S.T. (2014)	Life Cycle Assessment	85
[10] Huang, Y. et al. (2013)	Applied Energy	84
[50] Hoffmann, S. et al. (2014)	Solar Energy Materials and Solar Cells	82
[51] Lee, S.H. (2015)46	Energy	79
[52] Ghai, S.K. et al. (2012)	IEEE International Conference on Pervasive Computing and Communications	77
[53] Yin, R. et al. (2012)	Energy and Buildings	77
[54] Fregosi, D. et al. (2015)	IEEE 1st International Conference on Direct Current Micro grids	76
[55] Ma, J. et al. (2014)	Process Control	75
[56] Maasoumy, M. et al. (2014)	Proceeding of American Control Conference	73
[57] Kua, H.W., & Wong, C.L. (2012)	Energy and Buildings	72
[58] Huang, Y., & Niu, J.L. (2015)	Energy	71
[59] Meegahapola, L.G. et al. (2014)	IEEE Transactions on Sustainable Energy	67

Table 2. *Cont.*

Article	Document Source Title	Citations
[60] Jo, J.H. et al. (2010)	Building and Environment	67
[61] Gulbinas, R., & Taylor, J. E. (2014)	Energy and Buildings	65
[62] Liu, F., et al. (2017)	Safety Science	62
[63] Hwang, B. G., et al. (2017)	Sustainable Cities and Society	60
[64] Hou, J., et al. (2016)	Energy Policy	58
[65] Qi, R., et al. (2014)	Energy Conversion and Management	58
[66] Jiang, M. P., Tovey, K. (2010)	Building and Environment	57
[67] Jiang, P., & Keith Tovey, N. (2009)	Energy Policy	57
[68] Luo, X. et al. (2017)	Applied Energy	56
[69] Papadopoulos, S., et al. (2019)	Building and Environment	55
[70] Kamilaris, A., et al. (2014)	Renewable and Sustainable Energy Reviews	55
[71] Wang, N., et al. (2010)	Building and Environment	55

The paper "Life-cycle carbon and cost study of energy efficiency measures in new commercial buildings" [36] has the most citations. The National Institute of Standards and Technology's Office of Applied Economics in Gaithersburg and the United States Fire Research Laboratory supported the article [36].

This paper uses an integrated design method to evaluate life-cycle energy savings, carbon emission reductions, and the cost-effectiveness of energy efficiency measures in new commercial buildings, as well as the cost of energy-based carbon emissions. For 12 archetypal structures in 16 cities, 576 energy simulations were performed with three building plans for each building–location combination. The cost-effective life cycle and carbon emissions of each design are calculated using simulated energy consumption and a building cost database. The findings show that traditional energy efficiency measures can reduce energy consumption in new commercial buildings by an average of 20 to 30% and in certain types of buildings and places by more than 40%. Because greater efficiency makes it possible to install smaller, less-expensive air conditioners, these savings are usually achieved with negative life cycle costs. This upgrade saves money and energy while reducing the building's carbon footprint by an average of 16%. Because energy is more expensive, the cost of carbon emissions from energy consumption increases the return on investment in energy efficiency and makes some economically viable initiatives possible [36]. This study offers significant insights regarding the potential for energy conservation through the implementation of efficient building design strategies. Nevertheless, it is important to acknowledge that the savings in energy costs do not exhibit a perfect correlation with reductions in energy usage. This discrepancy arises from variations in the marginal costs of electricity and natural gas among different states, the region-specific price projections provided by the Energy Information Administration (EIA), and the loads associated with the building processes. This observation underscores the intricate nature of the matter and implies that a more sophisticated methodology may be required to comprehensively comprehend the economic ramifications of energy-efficient design.

The study "Sentinel: Occupancy Based HVAC Actuation using Existing WiFi Infrastructure within Commercial Buildings" [37], sought to design and implement a system that detects occupancy patterns using commercial buildings' WiFi infrastructure. The Sentinel device accurately detects occupants to optimize the operation of HVAC systems. The project sought to improve commercial building energy efficiency by restricting HVAC system operation to occupied spaces. The Sentinel technology reduced HVAC system electrical energy consumption by 17.8% compared to static scheduling. Sentinel was used to regulate 23% of the building testbed's HVAC zones. The research also showed that the system accurately identified MAC addresses linked with changing occupancy status in an individual's personal space in most cases. This study shows how occupancy-based HVAC actuation can save energy. However, the system's functionality depends on consistent WiFi connectivity, which may be affected by network coverage, outages, or device power

depletion. The analysis also shows that the existing system only covers office personal spaces. This means that covering shared places could improve the system's effectiveness.

The authors of [38] estimate commercial building energy usage using machine learning. XGBoost, Bagging, MLP Regressor, Random Forest Regressor, and other machine learning models were tested on a dataset of over 5000 commercial buildings. The XGBoost model performed best in terms of mean absolute error, median absolute error, and r2 values, providing the maximum energy consumption forecasting accuracy. Energy usage was also predicted by square footage, cooling degree days, heating degree days, and building type. This study sheds light on whether machine learning can estimate commercial building energy use. However, the study relies on a dataset of commercial buildings, thus its conclusions may not apply to other building kinds or locales. Although XGBoost performed best, other models performed well too. This suggests that the use of various machine learning methods may benefit this approach.

In "Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants" [39], Levinson and Akbari explain how cool roofs reduce solar absorption and increase heat emission. This reduces roof-to-building heat transfer, lowering space-cooling energy consumption in conditioned structures. This study examines commercial cool roof benefits. Cool roofs can reduce cooling energy consumption, increase heating energy consumption, save energy, and reduce emissions, according to building energy models. At the same time, the authors note that cool roofs may increase heating energy demand in colder places. The paper thoroughly evaluates cool roofs' pros and disadvantages.

Energy efficiency in electrical engineering is highlighted in the article "A review on lighting control technologies in commercial buildings, their performance and affecting factors" [40]. The need to conserve world resources and reduce conventional energy's environmental impact drives this research. Lighting accounts for a large component of electricity use, especially in commercial buildings, thus reducing lighting consumption can have significant benefits. Researchers are also working to improve lighting efficiency to maintain ideal illumination settings while reducing energy use. This study reviews commercial building lighting control technology. The article discusses manual, occupancy-based, daylight-linked, and time-scheduled lighting controls. These control systems also conserve energy, according to the research. In evaluating these control systems, occupant behavior, occupancy patterns, daylight availability, and control parameter tuning are important.

"Scope-based carbon footprint analysis of U.S. residential and commercial buildings: An input-output hybrid life cycle assessment approach" [41] investigates US residential and commercial building carbon footprints. Since the building industry accounts for a large amount of US greenhouse gas (GHG) emissions, this study seeks to understand and reduce these emissions. Scope-based carbon footprint analysis uses an input-output hybrid life cycle assessment approach. Scope 2 emissions—indirect emissions from energy generation—make up the majority of residential and commercial buildings' carbon footprints, according to the study. Electricity, on-site natural gas, commuting, and the construction supply chain all contribute to the carbon footprint. A total of 91% of GHG emissions come from building use. This study analyzes the carbon footprint of US buildings, focusing on power usage and building operations. However, the study's dependence on past data may limit its capacity to correctly reflect current conditions. Energy efficiency and renewable energy technology have advanced significantly since the time of the study. In addition, the study's focus on national statistics may overlook regional differences in variables like power fuel source composition.

"Commercial Building Energy Saver: An energy retrofit analysis toolkit" [42] discusses the construction and use of the CBES, a toolkit for examining commercial building energy retrofits. The need to improve energy efficiency in business buildings—major energy consumers—drives the research. The CBES toolset provides energy benchmarking, load shape analysis, and preliminary retrofit analysis to discover energy conservation options.

This study uses the CBES toolbox on a medium-sized San Francisco office building. The toolkit benchmarking results showed that the building consumed 88% more energy than comparable buildings. This indicates energy conservation potential. Load shape analysis showed energy waste during non-operation. The initial retrofit analysis suggested installing an HVAC air economizer, plug load controllers, and lighting system upgrades. This study shows how the CBES toolset can identify commercial building energy conservation opportunities. However, this study focuses on a single case study; therefore, its applicability to other building types or geographical situations is unclear. In addition, the research does not evaluate the toolkit's accuracy or reliability.

"Optimisation of energy management in commercial buildings with weather forecasting inputs: A review" [43] examines commercial building energy management optimization strategies, focusing on weather forecasting inputs. Energy efficiency and cost reduction in commercial buildings drove this research. This study addresses statistical, machine learning, physical, and numerical methods for energy consumption prediction and management in buildings. The analysis shows that forecasting methods have pros and cons. ARMA and ARIMA models are simple, computationally efficient, and accurate. However, they cannot capture non-linear trends and require previous data. Artificial neural networks (NNs) model non-linear patterns accurately but are computationally costly. White- and grey-box engineering approaches are complex and slow but accurate and independent of historical data.

3.1.4. Keyword Analysis and Areas of Research Focus

For scientometric analysis, keywords must be determined and a map visualization must be provided. Keywords describe the most important aspects of a study and reveal the domain's focal regions [25]. To construct the co-occurrence map based on the bibliometric data, a minimal number of co-occurrence keywords is needed. This enables proper study theme clustering [21].

A total of 133 of the 3581 keywords were discovered using "Author Keywords" and "Index Keywords" as well as at least seven simultaneous repetitions of keywords, using VOSviewer. Table 3 summarizes the top 30 keywords in detail.

Table 3. Top 30 keywords.

Keywords	Avg. Citations	Occurrences	Total Link Strength
Commercial building	20	251	2120
Energy efficiency	23	146	1436
Energy conservation	29	106	1181
Air conditioning	23	70	749
Retrofitting	21	46	502
Sustainable development	22	39	446
Energy management	20	39	369
Architectural design	15	38	374
Intelligent buildings	18	36	400
Greenhouse gases	28	31	390
Life cycle	28	30	338
Cooling	29	23	296
Thermal comfort	16	22	223
Carbon dioxide	19	22	240
Energy performance	11	20	193
Ventilation	22	19	237
HVAC	32	18	179
Sustainability	18	18	142
Climate change	22	18	200
Climate control	33	18	169
Solar buildings	18	16	196

Table 3. *Cont.*

Keywords	Avg. Citations	Occurrences	Total Link Strength
heating	31	15	188
Air quality	21	15	172
roofs	33	15	190
Environment management	5	14	153
Indoor air pollution	11	14	147
lighting	32	13	114
Solar energy	28	13	163
Walls	20	13	143
Floors	23	11	114

Table 3 is in a standard output format from VOSviewer, which provides quantitative information about each keyword. Below is an explanation of each column:

- Keywords: These are the words that have been frequently used in the articles, abstracts, titles, or other textual data under analysis. These words usually represent key themes or topics in the set of documents.
- Avg Citations: This column shows the average number of times the papers associated with each keyword have been cited. This gives an idea of the impact or influence of the work associated with that keyword. A higher average citation count might indicate a keyword associated with high-impact or influential work.
- Occurrences: This is the total number of times each keyword appears in the dataset. A higher occurrence typically indicates a more common or important topic in the research field under investigation. However, a high occurrence does not always mean high importance, as it could also result from a large number of less significant papers mentioning the keyword.
- Total Link Strength: This measure provides an overview of the interconnectedness of each keyword with all other keywords. It is calculated by adding up all the weights of the links connected to a particular keyword. The strength of a link between two keywords usually represents the number of documents in which these two keywords co-occur. A higher total link strength indicates that the keyword is strongly associated with many other keywords, suggesting that it might be a central or foundational topic in the research field.

This table provides valuable information about the most commonly occurring and influential keywords related to "Commercial Buildings".

1. Frequency of occurrence: "Energy efficiency" is the most commonly occurring keyword, followed by "Energy conservation" and "Air conditioning". This shows that these are the most often discussed subjects in the commercial building context.
2. Average citations: The keywords with the highest average citations are "Climate control", "HVAC", and "Cooling". This suggests that articles on these topics are mentioned more frequently, implying that they are significant topics in the area. They could be linked to major works or significant advances.
3. Total link strength: "Energy efficiency", "Energy conservation", and "Air conditioning" have the highest total link strength, indicating that they have strong links with many other terms.

Although these metrics provide some insight into the importance and influence of certain topics, it is also worthwhile to examine keywords that are less frequently mentioned. For example, "Environmental management" and "Indoor air pollution" have low occurrences and total link strength, but they may reflect growing or specialist themes. Significantly, "Environmental management" has a notably low average citation count, indicating that it may be an understudied issue worthy of more inquiry.

Investigating the correlations between distinct keywords offered further insights. For example, "energy efficiency" and "retrofitting" both have high occurrences and overall link strength, indicating that they are not just important issues in their own right but are also tightly related to other topics.

Retrofitting and Energy Efficiency: Given the relatively high frequency and total link strength of both "Retrofitting" and "Energy efficiency" it appears that these two topics have a significant connection. This shows that retrofitting commercial buildings for energy efficiency is a priority. It may be worthwhile to look into how these areas interact, such as researching the most effective retrofitting strategies for increasing energy efficiency or comprehending the hurdles and enablers of energy-efficient retrofitting in commercial buildings.

Intelligent Buildings and Energy Management: Both "Intelligent buildings" and "Energy management" have a moderate frequency but a comparatively high link strength. This could imply an increase in interest in the intersection of these areas. For example, research might look into how intelligent building technologies can be utilized to improve energy management, as well as the function of AI and machine learning in energy management inside intelligent buildings.

Greenhouse Gases, Carbon Dioxide, and Climate Change: Because they all have an impact on the environment, the intersection of "Greenhouse gases" "Carbon dioxide" and "Climate change" could provide fascinating results. For example, studies might look into how commercial buildings contribute to greenhouse gas and CO_2 emissions, as well as the implications for climate change.

Architectural Design and Sustainable Development: These two terms have a moderate number of occurrences and a pretty high link strength, showing that they are related. Research could look into how sustainable development ideas can be incorporated into the architectural design of commercial buildings. This could include investigating how to use sustainable materials, create energy-efficient structures, or incorporate biophilic design aspects.

3.1.5. Keyword Maps of VOSviewer

Keyword maps are a popular type of visualization offered by VOSviewer that illustrate which terms are frequently related to one another in the literature.

Each circle (or node) in the VOSviewer map in Figure 5 indicates a keyword. The size of the circle usually corresponds to the keyword's weight. In a keyword map, for example, a larger circle could signify a keyword that is used more frequently. The lines (or edges) connecting the circles represent the entities' relationships or links.

In VOSviewer maps, the color of the circles represents clusters. A cluster is a group of entities that are tightly connected. Keywords that frequently appear together in the same papers would create a cluster in a keyword map. The colors are assigned by the software and serve no use other than to distinguish distinct clusters.

Clusters in VOSviewer can help researchers in a variety of ways:

- Identifying research trends: researchers can identify current trends and popular topics in their field by monitoring which terms are closely connected (i.e., belong to the same cluster).
- Identifying gaps in the literature: isolated or less connected clusters may suggest unexplored themes or research gaps.
- Understanding the structure of a research field: clusters can indicate how different subtopics within a research field are related, which can aid in the organization of literature reviews or the development of new research lines.

In Figure 5, the 133 keywords identified in the analysis are organized into five groups. Each cluster is made up of related keywords. The clusters are:

Cluster 1—Thermal Comfort in Energy Management: this is displayed in red and includes 23 keywords such as "air quality", "temperature control", HVAC, "lighting", "cooling", "heating", "ventilation", and so on.

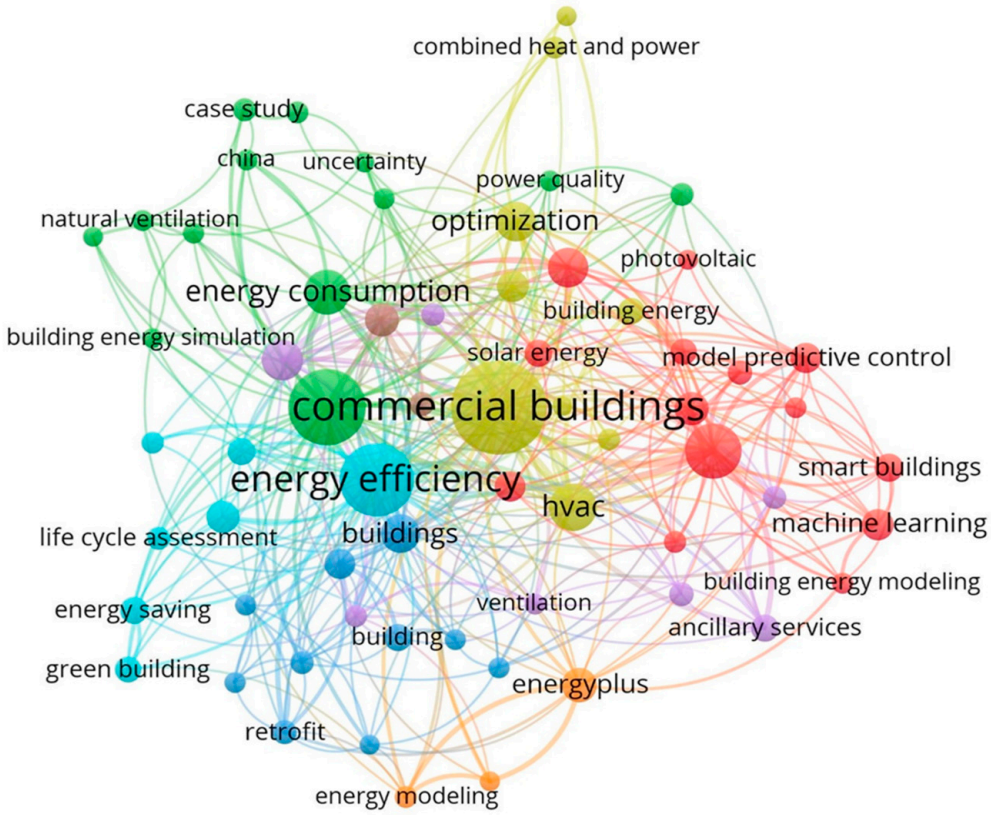


Figure 5. Network visualization map of co-occurring keywords.

Cluster 2—Architectural design sustainability: this is displayed in green and comprises 20 keywords. "Green structures", "building materials", "life cycles", and so forth are examples.

Cluster 3—Commercial Building Retrofitting: the 19 keywords in this cluster are displayed in blue in Figure 3. "Energy efficiency", "energy performance", "solar buildings", "walls", and other terms are among them.

Cluster 4—Carbon dioxide: this is displayed in yellow and includes 11 keywords including "renewable energy resources", "solar energy", "greenhouse gases", and so on.

Cluster 5—Commercial Building Energy Savings: this is shown in purple and is made up of four terms linked to "atmospheric temperature", "building energy simulation", "roofs", and "building energy".

In Figure 5, the map's connection lines also depict the relationship between two keywords. As portrayed, retrofitting is linked to energy efficiency and performance [10,64], carbon dioxide is linked to renewable energy resources and solar energy [36,41], and thermal comfort is linked to HVAC, air quality, climate control, and lighting [36,41], while thermal comfort is linked to HVAC, air quality, and climate control [39,69].

3.2. Qualitative Analysis

The qualitative analysis sought to identify the most-cited documents' primary findings, conclusions, and consequences. The results of the investigations were consistent with prior studies [23]. This approach allowed for a deeper understanding of the research topics and their significance in the field.

Summary of Most-Cited Articles

The most frequently mentioned documents were gathered and evaluated hermeneutically. Table 4 shows the results of the qualitative review of the most-cited documents.

One of the growing interests in commercial buildings sustainability research is building carbon emission analysis [41]. Evidence of these studies can be observed in the study by

Kneifel [36], which uses an integrated design method to estimate life-cycle energy savings, carbon emissions reduction, and the cost-effectiveness of energy efficiency measures in new commercial buildings, as well as to assess the consequences of the cost of energy-based carbon emissions. This study carries out a total of 576 energy simulations for 12 archetypal structures in 16 cities, with three building designs for each building–location combination [36].

The findings reveal that traditional energy efficiency measures can reduce energy consumption in new commercial buildings by 20–30% on average, and by more than 40% in specific building types and locations. These upgrades save money and energy while lowering a building's carbon footprint by an average of 16%. Because greater efficiency allows the installation of smaller, less expensive HVAC equipment, these savings can sometimes be accomplished at a negative life-cycle cost [37].

The authors of [37] point out that 39.6% of energy consumption in commercial buildings is related to HVAC systems.

Indeed, adhering to these guidelines in the construction of new buildings has been shown to effectively mitigate energy consumption. However, it is imperative to acknowledge the significant challenge associated with the task of diminishing energy consumption in existing buildings. The significance of this matter is of considerable magnitude, as evidenced by the dedicated efforts of the REHVA (The Federation of European Heating, Ventilation, and Air Conditioning) task force [72] comprising representatives from nine European nations. Their primary focus lies in the refurbishment of existing structures, with particular emphasis placed on the modernization of heating, ventilation, and air conditioning (HVAC) systems [73].

The role of HVAC systems in the deep renovation of existing buildings is crucial as it can help achieve significant energy savings when operated properly. The building envelope is also considered an essential aspect in initial efforts to reduce energy demand.

But renovation should not be limited to the building envelope; energy savings can be maximized, and payback time reduced by also focusing on HVAC systems and energy education of building occupants. Adapting HVAC systems to varying building energy demands can improve indoor environmental quality (IEQ) and occupant satisfaction [73].

Prior studies have advocated employing wireless occupancy sensors or even cameras for occupancy-based actuation to reduce HVAC energy use, with energy savings of up to 42%. However, most of these solutions necessitate the design, deployment, testing, and maintenance of these sensors and their accompanying networks within existing buildings, which is prohibitively expensive. Conversely, the authors of [37] present Sentinel, a system that uses existing WiFi infrastructure in commercial buildings, as well as smartphones with WiFi connectivity carried by building occupants, to offer fine-grained occupancy-based HVAC actuation. Similarly, the authors of [74] present a comprehensive review of research work on the existing technologies and applications of Internet of Things (IoT) technologies in residential and commercial buildings.

As shown in Table 4, the paper with the third highest number of citations is [38], published in the Applied Energy Journal. By teaching machine learning models using national data from the study of energy consumption of commercial buildings, this research proposes a new technique for estimating the energy consumption of commercial buildings from several building characteristics (CBECS). Their findings show that gradient amplification regression models are the most accurate models in predicting the energy consumption of a commercial building, with predictions that are often in the coefficient of two real values (with an r2 score of 0.82).

Urban and rural temperatures have diverged in recent decades. The urban heat island (UHI) effect—caused by urban design, human heat, air pollution, sun intensity, wind speed, and anticyclone conditions—is well documented. UHI increases greenhouse gas emissions and air conditioning energy demand. Human comfort and climate change mitigation requires UHI solutions. One of the best passive cooling solutions is increasing the building's exterior albedo, especially in relation to its roofs [80].

The majority of roofing materials absorb solar radiation and reflect only a small part of it. In warmer areas, for example, solar heat gain through the building's facade accounts for a significant part of the total heat gain. The energy entering a structure through its walls, floors, and ceilings is equally significant. Although a traditional dark-colored roof's total heat gain can be as high as 366 kJm^2, the heat loss through the same roof is only around 4.2 kJm^2; heat gain is the major process for these roofs throughout the day. On hot summer days, dark roofs can achieve temperatures of over 60 degrees in many regions, allowing significant heat transfer into the building through roof insulation. Any alteration to a building's roof that reduces solar heat gain will save the building owner money on energy costs and reduce the property's overall environmental impact [60].

Table 4. Qualitative Summary of Most-Cited Publications.

Authors	Year of Publication	Aim	Similar Articles
[36] Kneifel	2010	Estimate life-cycle energy savings, carbon emission reduction, and cost-effectiveness of energy efficiency measures	[57,71]
[37] Balaji et al.	2013	Propose strategies to reduce energy consumption in HVAC systems	[56,58,69]
[38] Robinson et al.	2017	Introduce a new technique for estimating the energy consumption of commercial buildings with machine learning models	[69]
[39] Levinson et al.	2010	Weathered cool white roof	[60,75,76]
[40] Haq et al.	2014	Automatic lighting control system	[62,77,78]
[41] Onat et al.	2014	Analyze building-related carbon emissions	[47,48]
[42] Hong et al.	2015	Introduce a toolkit of Commercial Building Energy Saver (CBES), that includes a web app for integrating CBES with other energy software tools	[51,79]
[43] Lazos et al.	2014	Analyze the dependence of various building components on weather conditions	[10]
[44] Zuo et al.	2012	Identify factors contributing to or impeding the achievement of carbon-neutral commercial building development	[66]
[45] Liao, & Barooah	2010	Apply an agent-based model to simulate the behavior of all the occupants of a building, for solving the problem of real-time estimation of occupancy	[71]

Green roofs and facades have high installation and operation costs, while solar reflecting materials like "cool roofs" can reject solar radiation over the visible and invisible solar spectrum. Solar reflectance (300–2500 nm) and thermal emissivity (4000–40,000 nm) are high. White cool roofs were introduced [80].

Cool roofs are designed to minimize the absorption of solar energy and maximize the emission of thermal energy, resulting in reduced heat transfer from the roof to the building. This, in turn, decreases the demand for space-cooling energy in air-conditioned buildings [39].

The cool roof system yields indirect environmental benefits, primarily through reductions in environmental damage and peak-time electricity demand, resulting in electricity savings [60].

In cold climates, the implementation of cool roofs may potentially result in an increased demand for heating energy. In the context of commercial buildings, it is commonly observed that the reduction in the annual cooling load tends to surpass the corresponding increase in the annual heating load [34].

However, in a study conducted by the authors of [76], the DOE-2.1E software was employed to model and analyze the energy usage of various office and retail buildings in four cold-climate cities in North America, namely Anchorage, Milwaukee, Montreal, and Toronto. A function was defined to calculate the daily U-value and absorptivity of the roof in order to simulate the impact of snow on it. The findings indicated that the

implementation of cool roofs in the simulated buildings led to significant reductions in annual energy expenditures across all cold climates [76].

The initial white and colored cool roof studies employed polymeric membranes and paints since these do not require long manufacturing cycles. Without maintenance, cool roofs last only a few years. Cool roofing in European towns using ceramic and clay roof tiles requires solar-reflective tile materials. This improves solar effectiveness and durability because tiled sloped roofs should not be cleaned. New glazed and engobed solar reflecting solutions are spreading this technology to ceramic and clay roof tiles. The use of ceramic glaze makes such objects weatherproof and durable. Traditional tile methods can improve solar reflection and insulation without changing the roof. Studies discuss the most often used pigments for external tile systems in ceramic glazes with gloss, matt, and Zirconium Silicate finishes and typical ceramics heating treatment, making first-generation glazed cool-colored tiles possible [80].

It is noteworthy to consider that the solar reflectance of cool roofs can be influenced by weathering, soiling, and biological growth. The solar spectral reflectances of 12 roofing membranes were measured in a study [69]. The measurements were taken before exposure and at various intervals of natural aging, specifically after 3, 6, 12, 18, and 24 months. The study was conducted in Rome and Milan, Italy. The findings indicated that the process of aging resulted in a decrease in the potential cooling load savings attainable from a new white membrane. Specifically, the reduction ranged from 14% to 23% in Rome and from 20% to 34% in Milan. Furthermore, in the case of Milan, there is evidence to suggest that an older, white roof with high insulation properties, possessing a solar reflectance value of 0.56, could potentially experience a surface temperature increase of 16 °C compared to a newer roof with a higher solar reflectance value of 0.80. Hence, with respect to the implementation of cool roofs in other urban areas, this aspect warrants due consideration [75].

Lighting is another important factor in commercial building energy use [40]. According to the authors of [80], artificial lighting is a large power consumer in commercial buildings, accounting for around 17% of overall electrical energy consumption. Therefore, intelligent control strategies are widely implemented to reduce lighting energy consumption [77]. As a result, adopting intelligent lighting control systems, such as the combination of sensor technologies (occupancy and light sensors), advanced designs (wireless- and network-based architectures), and intelligent control approaches, has huge potential to minimize energy usage (artificial intelligence and optimization). Furthermore, an intelligent control system can improve visual comfort for occupants while lowering electricity usage and greenhouse gas emissions. Lighting control systems can be divided into three types: controller, optimization-based control, and hybrid control [78].

The decarbonization of buildings is widely recognized as a significant challenge in the pursuit of achieving the United Nations' sustainable development goals by 2050. In conjunction with the objective of minimizing electricity usage, an equally significant concern in mitigating greenhouse gas emissions within the building sector pertains to the substitution of gas boilers. The potential of heat pumps, district heating, and hybrid solutions as alternatives has been highlighted by the REHVA task force. The aforementioned study has brought attention to the potential advantages of transitioning away from natural gas in buildings, including the reduction of greenhouse gas emissions, the enhancement of air quality, and the promotion of energy efficiency [81].

As shown in Table 4, computer simulation tools are an effective instrument for estimating building performance under various scenarios and giving a theoretical basis for retrofits that produce cost-effective energy savings. In their article, the authors of [42] introduce a toolkit of Commercial Building Energy Saver (CBES) that includes a web app for integrating CBES with other energy software tools.

In addition, the authors of [10,43] claim that the thermal performance of building envelopes is the deciding element of building energy consumption, and that envelope retrofitting is an extraordinarily successful technique for reducing energy consumption in existing structures (Table 4). Because variables like temperature, humidity, and solar

radiation directly affect heating and cooling in a structure, as well as the availability of solar and wind energy, multiple ideal retrofitting techniques may exist for different climates.

4. Conclusions

The implementation of bioclimatic retrofitting in commercial buildings is a nascent field, particularly in terms of its energy implications. This study investigated the bioclimatic retrofitting approach as a crucial strategy for mitigating energy consumption and adapting to climate change.

The authors carried out an examination of scholarly articles and conference papers pertaining to the implementation of bioclimatic retrofitting in commercial buildings. These sources were obtained from the Scopus database through the utilization of a bibliometric search, which is a scientific methodological approach. Additionally, a comprehensive qualitative analysis was performed to gain a deeper understanding of the subject.

The scientometric procedure utilized quantitative dimensions, including the number of intermediate citations, occurrences, average publication year, and general connection power.

A longitudinal examination of research publication patterns spanning from 2008 to May 2022 has indicated a discernible upward trajectory in scholarly investigations pertaining to the domain of commercial buildings during this 15-year period. Nevertheless, research on the topics of bioclimatic design, retrofitting strategies, and green building practices in commercial settings exhibits a more gradual rise, displaying an almost linear trend between the years 2016 and 2020. The disregard for bioclimatic effects in commercial buildings may be attributed to factors such as the intricate nature of the process, the dense urban fabric typically surrounding these buildings, and the ready availability of cooling and comfort activation technologies. Moreover, the potential impact of bioclimatic design on commercial buildings may have been overlooked as a result of insufficient comprehension and awareness. However, scholarly investigations into the field of bioclimatic design, retrofitting, and green buildings within commercial contexts have revealed an emerging trend that extends beyond the year 2020. This observation suggests a growing recognition of the importance of incorporating sustainable and energy-efficient principles in the design and operation of commercial buildings.

"Energy and Buildings", "Applied Energy", "Building & Environment", "Energy", "Renewable & Sustainable Energy Reviews", and "Energy Efficiency" were identified as useful publications outlets for studies on bioclimatic retrofitting in commercial buildings.

These publications have seen significant increases in citations in recent years, with 20 of the 38 most-cited works appearing in these publications. The citation analysis of documents indicates that articles [31–38] were the most-cited documents in the field of the bioclimatic retrofitting of commercial buildings and had a citation index above 100.

Furthermore, the keywords with the most citations were found to be climate control, roofs, lighting, HVAC, heating, cooling, energy conservation, life cycle, greenhouse gases, and solar energy. Conversely, keywords like commercial building, energy efficiency, energy conservation, air conditioning, retrofitting, sustainable development, architectural design, intelligent buildings, and energy management appeared more frequently.

Cluster analysis showed the research emphasis areas for this domain. These consist of thermal comfort in energy management and climate control and ventilation, sustainable development for architectural designs and green buildings, retrofitting in commercial buildings and energy efficiency, carbon dioxide and energy resources and solar energy, energy-saving and atmospheric temperature, and building energy simulation. The results of the in-depth qualitative content analysis revealed certain grey areas that will be investigated more in the future.

Suggestions for future research are offered below based on the information gained in this study:

Utilizing Bioclimatic Strategies for Optimal Energy Efficiency and Environmental Sustainability:

In order to initiate a trajectory toward sustainable retrofitting, it is imperative to effectively utilize bioclimatic strategies. These novel methodologies utilize the inherent characteristics of the location and its natural components to optimize energy usage and improve the comfort of occupants. Through the examination of the complex relationship between site attributes, microclimatic conditions, and architectural design, scholars will have the potential to discover innovative approaches to reducing energy usage while optimizing the utilization of sustainable resources.

Architectural Design Sustainability: One prospective field of study pertains to bio-inspired or biomimetic design principles, which involve the examination and emulation of natural phenomena, with the aim of enhancing the sustainability of commercial buildings. An intriguing field of study involves the utilization of 3D printing and digital fabrication methodologies for the production of environmentally sustainable components in the construction industry.

The incorporation of passive design principles:

The other fundamental principle in retrofitting commercial buildings involves the incorporation of passive design principles. The focal point of this approach lies in the optimization of the building envelope, thermal insulation, and natural ventilation in order to minimize the dependence on mechanical systems. The investigation of novel materials, including advanced phase-change materials, presents a promising opportunity for researchers to expand the limits of energy-efficient architecture. Through the integration of these novel materials, structures have the capacity to efficiently modulate variations in temperature and substantially reduce energy consumption.

Energy Savings in Commercial Buildings:

Research could focus on the role of smart meters and energy management systems in optimizing energy consumption. Another area of research might be the deployment of energy-saving techniques such as daylighting and natural ventilation. Furthermore, research into passive design solutions can aid in energy savings while maintaining comfort.

The Adoption of Technological Innovations:

The incorporation of advanced technologies is of the utmost importance in our pursuit of sustainable retrofitting. Recent technological advances in the field of sensor networks, building automation systems, and data analytics have provided architects and engineers with the ability to effectively monitor and optimize energy consumption in real time. Researchers can achieve optimal energy performance and maintain a comfortable indoor environment by incorporating intelligent automation and machine learning algorithms to enable buildings to dynamically adapt to occupants' needs.

Thermal Comfort in Energy Management:

Research can concentrate on the incorporation of IoT (Internet of Things) devices in the management and optimization of HVAC systems for improved thermal comfort and energy efficiency. Furthermore, research might be conducted to investigate the application of AI and machine learning algorithms for predictive control of HVAC systems based on occupancy trends and weather forecasts.

Commercial Building Retrofitting:

Research might be devoted to incorporating smart building technologies, such as smart windows and responsive building envelopes, into retrofitting. Further research could focus on the integration of renewable energy technology such as solar panels, as well as upcoming technologies such as building-integrated photovoltaics (BIPV).

Carbon dioxide:

Research could concentrate on carbon capture and storage (CCS) technology for commercial buildings. The net-zero energy building (NZEB) concept could potentially be investigated with the goal of balancing the amount of energy consumed with the amount of renewable energy generated on-site, thereby minimizing the building's carbon footprint.

Building resilience:

The imperative of cultivating resilience has become increasingly apparent in light of escalating risks posed by natural disasters and other disruptive phenomena. Consequently,

there is a pressing demand to advance the development of building designs and materials capable of withstanding the formidable challenges presented by extreme weather events and other unforeseen shocks. Subsequent investigations may be directed towards the advancement of building systems with enhanced resilience, encompassing the exploration of modular construction techniques and the utilization of advanced materials capable of absorbing impact and exhibiting resistance to damage.

Energy storage:

The utilization of renewable energy sources, such as solar and wind power, is increasingly common in the design of commercial buildings. However, the effective storage of energy continues to pose a significant obstacle. Future research may prioritize the exploration and advancement of energy storage solutions that exhibit enhanced efficiency and cost-effectiveness, including but not limited to advanced battery technologies and thermal storage systems.

Circular economy:

The construction industry is accountable for a substantial quantity of waste and carbon emissions, necessitating a shift towards a circular economy framework that emphasizes the reuse and recycling of materials. Subsequent investigations may delve into avenues for devising architectural structures that possess the capacity to be dismantled and repurposed upon reaching the culmination of their functional lifespan. Additionally, the pursuit of novel materials and construction techniques that exhibit heightened sustainability merits further scholarly attention.

Health and safety in the post-COVID era:

The significance of indoor air quality, ventilation, and other factors that affect the well-being and safety of individuals within buildings has been underscored by the COVID-19 pandemic. Future research may be directed towards the advancement of design solutions and technologies aimed at mitigating the transmission of airborne pathogens and other contaminants, thereby fostering an indoor environment that is both safer and healthier.

Researchers, practitioners, and government agencies will benefit from the findings of this study. Graduate students and researchers can theoretically study research gaps. In practical terms, the information supplied in this study can assist stakeholders in the construction industry in making decisions.

It is important to acknowledge that this study has its limitations. These limitations extend from the use of a single database (Scopus) and only picking texts written in English. As a result, the study may not have addressed all of the existing literature on the topic under consideration. However, despite these flaws, the research's purpose of evaluating the current status of research on bioclimatic retrofitting in commercial buildings and identifying areas for further research was met. To aid comparisons, future research that avoids these restrictions can be carried out.

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