

## SUSTAINABILITY OF CONSTRUCTION MATERIALS USED IN BUILDING ENVELOPE: BIBLIOMETRIC ANALYSIS USING R-TOOL 2002-2022

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### ABSTRACT

Achieving sustainability in building materials is a difficult task. In this research, the aim is to identify intellectual roots and to find an organized outcome of the status and trends analyzing the sustainability of Construction materials used in Building envelopes of group housing buildings and the construction industry. To provide support for the research, the PRISMA methodology is used for the extraction of related literature to identify articles for bibliometric analysis. The R-tool is then used to process the data extracted from the database in a graphical mapping analysis, which is used to evaluate the systematic literature review on this research domain. Using data from the Web of Science and Scopus databases, 50 papers were chosen for analysis. The study then extracts the annual publication on the topic, the authors' contributions, the articles' citation counts and conclusions, the contributions of various countries, enduring publications, and keywords. This study only discusses the elements that are now acknowledged in the literature to assess the sustainability of building materials, which are generally regarded as sustainable materials in India and throughout the world (environment, economics, and society). This study aids researchers and policy-makers in developing sustainability assessment frameworks for building material selection, identifying research gaps, and offering recommendations for future research.

**Keywords:** *Building Materials, Building Envelope, Bibliometric, R-Tool, Sustainability*

## 1. INTRODUCTION

Sustainability has been a keen interest area for researchers, for which area of interest includes environmental safety, social advancement, and economic viability. In the construction industry, the sustainability of a building can be assessed or preserved in the building as a whole or for each building life stage individually. Considering that building materials are the components of each building life cycle stage having a major contribution to environmental deterioration (CO<sub>2</sub> emission, GHG emission, Embodied energy, etc.), the capital cost of a building depends on building materials and as well as social (labor job security, cultural heritage, community engagement) (Bhyan et al., 2023). Building materials being the major component of the construction industry serve as the major scope of understanding the use, efficiency, and sustainability of different materials. With increasing urbanization and massive demographic growth increased demand for housing is an upsurging challenge (Package, n.d.). Group housing over time has received the desired jump in stock development of housing as mass housing projects. This scenario is well supported by increasing housing Finance supplies, but still, stakeholders find major difficulties in delivering housing stocks with quality materials and affordable prices as input costs for various materials like steel, and cement keep on increasing with labor costs as well. Considering sustainability, Materials are required to be environment-friendly, socially acceptable, and affordable in stock.

The concept of "sustainability" encompasses ecological growth as well as stakeholders' ability to protect and use resources for future generations. Since the construction industry is responsible for rising pollution levels due to energy consumption and poor building design and construction management during the extraction, processing, and transportation of raw materials, it is crucial to understand the use, efficiency, and sustainability of various building materials (Morel, Mesbah, Oggero, & Walker, 2001). In addition, as a result of growing urbanization and population growth, there is an increased demand for housing, which makes it difficult to provide high-quality housing at competitive rates due to rising labour and material costs.

A thorough material-based database that allows the evaluation of construction materials' life cycles in speedy group housing development is urgently needed to address sustainability issues. On house construction sites, the accessibility of material options frequently does not match the availability of those options, leaving a gap in sustainable construction methods.

This study bridges the gap between the practical application of accessible materials and the sustainability of construction materials used in building envelopes of group housing. To do this, a thorough study of the literature has been carried out using the reputable databases Web of Science and Scopus, together with bibliometric analysis carried out with the help of the reliable software "R-Tool." The following are the research questions that will direct this investigation:

(1) Which are the major contributing authors, journals, and years of publications? (2) What are the most persistent used author keywords? (3) Which are the most contributing countries? (4) Which are the most contributing journals? (5) What are annual publication trends? (6) List of sustainability parameters for housing envelope when it comes to assessing the sustainability of construction materials?

This study's main goal is to thoroughly comprehend the body of knowledge on construction material sustainability research as it relates to group housing building envelopes. To the best of our knowledge, no prior literature has investigated this particular topic using bibliometric techniques and systematic analysis. This study aims to add significant knowledge to the field of residential construction material sustainability assessment by addressing the aforementioned research challenges.

There are six sections to the article: The first section provides an overview of the starting research topic's applicability. The literature that examined the sustainability of the building materials used in group housing building envelopes and supported the research gap is included in Section 2. The third section provides a detailed explanation of the study's methodology. The results of the bibliometric investigation are presented in graphs, tables, and networks in Section 4. Limitations and a debate are presented in part five, and conclusions are concluded in section six.

## 2. LITERATURE REVIEW

In this study, two-level systematic literature reviews were conducted:

- The relation between the sustainability dimensions and the building envelope materials; and
- Sorting Parameters from the existing literature for sustainability assessments of building materials

### 2.1 Sustainability Dimensions and The Building Envelope Materials

Three main dimensions of “Sustainability” include the environmental, economic, and social dimensions (Onat et al., 2014). The sustainability of materials in terms of environment is broadly discussed in terms of their CO<sub>2</sub> emission and embodied energy throughout their life cycle (extraction, manufacturing, transportation, construction, operation, maintenance, and demolition) (Bin Marsono & Balasbaneh, 2015; Khoshnava et al., 2018). The sustainability of materials in terms of economics includes the life cycle cost of materials in most of the studies from literature (Ahmad & Thaheem, 2018; Del Rey et al., 2015; Figueiredo et al., 2021; Sahlol et al., 2021). Sustainability of materials in terms of the social dimension of sustainability includes health and safety, aesthetics, and local availability of materials. Whereas, the selection of materials with the lens of sustainability should also include the functionality of material and constructability of materials to serve as sustainable materials regionally and globally. The availability of the materials played a major role in the decision-making process since locally accessible resources provided the benefit of easily accessible and reasonably priced skilled labor (Tyagi et al., 2023). It is observed from literature and observation that each material belongs to nature either directly(non-renewable materials) or indirectly(mixed compositions like using fly ash in bricks). Natural materials are said to be more sustainable as they utilize less processing energy and transportation(Janjua et al., 2019). But it can be contradicted if we start using natural materials to an extent they will start depleting and no sustainability sustains in such a process. Besides only considering the environmental impacts of building materials, the sustainability of building materials also depends on parameters like non-toxicity, fire resistance, thermal resistance, renewability, social concern psychological and physical comfort, and service life of building material (Janjua et al., 2019). One major aspect of the sustainability of material is its service life. The life of a building majorly depends on its choice of building materials and it has been discussed in the literature in terms of the assessment of building requires estimation of building service life varying with alternative material used.

### 2.2 Buildings materials Service Life

The duration (days, months, or years) that a building is considered to be in use is referred to as its "building service life," "building utility life," or "operational life of buildings" (Rauf & Crawford, 2015). The availability of building service life statistics may be useful in determining how often to replace and maintain the materials or structures needed for a building. When it comes to environmental sustainability, a building's longer useful life combined with regular maintenance and material replacements eventually leads to more embodied energy, which causes the evaluation of environmental sustainability to be inaccurate at the time of projection. The most significant factor in economic sustainability is building utility life, as a longer structure's life raises construction costs and lowers residual value when a utility life is determined for its economic sustainability. This study employed two building service life spans of 50 years and 100 years to determine expenses. As a result of extending the service life to 100 years, costs increased by 44%.

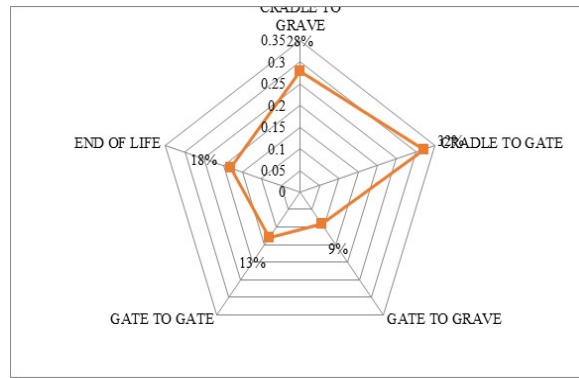


Figure 1: Building Life Cycle Stages Included in Selected Articles  
(Source: Compiled by Author, 2021)

Non-structural materials including wall materials, flooring, external/internal finishes, and Door & window frames) in group housing are considered as building envelope materials.

In the construction industry, building envelope materials are classified into three broad heads traditional materials, convention materials, and modern/modular materials. Discussing the Traditional materials “Materials those are being used in the construction industry of the belonging region and nation in natural form, from many decades.” definition by authors. Conventional material can be defined as “Materials that are evolved in terms of their durability and strength with mix compositions with natural materials and are being used for a long time in region and nation” definition by authors. Whereas modern materials can be explained as “Materials that are engineered for fast construction and durability and mass construction with innovative techniques for region and nations construction advancement”.

### 2.3 Parameters from the existing literature for sustainability assessments of building materials

To achieve the sustainability of construction materials, sustainability assessment tools are becoming a handy technological way of examining and evaluating the environmental effect of building materials for building ratings. When evaluating the sustainability of materials, GBRS primarily takes into account the environmental aspects (embodied energy, CO2 emissions), while only taking into account the economic factors (low-cost materials) and the social aspects (locally available materials), which are always given the least consideration. Since there are no global standards for rating buildings or construction materials, the social component is particularly important to assess and grade. Although the Green Building Standards (GBRS) take the sustainability of building materials into account throughout their life cycles, they do not take into account the whole building life cycle or even treat all three dimensions equally. The official sustainability index for evaluating construction materials was created by CPWD in India in 2014. It has 12 criteria, the majority of which are focused on the environmental aspect of sustainability (Department, 2014). The Sustainability Assessment of construction materials and the GBRS standards differ significantly.

Contributing to the analysis of the sustainability of construction materials would help to understand the listing of various alternative materials through the lens of sustainability. a research contribution has been made by listing the precise parameters for the sustainability assessment of construction materials for group housing materials from the literature review and around 12 parameters have been introduced by authors in Table 3.

Table 2: Parameters from the existing sustainability assessments of building materials

Sustainability Assessment	Explanation	References
<b>PARAMTERRS for construction materials for group housing materials</b>		
Environment	Encouraging NMTs and walking	Anti-skit material Encouraging NMTs and walking
	Urban Heat Island effect	Materials with less UHIE result in less energy demand inside the building
		(Govindan et al., 2015; Zavrl et al., 2009) (Bin Marsono & Balasbaneh, 2015; Govindan et al., 2015;

			Jeanjean et al., 2013)
	Utilization of BIS-recommended waste materials in the building structure	The use of waste materials /recycled materials reduces C&D Waste and reduce embodied energy by use of recycled materials	(Govindan et al., 2015; Zavrl et al., 2009)
	Use of regional/local materials	The use of locally available materials can reduce transportation emission	(Danso, 2018)
	Use of renewable materials	Renewable materials used in a building can help in less CO2 emission	(Danso, 2018; Govindan et al., 2015)
	CO2 emission	Carbon emissions during extraction, production, manufacturing, and construction should be as less as possible to stop environmental exploitation	(Khoshnava et al., 2018; Morel et al., 2001; Zhang et al., 2019)
	Embodied Energy	Materials with less embodied energy are recommended	
	Cast in situ cost	Cost of construction of material on site (labor, equipment, etc.)	Introduced By authors
	Transport cost	Cost of transport in kilometers and amount of material transported cost	Introduced By authors
Economic	Material Cost(cost per cubic meter)	Primary cost of material(as ready to use on-site) per cubic meter	(Balasbaneh et al., 2018; Department, 2014)
	Maintenance Cost	Cost of maintenance of material (watering, strength check, durability, etc.)	(Department, 2014)
	Replacement Cost	Cost of replacement of material(primary cost and transportation cost, labor cost equipment )	
	The burden on Housing Costs	Estimation of burden of capital maintenance cost of material on total housing cost	(Emami et al., 2019)
	Maintenance affordability	Estimation of maintenance affordability of material(if high should choose alternative material in terms of locally available)	Introduced By authors
	Cultural heritage preservation	The material used should be suitable to preserve the cultural heritage of the region	(Heijungs et al., 2010; Nguyen et al., 2018)
	Aesthetic quality	The material should be aesthetic to be adopted easily	(Hosseinijou & Mansour, 2014)
	Adaptability	High adaptability of material by users and stakeholders would increase its market presence	
	Healthy Living condition	Fewer efflorescence issues or foul smell by material make it socially adaptable	
	Psychological and physical comfort	The material should be psychologically and physically comfortable for all (gender, age, education, and income class)	Introduced By authors
Social	Familiarity with the material	More information and examples of successful projects with the material will increase familiarity with the material	(Department, 2014)
	Height limitation	To what height material can be solely used without any additional support and equipment	Introduced By authors
	Fast construction	Time is taken for construction using material	Introduced By authors
	Design flexibility	The flexibility of material with architectural designs	Introduced By authors
	Service life	The durability of material after the construction stage	Introduced By authors
	Sound insulation	Does the material require any other material for sound insulation	Introduced By authors
	Labour needed	Number of labor required for laying the material	Introduced By authors
	Equipment	Num of equipment required for laying the material	Introduced By authors
	Construction Safety	Safety measures required for material	Introduced By authors
	Market presence of material	Availability of innovative material	(Department, 2014)
Functionality of material	Lightweight materials	Weight of material affecting load on the structure	
	Plaster requirement	Nonstructural materials with less need for plasters are highly recommended as they save time, cost, and the environment	Introduced By authors
Constructability			

### 3. METHODOLOGY

To find the most pertinent papers for the study's goals, the PRISMA approach (Bhyan & Shrivastava, 2019; Liberati et al., 2009) was employed. There are three main stages involved in choosing which articles to evaluate.

Identification of articles is processed by various keywords to screen the relevant articles as the need for the study. Keywords used in 'TITLE' of database Scopus and Web of Science:

- Building materials/construction materials/green materials/building envelope materials/conventional materials/modern materials/traditional materials
- sustainability/sustainable materials/environment-friendly materials/economic materials/fast construction materials
- House/Housing/Residential/Building/group housing/mass housing

Additionally, a search in the Web of Science and Scopus databases is part of the identification step. The findings provide 1493 and 990 items, respectively. 996 duplicate articles were discovered after the duplication of articles was removed. 95 items were deleted for various reasons, while 97 articles that were deemed to be ineligible by the automated program remain. The English-language screening, article accessibility, and articles of significant significance are all included in the second step. A three-stage screening process rejected 644, 276, and 326 items, respectively. The papers taken into consideration for the review of the body of current literature are included in the final step of the PRISMA process. Fifty items are chosen once the articles in the affected region are eliminated. After that, the prospective and chosen publications were downloaded in a "bib" format so that they could be used for further network research and literature review.

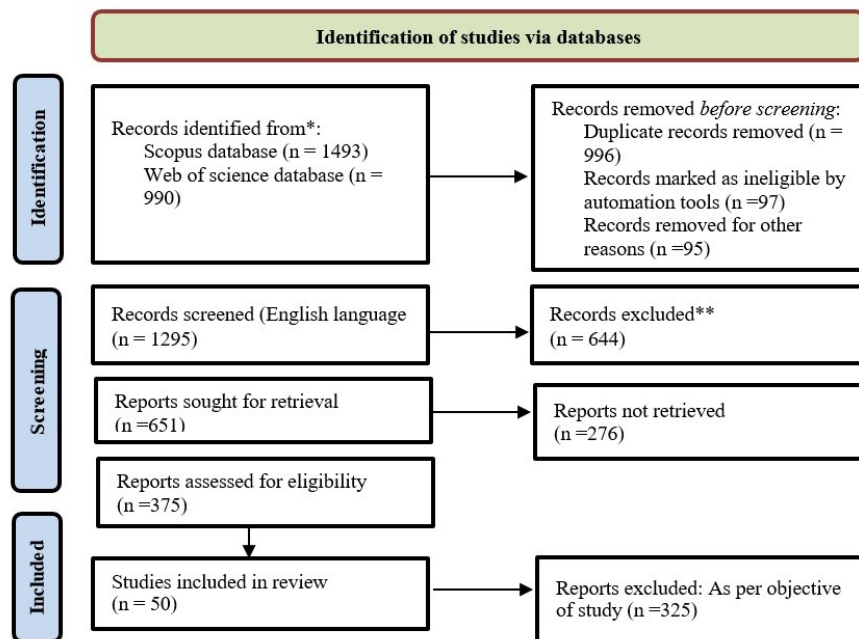


Figure 2 Methodology for identification of articles in Scopus and Web of Science database

### 4. BIBLIOMETRIC ANALYSIS

According to the study's definition, the growing trend in the sustainability of building materials over time necessitates technical work to gather information toward a certain goal. Consequently, bibliometric analysis is increasingly taking center stage when it comes to literature reviews among academics. Bibexcel, CiteSpace, Histcite, Pajek, Publish or Perish, Scholarometer, VOS viewer tool, and R-tool are a few examples of tools that can be used for bibliometric analysis (Jayasree and Baby

2019). In this study, the bibliometric analysis of the published literature is done using the "R-tool" (Lazar & Chithra, 2020). The meticulous methodology followed for bibliometric analysis includes data analysis as shown in Fig.2.

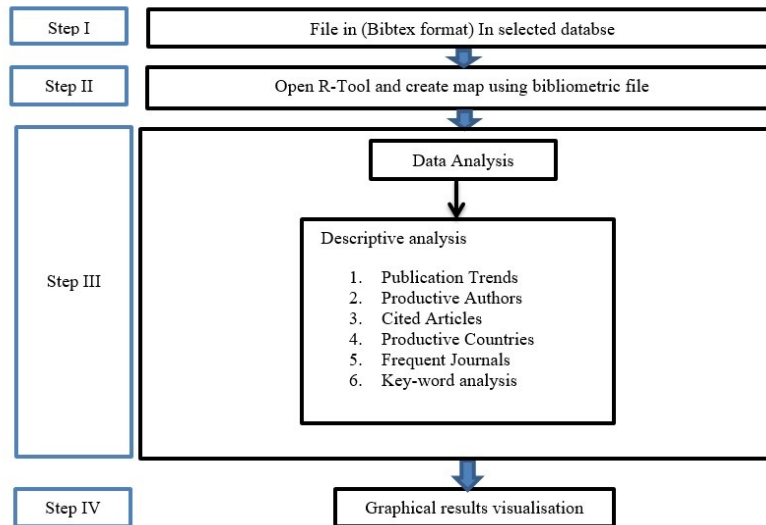


Figure 3 Method for bibliometric analysis using Vos-viewer Tool

## 4.1 DATA ANALYSIS

A total of 50 documents that were obtained from 29 sources, comprising more than 230 keywords, are discussed in the selected articles that introduce the study issue. The data retrieval period considered for the bibliometric study is 2002–2022, illustrating the collective contribution of the aforementioned 170 writers. The descriptive analysis talks about how a research subject has become more popular over time and how researchers' interest in the present study has grown dramatically. Table 3 displays information on a few selected articles.

### 4.1.1 Annual trends

In contrast, the publishing trend in 2021 reached 8 articles, which is the largest number of publications ever recorded in a single year following 2015. The publishing trend line for the years 2000–2020 is further described in Fig. 3. The trend line published with the results indicates a decrease in growth until 2020 and a significant increase in growth from 2015 to 2021. Even yet, there is a decline in 2018 followed by a rise in 2018, and so on until 2020. While a growing number of academics and researchers are exhibiting interest in the issue of sustainability of construction materials used in building envelopes for group housing, the idea of sustainability of construction materials is still not well understood. The official sustainability index for evaluating construction materials was created by CPWD in India. It has 12 categories and primarily focuses on the environmental dimension of sustainability (Department, 2014).

. Table 1: Description of selected articles

Description	Results
Timespan	2002:2022
Sources (Journals, Books, etc)	29
Documents	50
Average years from publication	5.9
Average citations per document	40.28
Average citations per year per doc	5.179

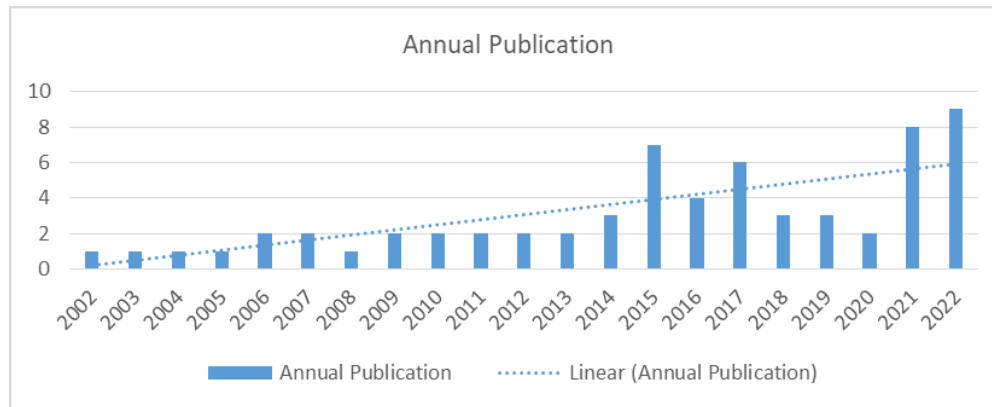


Figure 4: Annual Publication Trends

#### 4.1.2 Most-cited articles

Bibliometric analysis extracted the top ten most cited articles in the domain to understand the sustainability of construction materials of group housing envelopes. Table 4 discusses the author name, year of publication of the article, journal name, DOI of an article(with hyperlink), Total citations, and findings of articles. A total of 50 articles have been reviewed out of which the top 10 are discussed with findings as per their citation count and recommendations, this includes 4 articles, 5 survey analyses, and 1 review article.

Table 2: Top 10 most cited articles by total citation count

Author Name, Year and Journal Name)	Total Citations	Findings
ZHANG Z, 2014, CONSTR BUILD MATER	311	A comprehensive review of Geopolymer Foam Concrete with great environmental benefits for the housing industry. Concrete with sustainability parameters low cost, high strength/weight ratio, and potential fire resistance. And remarkable issues like Efflorescence, shrinkage, less durable and non-structural material
MOREL JC, 2001, BUILD ENVIRON	255	The paper justifies the use of local materials (soil, stone, and timber) for house construction as it supports sustainability parameters less embodied energy, less CO2 emission by the transportation of materials, and no need for thermal insulation materials.
GONZALEZ MJ, 2006, BUILD ENVIRON	214	This is an analytical study that explains the CO2 emission of the building can be reduced up to say more than 25% with the correct selection of material with sustainability parameters The design flexibility of the material, Selection of material with sustainability parameters rather than choosing conventional materials



Author Name, Year and Journal Name)	Total Citations	Findings
GIESEKAM J, 2014, ENERGY BUILD	72	This is a Descriptive study that explains the GHG emission and mitigation options of building materials used in UK. with sustainability parameters The design flexibility of the material, material efficiency, less embodied energy, less CO2 emission Identifies barriers to acceptance of alternative materials, technologies, and practices
KARIYAWASAM KKGKD, 2016, CONSTR BUILD MATER	66	A comprehensive review of cement stabilized rammed earth (CSRE) with great environmental benefits for the housing industry. CSRE with sustainability parameters strength, erosion resistance, shrinkage, and durability but low in embodied energy and low life cycle cost

### 4.1.3 Persistent journals

As seen in Figure 5, a selection of 50 papers were published in 29 publications. The publications "Journal of Cleaner Production," "Materials," "Energy and Buildings," and "Construction and Building Materials" are the most often used. The majority of papers addressing the sustainability of building materials were first published in the Journal of Cleaner Production, and then in the Construction and Building Materials journal. As time goes on, both publications are becoming more productive.

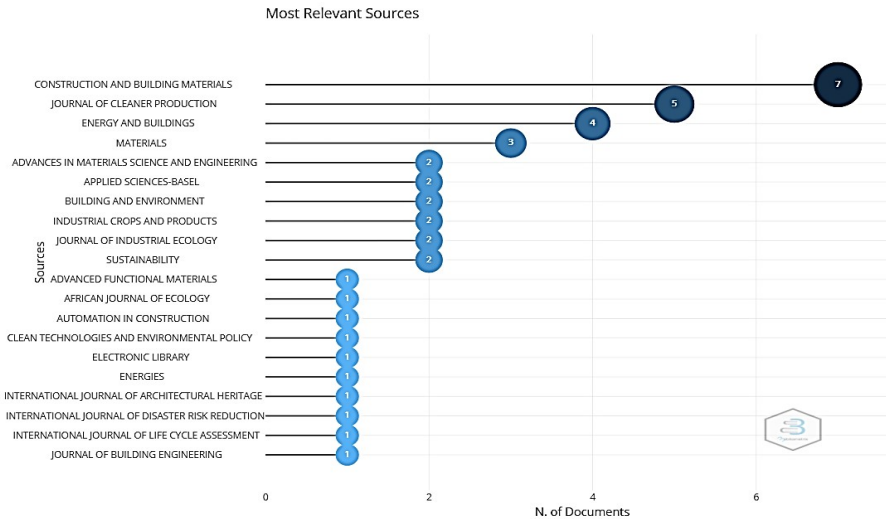


Figure 5 Most Persistent Journals

### 4.1.4 Keyword analysis

The co-occurrence of keywords based on the 50 retrieved articles on the study aim in "BibTeX" format is included in the keyword analysis. Figure 6 displays the co-occurrence of terms by country using five strong clusters, with the analysis's standardization of text size. The co-occurrence of keywords indicates how strongly the terms "sustainability," "material," and "residential building" are related. The primary strength among the keywords is indicated by the size of the circles in Figure 6.

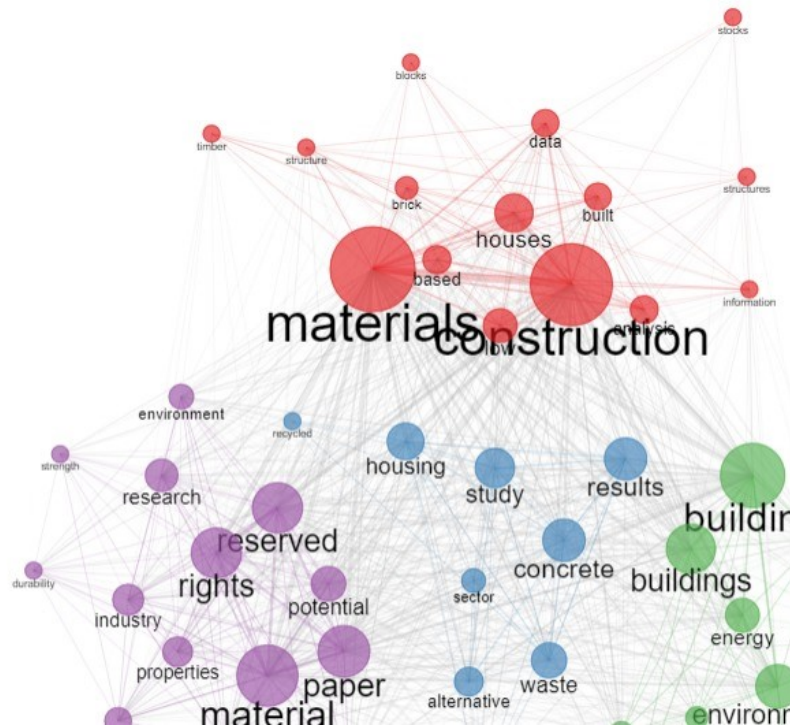


Figure 6: Keyword analysis

#### 4.1.5 Countries Collaboration analysis

Countries Collaboration analysis includes various collaboration frequencies, countries based on the extracted 50 articles on research objectives in ‘BibTeX’ format. In Table 5. the collaboration of countries reveals a strong link strength the USA, UK, SPAIN, etc.

Table 3: Countries Collaboration Analysis

Region	Freq
USA	21
UK	10
UGANDA	2
THAILAND	5
SWITZERLAND	7
SPAIN	18
SOUTH KOREA	5
PORTUGAL	7

## 5. CONCLUSIONS

In conclusion, the study emphasizes, how important it is to comprehend the sustainability of building materials in both developed and developing nations. This study uses a rigorous approach which includes bibliometric analysis and a systematic literature review. This research employs an R-Tool bibliometric method, to focus specifically on the sustainability of construction materials used in building envelopes. Using the PRISMA approach, the research study examined the publishing trend

line of the most contributing nations, frequent journals, contributing authors, most cited publications, and most popular keywords in the context of research from 2002 to 2022.

Despite the growing trend of publications in sustainability evaluation, there is still a dearth of literature that addresses all three sustainability criteria for building materials when choosing construction materials. The research study displays the results of the bibliometric analysis and systematic review that were published in 29 journals up until 2022 using the WOS database. Table 2, which displays the most cited papers over time, presents the results of this study's analysis of the most prolific writers and articles. Figure 2 displays the yearly publishing trend for the years 2002–2022.

In the construction business, the first article on sustainable building materials was published in 2003. The terms "residential buildings," "materials," "sustainability," and "cement" are most commonly used among the chosen 50 articles. The most often used keywords are "cement," "residential buildings," and "embodied energy," which indicates that sustainable materials have already been used to reduce carbon emissions and that additional socioeconomic frameworks are required for material selection. The cooperation of nations shows how strongly the "USA," "UK," and "Spain" are linked. Diagram 6. Table 4 shows that a selection of 50 papers were published in the 29 journals. The publications "Energy and Buildings," "International Journal of Life Cycle Assessment," "Journal of Cleaner Production," and "Construction and Building Materials" are the most frequently read ones.

#### **Future Recommendations Include:**

1. For group housing, a thorough framework is necessary for suitable inventory evaluation and holistic material selection.
2. When choosing materials for a framework with summarized sustainability requirements, all three dimensions must be taken into equal and holistic consideration.
3. One of the most important aspects of evaluating the sustainability of residential structures is the construction materials, which should be given careful thought and priority in the building's sustainability evaluation.

#### **Implications and Findings:**

The systematic and bibliometric analysis findings show that the research in the group housing materials is limited to resource consumption and CO<sub>2</sub> emissions. The study's findings suggest that a thorough framework is needed for the social, economic, constructability, and functional aspects of material sustainability, as well as for the holistic material selection and suitable inventory evaluation for group living. Furthermore, to assist sustainability in a variety of international contexts, the study highlights the urgent necessity for a rigorous sustainability evaluation methodology for determined inventory development.

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