



Research Landscape of Modular & Living Buildings: A Bibliometric Analysis (2003-2022)

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Abstract : Technological advancement shifts the entire paradigm of education to make learning more effective. The purpose of this study is to examine the research landscape of Modular or Living Building Construction Techniques from 2003 to 2022. A bibliometric approach was applied to analyze the yearly growth pattern, trends, and scientific production and presented a thematic analysis in the field of Modular/Living Building Construction Technology. The bibliometric study included 50 articles extracted from the Web of Science database during the last 19 years. This study will provide an important outlet for young scholars to understand how the research in the current area of study has progressed over the past nineteen years. In respect of publications, a thematic background study of the research topic including contributions made by different authors and countries will guide the researchers as to what aspects of Modular/Living Building Construction need to be explored. This paper intends to build a scope of further research in this field and help the researchers, engineers and construction companies to take decisions and build strategies towards this relatively new technology for sustainable growth in the infrastructure sector.

Index Terms - Modular Building, Living Building, Bibliometric analysis, BibliometrixR package, Science mapping, Research trends, Biblioshiny.

I. INTRODUCTION

Modular building construction technique involves construction of building using modules that are constructed off-site at a manufacturing unit. This off-site fabrication refers to volumetric units which act as structural elements of a building thereby improving quality of construction, reducing overall construction schedule, and minimizing resource wastage. The disadvantages include relatively small structural spans due to module transport limits and the lack of design guidance. However, the advantages of modular building construction technique exceed its disadvantages especially for schools, hotels, and residential buildings.

Two types of Modular Buildings exist:

1. Permanent Modular Construction (PMC) is a cutting-edge, environmentally friendly form of constructing that prefabricates single- or multi-story entire building solutions in deliverable module pieces using off-site, lean manufacturing processes. When compared to site-built construction projects, PMC modules may be provided with MEP, fixtures, and interior finishes in less time and with superior quality control. They can also be incorporated into site-built projects or used independently as a turn-key solution.
2. A Relocatable Building (RB) is one that is built at a building manufacturing factory utilising a modular construction procedure, and it may be partially or fully completed depending on the applicable rules or state restrictions. Relocatable structures can be built with the intention of being recycled or reused repeatedly. They can also be moved to various construction sites. They are mostly used to build up temporary structures such as sales centres, first aid stations, and offices on construction sites. These structures are favoured because to their rapid construction, inexpensive reconfiguration, simplicity of relocation, and extreme adaptability. As a result, these structures are sometimes referred to as Living Buildings.



Figure 1: On-site construction of Living Building

The focus of this research paper is to create an opportunity to understand how the construction of Modular/Living Buildings has grown and how its discussion has progressed among scholars in the literature over the past years. A comprehensive literature review in the area is therefore important. Firstly, it will provide an overview of progress made by researchers, and secondly, it will depict the critical information that will guide academicians and researchers in making decisions towards areas to focus on for future research and guide the publication outlet suitable for their work.

II. MODULAR CONSTRUCTION TECHNIQUE: TECHNOLOGY DEVELOPMENTS

Modular or Living building construction techniques became popular after the Second World War (1939-1945) to account for the rapid construction of buildings so as to replace bomb-damaged buildings for the general public and to accommodate the returning armies. The advantages of these structures made them popular. However, owing to their less aesthetic designs as compared to traditional buildings, modular construction techniques fell out of favor.

When building the 314 cube-shaped terraced houses on The Torton Estate (1926–28), Walter Gropius developed his idea of modular construction to reduce the cost of construction during a time when the German economy was always in trouble. The ceilings were formed of reinforced concrete joists, while the load-bearing walls were constructed from cheap, prefabricated, hollow slag-concrete blocks. The structural elements were all manufactured on the spot. However, as soon as the homeowners moved in, several building flaws were visible.

In 1945, Richard Buckminster Fuller created the Dymaxion House, a lightweight, readily flexible, circular aluminium home featuring natural ventilation, natural light, water recycling, and wind turbines. Despite the favourable public response, this prototype was not commercially manufactured due to expensive retooling expenses.

The Habitat 67, a cuboid building with 158 apartments designed by Moshe Safdie, is credited with introducing the concept of modular high-rise housing. Steel cables and high-tension rods were used to link the intricate stack of concrete boxes. The design allowed for 15 various home styles, with gardens and terraces filling in the empty spaces and 6 elevator pillars allowing access up and down. However, because the modules were prefabricated on site in a facility that was specifically designed for the purpose, building costs soared to C\$22 million. The idea persisted, though, with Safdie's Sky Habitat project from 2012 in Singapore, which aimed to build a network of interconnecting gardens, streets, and terraces in the sky.

Kisho Kurokawa constructed the 140 prefabricated concrete capsules that make up the 13-story Nakagin Capsule Tower (1972), each of which measures 2.3 metres by 3.8 metres by 2.1 metres and is attached to a shaft by high-tension bolts. The building's owners decided to tear it down in 2007 due to crowded circumstances. Kurokawa noted that the outdated boxes may be easily swapped out for new ones. Neither idea has been implemented yet.

Furniture House 1, Yamanashi built by Shigeru Ban in 1995, consists of 33 wooden units, prefabricated in two different sizes and joined together with a wooden girder. These units acted as a structure, space-defining elements and furniture - all at the same time. Each unit weighed about 80 kg and could not only be handled by a single person easily but was also earthquake-resistant due to its lightweight.

One of the most recent contributions to the modular building timetable is the modular strategy used by Michael Maltzan for Star Apartments, Los Angeles in 2014 for a homeless shelter. The site formerly had a single-story business structure, but the architect chose

to build on top of it rather than demolish it. Therefore, the original building was covered with a concrete superstructure that contains 102 flats, and five stories of prefabricated modules were craned on top. The bathrooms, cupboards, appliances, surface treatments, and communal area were all pre-installed in the flats.

Over the past few years, with the infrastructure sector seeking immense growth, there has been a rise of interest in modular construction techniques, keeping in mind that these structures can not only be sustainable and long-lasting but can also be aesthetically pleasing.

Recent dramatic examples of the evolution of living buildings across various parts include a 32-storey residential tower in Brooklyn, New York, USA and the 30-storey Tower Hotel in Yueyang, Wuhan, China.

III. RESEARCH OBJECTIVES

The focus of this paper is to perform the analysis of past literature in the field of Modular Construction using the 'biblioshiny software' developed by using the R language and based on this past research knowledge, give the future direction of the study.

The objective of this research is to:

- Identify all significant shifts in the field of Living or Modular building construction.
- Study the trends & growth of publication in the field of Modular buildings over the last twenty years and recognize relevant authors, journals, citations, and affiliations in this area of research.
- Identify the keywords and the most relevant documents contributed in this field.
- Present the literature review and thematic background of this field of research.

The purpose of this study is to help young scholars who are planning to do research in the field of Modular/ Living Buildings know the trend of research done and publications in this field of study. It will help them gain knowledge on the top articles contributed in terms of journals, scholars, citations, and related impact factors.

This paper will also assist in identifying the trending topics contributed to the field of Modular construction. The study is intended to answer the research question that how the research in the field of Modular construction has progressed over the last 19 years in terms of most relevant authors, sources, documents, affiliations, institutions, and country.

The VOSviewer software is used to identify the most relevant themes in this field and to know the future direction and scope of study in this field.

IV. RESULTS & DISCUSSIONS OF BIBLIOMETRIC ANALYSIS

The purpose of this study is to understand the research landscape of Modular construction over the last 19 years using the biblioshiny App developed using the R language. One of the greatest methods for doing a systematic literature review that is based on statistical measurement and provides a trustworthy analysis process is bibliometric analysis (Pritchard, 1969; Broadus, 1987; Diodato, 1994).

This study uses the R package bibliometrix to conduct a bibliometric analysis to comprehend the literature review in the area of modular building construction so as to synthesize the literature of the past nineteen years and utilize that existing research landscape to know the future direction of the study. The open-source software biblioshiny developed using the open-source software R language is used for bibliometric analysis and visualization (R core team, 2016). This open-source software offers various statistical and graphical techniques along with the potential of future expansion (Matloff, 2011).

The methodology used to perform the bibliometric analysis is divided into three parts:

- Part 1 includes the extraction & conversion of data.
- Part 2 includes the descriptive analysis to identify the most relevant authors, sources, countries that contributed to this field.
- Part 3 makes use of VOSviewer software to know the thematic background of the research by generating the density maps, as it has a robust graphical user interface (Cobo et al., 2011).

The details of all three steps are discussed in the below sections.

4.1 Data extraction, loading, and conversion

In the first step, WoS (Web of Science) database which is known for its quality research publication is utilized to extract the relevant documents. These documents are comprised of articles, book chapters and proceedings over the last twenty years using the keyword "Living Buildings" or "Modular Buildings". It considers various categories of documents like articles, proceedings, reviews, and book chapters. The study includes all research work done in the field of Living or Modular Buildings, with a total of 50 documents, including 40 articles, 1 book chapter, 3 proceedings papers and 6 review papers, extracted from the Web of Science database based during the last 19 years. These extracted documents were converted into plain text format and loaded in the notepad file.

4.2 Descriptive analysis using Bibliometrix software package

In the second part, detail of the analysis is presented which is presented in the result and discussion section. This section is further categorized into three sub-sections. Biblioshiny app user interface is used to perform the descriptive analysis. Biblioshiny app used the Bibliometrix package to extract the relevant documents contributed to the field of Modular construction.

- In the first subsection, the detail of the data extracted for the analysis is presented along with the trend of publications over the last twenty years in this field.
- The second sub-section talks about the most relevant sources in terms of the number of publications, citations and impact.
- The third subsection presented the detail of the most relevant authors, institutes and countries that contributed to this field.

4.3 Thematic background using VOSviewer software

To analyze and calculate the strength of interactions among keywords extracted from the WoS database, VOSviewer software is used. VOSviewer software is used to generate density maps and the heat map to know the keyword co-occurrence and develop the thematic background of the research in the field of Modular construction. The result of the Bibliometric analysis performed on the documents extracted from the WoS database published during the last 19 years is presented and discussed in this section. The result of the analysis is divided into five sections, which are further divided into sub-sections.

- In the first section, the description of the documents considered in this study is presented along with the growth and trend of research publications in the field of modular/living building construction.
- In the second section, the contribution of relevant journals contributed in this field is presented. This section presented the details like the most relevant and trending journals, and the most locally cited and high-impact factor journals that contributed to this field.
- In the third section, the detail of the relevant authors, institutions, and countries that contributed to the field of modular/living building construction is presented. This section provided the details of the most locally cited authors, their productivity, and their impact in this field. This section also provides the details of the most relevant affiliations and countries that contributed to this field.
- The detail of the relevant documents and keywords is presented in section four. This section provided details like most globally cited documents and locally cited references in this field of study. It also provides the details of the most frequent keywords published in various documents over the last twenty years.
- In the fifth section, the thematic background of the research in the field of modular/living building construction is identified, based on the keyword co-occurrence heat map created using the VOS viewer software.

4.4 Growth and trends of research

The data related to the keyword “Modular Building” or “Living Building” is extracted from the Web of Science database. Publication details of 50 extracted documents are presented in Table 1. The main information shows that it includes documents from the year 2003 to April 2022. This extracted data includes 31 sources, and with the average number of citations per document is 19.42. A total of 143 authors contributed to this field among which 4 documents were single-authored.

Table 1: Main Information about Data

Main Information about Data	Results
Timespan	2003:2022
Sources (Journals, Books, etc)	31
Documents	50
Average citations per documents	19.42
Authors	143
Authors of single-authored documents	4
Authors of multi-authored documents	139
Collaboration Index	3.02

Source: Author's elaboration

The trend of publication from 2003 to mid-April 2022 is shown in Table 2. The trend shows that no exceptional work was done in the field of Living or Modular Building Construction was done from the year 2003 to 2017, except in the years 2009 and 2016. However, research contributions have been made in the field from 2018 to 2022 at a constant but higher rate as compared to the previous years, which indicates that Living or Modular Building Construction is an emerging field of research and must be explored.

Table 2: Year-wise Publication

Year of Publication	Number of Articles
2003	1
2005	2
2008	1
2009	3
2015	1
2016	4
2017	1
2018	8
2019	8
2020	8
2021	9
2022 till April mid 2022	4

Source: Author's elaboration

4.5 Relevant sources of field publications

4.5.1. Most relevant sources

The details of the top journals that published articles on Living/modular building construction in the previous 19 years are shown in Table 3. The top two journals that have published articles in this field are “Journal of Building Engineering” and “Engineering Structures” with 7 and 4 articles in this field of research, respectively. The analysis was performed to know the most trending journals in this field.

Table 3: Top Relevant Journals

Sources	Articles
Journal of Building Engineering	7
Engineering Structures	4
Automation in Construction	3
Journal of Architectural Engineering	3
Journal of Constructional Steel Research	3
Structures	3
Applied Sciences-Basel	2
Journal of Green Building	2
Actamontanisticaslovaca	1
Advances in Civil Engineering	1
Annales-Analizaistrske in Mediteranskstudije-Series Historia et Sociologia	1
Architectural Design	1
Building and Environment	1
Buildings	1
Earthquakes and Structures	1
Engineering Failure Analysis	1
Facilities	1
Journal of Computing in Civil Engineering	1
Journal of Construction Engineering and Management	1
Journal of Environmental Radioactivity	1

Source: Author's elaboration

Figure 2 shows that the journal titled “Journal of Building Engineering” is the most trending journal from 2010 onwards, followed by the “Engineering Structures” journal which started publishing articles in this area of research at an increasing rate from 2012 onwards. “Automation in Construction”, “Journal of Architectural Engineering”, “Journal of Constructional Steel Research” and “Structures” also published articles in this field from 2010 onwards.

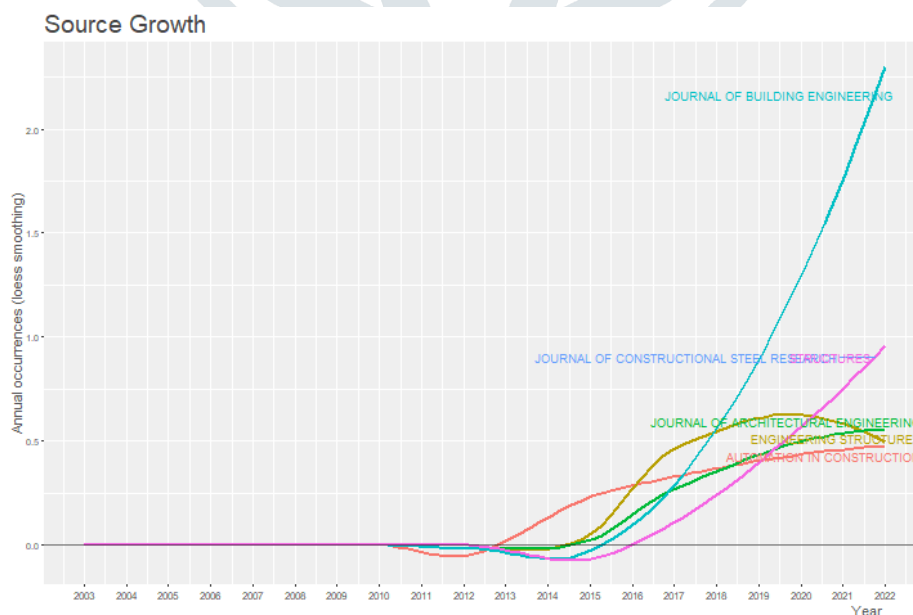


Figure 2: Source Dynamics over the years

The “Journal of Building Engineering” and “Automation in Construction” are not only in the list of top five journals with maximum contribution but also their trend of publication is increasing at a very fast pace. The above analysis also reveals that

“Engineering Structures” is second among the top three journals (Table 3) in this field, but its trend of publications is continuously reducing from 2019 onwards.

4.5.2. Most locally cited Journals in the field of Modular or Living Building Construction

The number of local citations can be measured as the number of citations any document gets from the documents included in the analyzed data. It also measures the document's impact on the analysis. The journals having a maximum number of local citations are shown in Table 4. The journal name “Engstruct” has a maximum number of 155 local citations, followed by “J Constr Steel Res” journal which has 86 local citations in this field.

Six journals have more than 30 local citations and twelve journals have more than 15 local citations. These facts and figures have a clear-cut indication that in the field of Modular/ Living Building Construction, very few journals have got a good number of local citations in the past 19 years, thereby indicating the extensive scope of research that can be done in this field.

Table 4: Top Local cited Journals

Sources	Articles
Engstruct	155
J Constr Steel Res	86
Automat Constr	71
J Architeng	51
J Build Eng	44
Thesis	33
Build Environ	31
Thin Wall Struct	30
J Clean Prod	29
Constr Build Mater	28
Constrmanag Econ	27
P I Civil Eng-Str B	27
Energ Buildings	23
Design Modular Const	19
J Earthqeng	19
J Structeng	18
J Structeng-Asce	18
Renew Sustenerg Rev	18
Compos Struct	15
Structures	15

Source: Author's elaboration

4.5.3. Journals with a high Impact factor

The h-index is used to measure the productivity and the citation impact of that journal. The list of journals with high-impact factors that have published articles in this field is shown in figure 3. The journal name “Journal of Building Engineering” has a maximum h-index factor. Six journals have an h-index of more than 2, which shows that the journals are getting high impact factors while publishing documents in this field. One more interesting thing to be noted is that the “Journal of Building Engineering” has not only published the maximum number of articles in this field but has a maximum h-index also, followed closely by “Engineering Structures” journal in both cases.

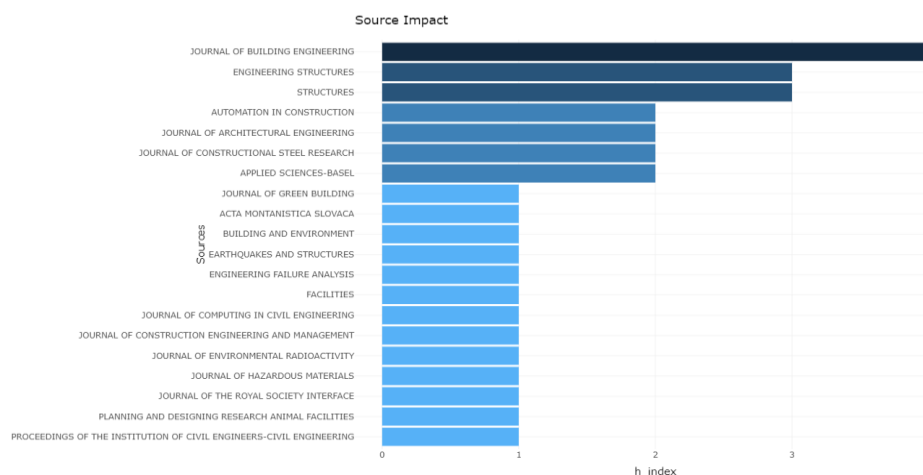


Figure 3: Journals with High Impact Factor

4.6 Prolific scholars, institutions, and countries

In this section, the result of bibliometric analysis based on the contribution of various authors, the most relevant affiliations, and countries that have a maximum contribution in the field of study has been presented.

4.6.1 Author's Impact in the field of Modular/Living Building Construction

The author's impact can be measured with the help of the h-index value. The details of the authors having a high h index involved in the publication of articles related to the field of study being discussed are shown in Figure 4. The author with the h-index of three is "Bai Y". All other authors have an h-index of 2.

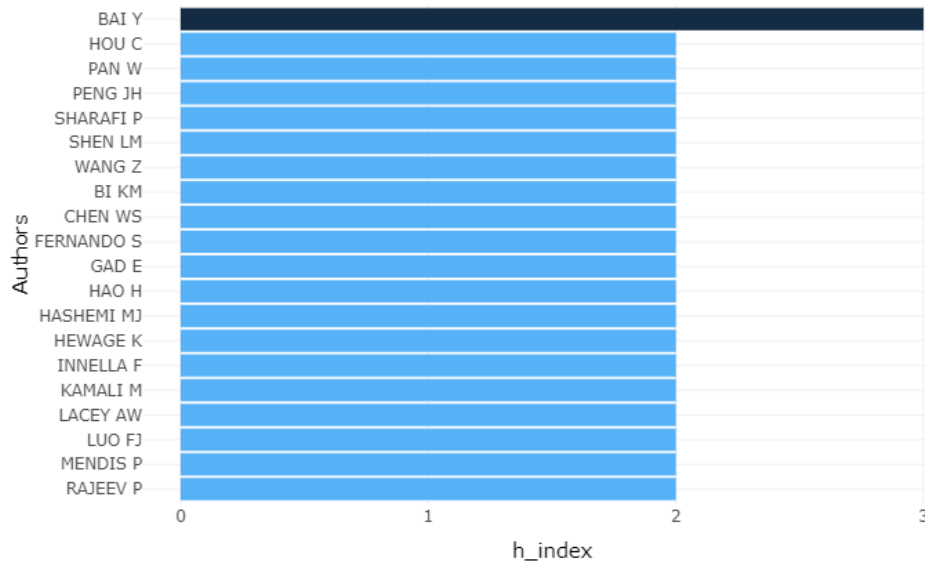


Figure 4: Authors of High Impact Factor

4.6.2 Most relevant affiliations in the field of Modular/Living Building Construction

The affiliation statistics related to the top Institutes/Universities producing the maximum number of documents in the current field of research. The details of the top twenty relevant affiliations in this field are presented in Table 5. The most dominant institutes that published 5 documents are "Monash Univ" and "Natl Univ Singapore".

The Monash University is a public university established in 1958 and based in Melbourne, Australia. It has four campuses in Victoria & one campus in Malaysia. National University, Singapore is a flagship university founded in 1980.

Research in the field of Modular/ Living Building Construction has also been carried out by Curtin University, Australia (founded in 1986) and Hanyang University, South Korea (established in 1939).

Table 5: Top Relevant Affiliations

Affiliations	Articles
MONASH UNIV	5
NATL UNIV SINGAPORE	5
CURTIN UNIV	4
HANYANGUNIV	4
PENN STATE UNIV	3
SOUTHERN UNIV SCI AND TECHNOL	3
UNIV HONG KONG	3
UNIV MELBOURNE	3
UNIV SYDNEY	3
WESTERN SYDNEY UNIV	3
CHINA UNIV MIN AND TECHNOL	2
SWINBURNE UNIVTECHNOL	2
TIANJIN UNIV	2
UNIV BRITISH COLUMBIA	2
UNIV LJUBLJANA	2
UNIV SOUTHERN QUEENSLAND	2
AALTO UNIV	1
ADAM MICKIEWICZ UNIV	1
BARTLETT SCH ARCHITECTURE	1
CENT S UNIV	1

4.6.3 Corresponding author’s country in the field of Modular/Living Building Construction

A country-by-country analysis was done to determine which nations contributed the most writers to publications published in the context of our present research. This analysis presented the name of countries having corresponding authors published a maximum number of articles in this field. The details of the most relevant countries having corresponding authors contributed most along with the frequency of the publication are presented in Table 6. Figure 5 represents single-country publications (SCP) and multiple-country publications (MCP) for the relevant countries.

Single-country publications (SCP) are works in which all the authors are associated with the same country. Multiple country publications (MCP) are articles in which authors are from different country affiliations.

The analysis shows that Australia has a maximum of 24 corresponding authors in this field. This country has a maximum frequency, SCP, and MCP, equal to 24, 21 and 3 respectively. China has 18 corresponding authors and USA has 8 corresponding authors in this field. This indicates that most of the publications have authors from multiple countries except India, which indicates that collaborative research promoting in this field. However, this technology is refrained to only the developed countries and has not been touched upon in developing countries like India.

Table 6: Country-wise Articles Published

Country	Articles
AUSTRALIA	24
CHINA	18
USA	8
SOUTH KOREA	7
UK	6
SINGAPORE	5
CANADA	3
DENMARK	3
GERMANY	2
IRELAND	2
SLOVENIA	2
AUSTRIA	1
FINLAND	1
ITALY	1
MALAYSIA	1
MONTENEGRO	1
NETHERLANDS	1
POLAND	1
QATAR	1
RUSSIA	1

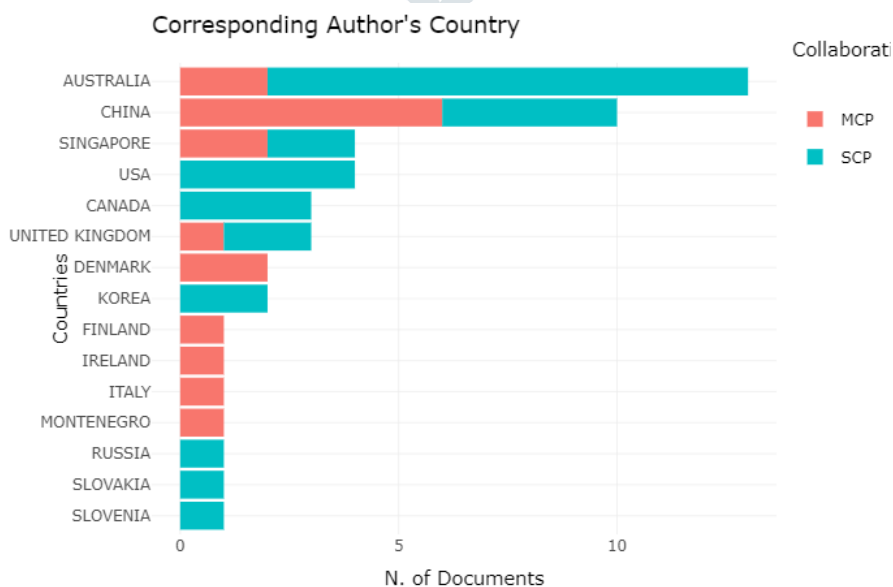


Figure 5: Country-wise corresponding authors

4.6.4 Most cited countries in the field of Modular/Living Building Construction

To determine which countries receive the most citations, different countries' citation data is analyzed. Australia is in the top position and has had more than 500 citations in the last nineteen years with an average article citation of 39.23. Canada is in the second position and has approximately 250 citations. China stands third with more than 50 citations, followed closely by USA and Russia. The details of various citations country-wise are shown in Table 7.

These figures indicate that Australia is leading not only in publication but also leading in citations and is far forward with respect to the other countries. It is noteworthy that even though Canada has only 3 publications, it has almost 250 citations with an average article citation of 82.67, thereby revealing the good quality of research being carried out in the country.

Table 7: Top most-cited countries

Country	Total Citations	Average Article Citations
Australia	510	39.23
Canada	248	82.67
China	53	5.30
USA	45	11.25
Russia	41	41.00
Slovenia	14	14.00
United Kingdom	13	4.33
Denmark	11	5.50
Finland	11	11.00
Slovakia	11	11.00
Ireland	6	6.00
Korea	3	1.50
Singapore	3	0.75
Italy	2	2.00
Montenegro	0	0.00

4.7 Documents and keywords analysis

In this section, the result of bibliometric analysis based on the most cited documents, the most relevant keywords, and trend of keywords over the last nineteen years in the field of Modular or Living Building Construction has been presented.

4.7.1 Most globally cited documents

Citations measure, how many times an article is cited by the other article in their published document globally. During the analysis, it has been found that the article "KAMALI M, 2016" is cited more than 150 times globally, which is the maximum in the field of Living/Modular Building Construction. Similarly, "FERDOUS W, 2019" and "LACEY AW, 2018" have more than 100 citations in this field.

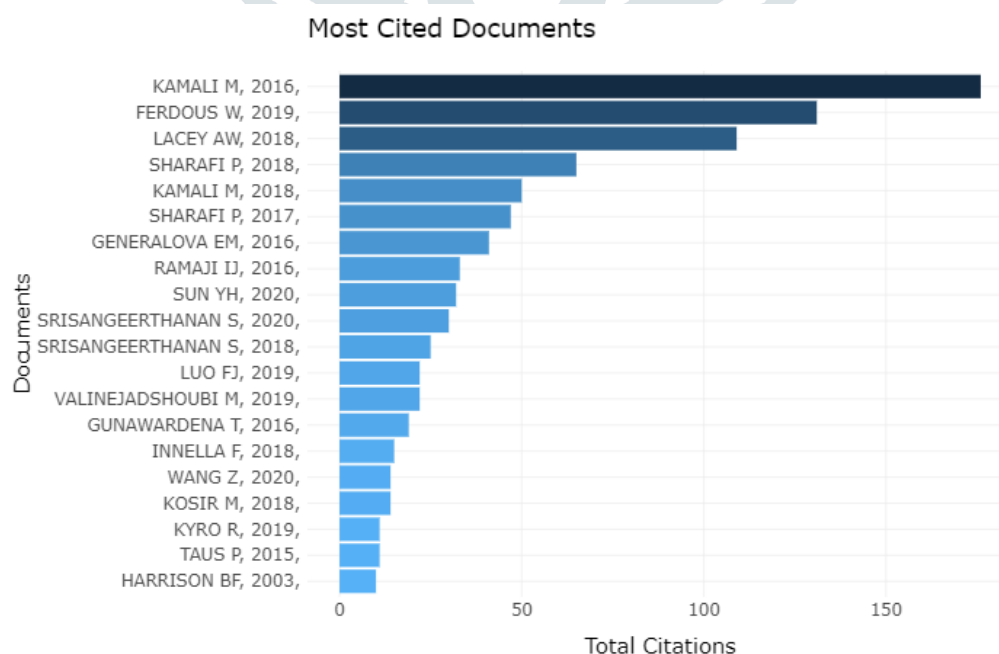


Figure 6: Top Global-cited Documents

4.7.2 Most frequent words

To determine the most pertinent keywords from the papers and to understand the conceptual framework of the study conducted in this subject, the co-word analysis approach is utilized (Callon et al., 1983). The most often occurring words and phrases



Figure 9: Trending topics over the last 19 years

V. CONCLUSION

The use of a range of structural methods and building materials is referred to as modular building. Because modular buildings require site connections, their performance differs from that of comparable classical structures. This study is also conducted to examine the research pattern of Modular/Living Buildings using thorough bibliometric analysis. The research included 50 articles extracted from the Web of Science database during the last 19 years. A bibliometric approach was applied to analyze the yearly growth pattern, trend, scientific production and presented a thematic analysis of this research area, and identified the main clusters of research collaboration in this field.

- The growth and trend of research publications in the field of Modular/Living Buildings indicate that the number of publications was stagnant between the years 2003 to 2017 but has increased at an annual growth rate of 3.5% from 2018 onwards.
- In the second section, the contribution of relevant journals contributed in the field of Modular/Living Buildings is presented. This section presented the details of the most relevant and trending journals, most locally cited and high-impact factor journals that contributed to this field. ‘Journal of Building Engineering’ and ‘Engineering Structures’ is found to be the most relevant journals contributed to this field. ‘Automation in Construction’, ‘Journal of Architectural Engineering’, ‘Journal of Constructional Steel Research’ and ‘Structures’ is the journals that follow closely.
- “Bai Y” is found to be the most contributing and impactful author in this field of study, followed closely by many others. The most dominant institutes are “Monash Univ” and “Natl Univ Singapore”.
- The analysis reveals that Australia and China have contributed the maximum number of articles and produced maximum articles as SCP and MCP countries. Australia and Canada found to be the most cited countries in this field.
- The analysis presented in this section depicts that few documents “KAMALI M, 2016”, “FERDOUS W, 2019” and “LACEY AW, 2018” have more than 100 global citations.
- Except ‘Rajeev P’, with author citation of 2.0, no other Indian author/ research scholar/ Indian University has contributed to the field of Modular construction technique, thereby indicating the need to address this technology for research purpose in India.
- The result of the analysis in terms of the trend of publications, relevant authors, institutes, country, and documents presented in this section will be a good outlet for the scholars pursuing their study or planning to conduct the study in the field of Modular/Living Building Construction.
- The trend shows that the word like “connection”, “design”, “construction”, “performance”, and “systems” are the more researched phrases over the last 19 years in relation to modular or living building construction. Furthermore, words like “Hong-Kong”, “prefabrication”, “plates”, “robustness”, “seismic performance”, “offsite walls” and “steel” also some of the common keywords used.

VI. STUDY LIMITATION AND FUTURE DIRECTION

Like every research, this study also has certain limitations. Researchers studying modular/living buildings may find the study's findings helpful in understanding the research environment and hotspots in the field.

Keeping in view industry 4.0, every sector of the economy is moving towards digitization and faster problem-solving techniques. Therefore, how a study of inter-panel joint connections, performance analysis and design of modular/living buildings can help this sector will be the future scope of the study for scholars. The analysis shows that many countries are contributing to research in this field but most of the countries are contributing as single-country contributions with less MCP ratio. Therefore, it is a good opportunity for the scholars to focus on a more collaborative study with other countries to enhance the research from a global perspective.

VII. DECLARATION OF CONFLICTING INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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