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## Applications of Biomimicry in Construction and Architecture: A Bibliometric Analysis

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# APPLICATIONS OF BIOMIMICRY IN CONSTRUCTION AND ARCHITECTURE: A BIBLIOMETRIC ANALYSIS

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## ABSTRACT

Biomimicry can be considered to be a way of connecting the environment created by man to the natural world. Biomimicry is a science that, as a model, a measure and a tutor, looks to nature. Via site work, construction and everyday operations, biomimicry can be used to enhance the way the built environment is constructed. The main objective of this paper is to perform a bibliometric study of biomimicry-related literature in order to discover the growth of biomimicry as an architectural method in recent years. The time frame considered for this survey is between 1990 and 2020. The findings, however, indicate that the first paper was not written until 2007. In this paper, bibliometric analysis focuses primarily on results from the Scopus database. For data visualization purposes, external software like iMapBuilder and VOSviewer are used. The research is intended to show the need for biomimicry in the modern world. The result of the study sheds light on the lack of biomimicry research and the need for more research on the subject. A new research approach for comprehensive research in biomimicry paves the way for the results of this analysis.

**Keywords:** Biomimicry; Buildings; Architecture; Construction

## 1. INTRODUCTION

There have been a variety of questions and concerns raised over the past few decades about how architects and designers can address complex issues between nature and architecture. Buildings, with very little respect for architecture and aesthetics, were thought of only as a way of obtaining shelter.

As time went by, there were issues and questions about the worldwide lack of energy and the heavy use of energy in houses. In recent times, another big problem has been the lack of shape and layout that a building has. As the number of problems began to develop, architects and designers had to break away from the usual design process and start thinking outside the box. All of a sudden, a

modern design style was brought into the world, a style that saw nature and architecture join forces to give us complete harmony in the field of design.

Biomimicry is the name of this modern expression of construction and design. It is possible to think of biomimicry as a means of connecting the man-made world to the natural world. It is a science that, as a model, a measure and a tutor, looks to nature. Biomimicry can be defined as the art of using the natural design freely provided by nature and then adding those thoughts to our own design. This idea has also been applied by buildings like the Eastgate Centre (Zimbabwe) and the Council House, CH2 (Australia). This philosophy, however, has spread exponentially, and is not only limited to engineers, architects and designers. This idea has already been applied by a variety of fields: medical, logistics, material production and small-scale companies. The end purpose is the same, although the uses of biomimicry differ, to bring harmony between the structure, the users and the natural environment. In the modern world, the following subsection discusses the necessity of biomimicry.

### **1.1. Background**

Biomimicry has brought unity between man-made structures and the natural environment. However, architects and designers have turned to this new philosophy of biomimicry to solve most of these problems due to the persistent problems facing the modern world. Biomimicry somehow helps to solve these problems in a way that we could only have dreamed of, with the increasing issues of energy consumption, lack of structural structures and simple designs. The field of biomimicry enables an engineer to create modern, fresh designs. In order to build a new mentality and pursue new solutions to disrupt conventional thought, biomimicry is needed to make structures energy-efficient. The internal temperature is controlled by designs such as those inspired by penguin feathers. The termite mounds are influenced by such structures, allowing for improved cooling and air circulation. As biomimicry is a modern and upcoming technology, it offers a new career opportunity - it allows project teams the opportunity to explore new solutions and brainstorm opportunities in new and creative ways to solve problems. If we are able to mimic nature in such a careful way, material creation will have similar characteristics to the inspired being of nature, thus minimizing material costs. In order to optimally use capital and eliminate needless expense, engineers must then be able to set up their different units and systems. The most significant point to remember, however, is that this sector preserves biodiversity and decreases natural resource use.

### **1.2. Need for the study:**

Bibliometrics is a branch of scientific research that deals with systematic study of various aspects of available literature. Geographic analysis, author analysis, journal analysis, etc. are included. Based on literature findings, it is noted that a systematic bibliographic survey is lacking in the area of biomimicry.

## **2. BIBLIOMETRIC SURVEY**

For accessing journal databases, there are two categories: open access and paid access. Through use of their university library portals or by registering separately on individual websites, one can access these publications. There are also many common methods for extracting data from the appropriate databases. Scopus, Clarivate, SCImago, Mendeley, ScienceDirect, DBLP, Google Scholar, and Study Doors, etc, are common publication databases. Scopus is the main collection of peer-reviewed academic abstracts and citations. Technology, engineering, technology, medicine, social sciences, the arts, the humanities, and literature. This paper has taken into consideration only results from the Scopus database, with the help of appropriate keywords listed in section 2.1.

The Scopus database was used from numerous publications, conference journals and research papers published between 1960 and 2020 to obtain sufficient literature relevant to ‘biomimicry’. All relevant data was collected on a single day, keeping in mind the regular updating of the databases.

**2.1. Selection of keywords**

One of the significant steps in performing research is data collection. This survey is performed with unique keywords that better characterize the search field that is suggested.

In bibliometric research, keyword selection plays an important part, as results vary with the use of a particular set of keywords. In the use of keywords, any use of the conjunctions 'AND' and 'OR' often varies. According to the Scopus database, AND should be included where analysis is needed to use both terminologies. The "OR" conjunction should be used where one or more words are used in the predicted search results.

Table 1: Keywords for bibliometric survey

Keywords Set	Conjunction
Biomimicry, Buildings, Architecture	AND
Construction	OR

In the search tab of Scopus, keywords set is added in the format ‘Biomimicry’ AND ‘Buildings’ AND ‘Architecture’ OR ‘Construction’.

**2.2. Preliminary survey of database**

Preliminary survey of the Scopus database using the aforementioned set of keywords yielded a total of 81 results. The survey results indicate that 43.2% of the total documents were submitted to conference papers, followed by articles corresponding to 39.5% of the publications. Among the 81 search results, five paper styles were found. There were a total of 67 reviews and conference papers out of 81 publications in total. The input from the publications is seen in the doughnut chart

(Fig. 1 below). Just a limited percentage of the cumulative 81 articles contributed to reviews, novel chapters and novels. Table 2 lists the number of the various document types.

Table 2: Document type and number of documents  
 Source: [www.scopus.com](http://www.scopus.com) (retrieved on 7<sup>th</sup> November 2020)

Document Type	Number of Publications
Conference paper	35
Article	32
Review	9
Book Chapter	3
Book	2

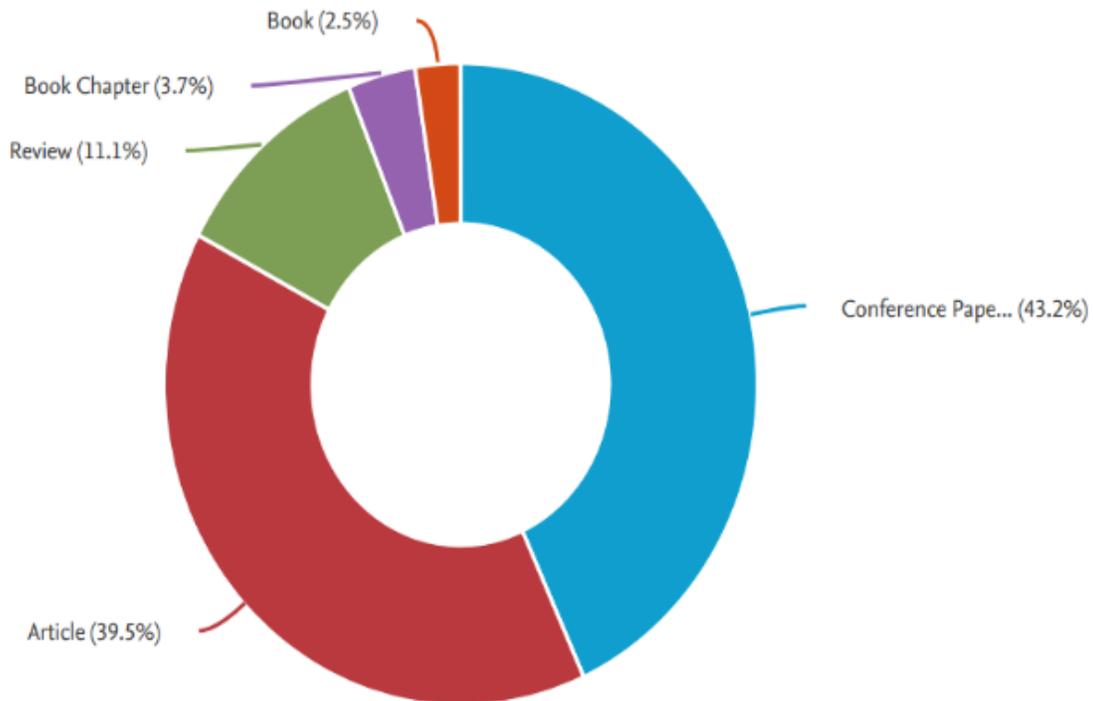


Fig. 1: The types of publications in biomimicry  
 Source: [www.scopus.com](http://www.scopus.com) (accessed on 7<sup>th</sup> November 2020)

### 3. RESULTS AND DISCUSSION

This section presents the results of the data obtained from the Scopus database. All the graphs and trends are analyzed. Documents are analyzed based on the annual trend, subject area, geographical location, authorship and affiliations.

### 3.1 Annual publications trend

The line graph in Fig. 2 shows the annual publications trend related to Biomimicry. The first article was published in the year 2007, and there was a very slow increase for the next 9 years. The survey was carried out for a total of 14 years, from 2007 to 2020. There was a total of 34 publications from the year 2007 to 2016. However, from 2017 to 2020 there were 42 publications, which shows the increased interest in the field of biomimicry in recent years. In the year 2019, 18 documents were published, marking the highest publications in any particular year. It is evident from the results that there is a need for more research in the field of biomimicry. However, the trend in recent years looks positive and it is clear that there is a growing interest in the field.

Table 3: Year-wise publication details

Source: [www.scopus.com](http://www.scopus.com) (retrieved on 7<sup>th</sup> November 2020)

Year	Number of Publications
2020	10
<b>2019</b>	<b>18</b>
2018	8
2017	11
2016	6
2015	7
2014	4
2013	5
2012	3
2011	4
2010	1
2009	1
2008	1
2007	2

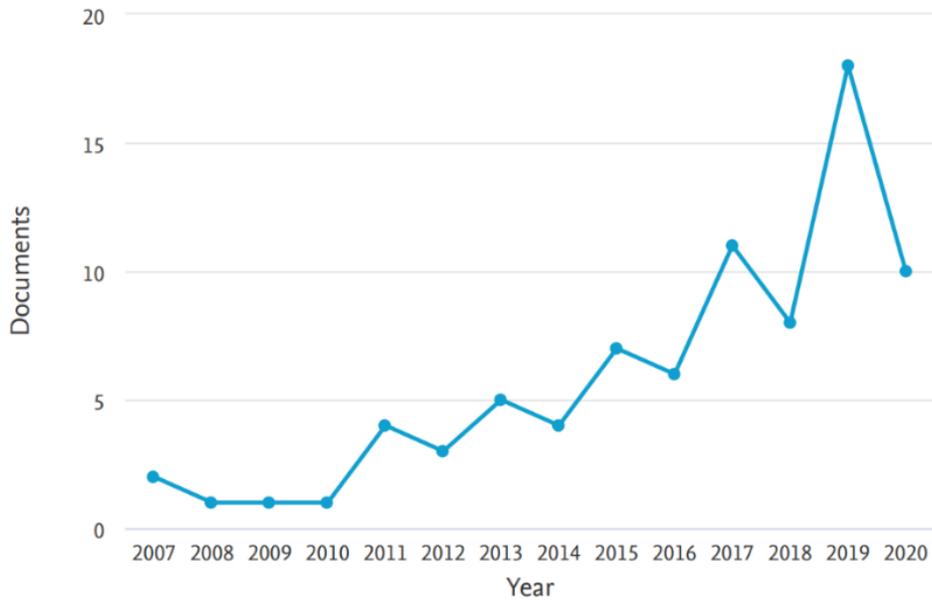


Fig. 2: The annual trend of Biomimicry-related publications  
 Source: [www.scopus.com](http://www.scopus.com) (accessed on 7<sup>th</sup> November 2020)

### 3.2 Geographical regions analysis

The bar graph in Fig. 3 shows the top 10 countries with the most publications. The USA has the highest publications (19) and contributes to around 23% of the total results. Table 3 shows all the countries that have publications related to Biomimicry. iMapbuilder.net is used to plot the regions according to the publications. The spread of the research work and the geographical attentiveness of publications are shown in the map in Fig. 4.

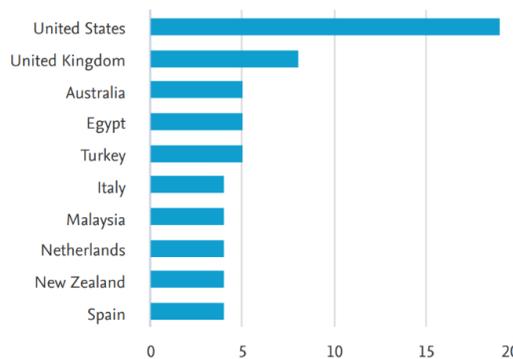


Fig. 3: Top 10 countries with the highest publications  
 Source: [www.scopus.com](http://www.scopus.com) (accessed on 7<sup>th</sup> November 2020)

Table 4: Country-wise publications  
 Source: [www.scopus.com](http://www.scopus.com) (retrieved on 7<sup>th</sup> November 2020)

Country	Number	Country	Number	Country	Number
<b>United States</b>	<b>19</b>	India	3	Iraq	1
United Kingdom	8	South Korea	3	Latvia	1
Australia	5	France	2	Panama	1
Egypt	5	Iran	2	Poland	1
Turkey	5	Portugal	2	Romania	1
Italy	4	South Africa	2	Saudi Arabia	1
Malaysia	4	Algeria	1	Slovenia	1
Netherlands	4	Austria	1	Sudan	1
New Zealand	4	Brazil	1	Switzerland	1
Spain	4	Croatia	1	Thailand	1
Canada	3	Denmark	1	UAE	1
China	3	Indonesia	1	Undefined	4



Fig. 4: Geographical region analysis  
 Source: <https://imapbuilder.net/> (created on 8<sup>th</sup> November 2020)

### 3.3 Authorship analysis

The bar graph in Fig. 5 shows 10 of the most productive authors in contributing to the field of biomimicry. The h-index measures the impact that an author's research work and publication have on the field of study. The purpose of this authorship analysis is to identify some of the most prominent authors in the field of biomimicry. Table 5 shows a list of the 10 most productive authors, along with their h-index.

Table 5: Authorship analysis with h-index

Source: [www.scopus.com](http://www.scopus.com) (retrieved on 7<sup>th</sup> November 2020)

Author	Number of Publications	h-index
<b>Garcia-Holguera, M.</b>	<b>3</b>	1
<b>Gaskin, S.</b>	<b>3</b>	14
<b>Sprecher, A.</b>	<b>3</b>	2
Agus Salim, N.A.	2	2
Clark, G.	2	10
Desha, C.	2	10
<i>Donnison, I.</i>	2	<i>41</i>
Gibbs, M.	2	21
Hayes, S.	2	1
Jones, P.	2	22

Key: Authors indicated in **bold** have the highest publication

Authors indicated in *italics* have the highest h-index



Fig. 5: Top 10 authors with the highest publications  
 Source: [www.scopus.com](http://www.scopus.com) (accessed on 7<sup>th</sup> November 2020)

The authorship bar graph shows that Garcia-Holguera, M., Gaskin, S. and Sprecher, A. have the highest publications in the field of biomimicry, making them the most productive authors. Donnison, I. has the highest h-index compared to any of the other authors, making him the most impactful author in the said field of research.

### 3.4 Subject Area Analysis

A categorization of subject area for the field of biomimicry is shown in the pie chart in Fig. 6. From the chart, it is evident that maximum research has been carried out in the field of engineering (31.0%). Extensive research has also been carried out in the fields of materials science, energy studies, environmental studies, computer science, social science, and other interdisciplinary others. Among others, research has also been conducted in the field of mathematics, physics, chemistry, medicine, etc. which, when combined, makes up 12% of the total subject area distribution.

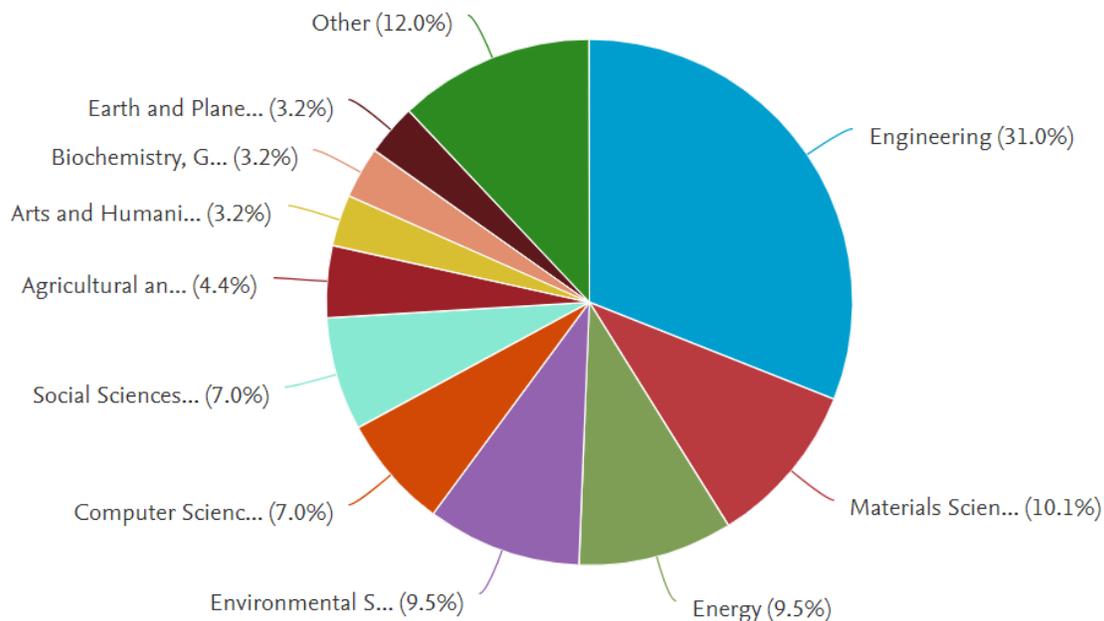


Fig. 6: Subject area distribution of literature in the field of biomimicry

Source: [www.scopus.com](http://www.scopus.com) (accessed on 7<sup>th</sup> November 2020)

Table 6 shows the total number of publications in each research area. The engineering field has the highest number of publications (49), followed by materials science (16). The contributions from the other sectors has been indicated clearly in the table below.

Subject Area	Number of Publications	Subject Area	Number of Publications
<b>Engineering</b>	<b>49</b>	Chemical Engineering	3
Materials Science	16	Chemistry	3
Energy	15	Mathematics	3
Environmental Science	15	Physics and Astronomy	3
Computer Science	11	Medicine	2
Social Sciences	11	Multidisciplinary	2
Agricultural and Biological Sciences	7	Business, Management and Accounting	1
Arts and Humanities	5	Decision Sciences	1
Biochemistry, Genetics and Molecular Biology	5	Pharmacology, Toxicology and Pharmaceutics	1
Earth and Planetary Sciences	5		

Table 6: Subject area-wise publications

Source: [www.scopus.com](http://www.scopus.com) (retrieved on 7<sup>th</sup> November 2020)

### 3.5 Institutional analysis

The bar graph in Fig. 7 shows the performance by institutions towards the contribution of research work in the field of biomimicry. The Victoria University of Wellington, in New Zealand, has the highest number of publications (4), making it the most productive institution in the concerned field of research. Universiti Sains Malaysia, in Malaysia, and McGill University, in Canada have 3 publications, each, while a whole host of institutions have either 1 or 2 publications. There is a wide spread of countries among the list of the top 15 institutions that have carried out research in the field of biomimicry.

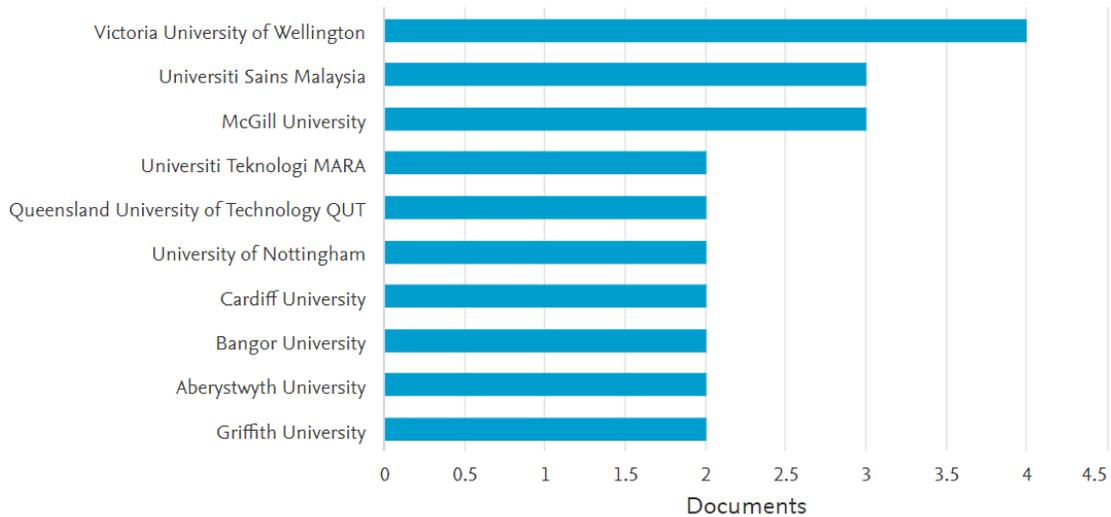


Fig. 7: Institution-wise publications in the field of biomimicry  
 Source: [www.scopus.com](http://www.scopus.com) (accessed on 7<sup>th</sup> November 2020)

#### 4. CITATION ANALYSIS

Table 7 shows the distribution of citations between the years 2010 and 2021 in the field of biomimicry. As of 7<sup>th</sup> November 2020, the total citation count was 716. The table shows that in the year 2020, there were 196 citations related to biomimicry (27.3%), the highest recorded number of citations between the years 2010 and 2021.

Table 7: Citation details of publications related to biomimicry  
 Source: [www.scopus.com](http://www.scopus.com) (retrieved on 7<sup>th</sup> November 2020)

Year	<2015	2015	2016	2017	2018	2019	<b>2020</b>	>2020	TOTAL
Number of citations	61	49	43	110	94	159	<b>196</b>	4	<b>716</b>

Table 8 shows the list of the top 5 publications with the highest number of citations in the field of biomimicry. The publication “Nanotechnology: Advantages and drawbacks in the field of construction and building materials” has the highest number of citations related to biomimicry with a total number of 280 (39.1%).

Table 8: Top 5 most cited publications  
 Source: [www.scopus.com](http://www.scopus.com) (retrieved on 7<sup>th</sup> November 2020)

Rank	Year	Document Title	Authors	Journal Title	Total Citations
1	2011	Nanotechnology: Advantages and drawbacks in the field of construction and building materials	Pacheco-Torgal F., Jalali S.	Construction and Building Materials	280
2	2017	The bio in the ink: cartilage regeneration with bioprintable hydrogels and articular cartilage-derived progenitor cells	Levato R., Webb W.R., Otto I.A., Mensinga A., Zhang Y., van Rijen M., van Weeren R., Khan I.M., Malda J.	Acta Biomaterialia	107
3	2015	Biomimetics: Forecasting the future of science, engineering, and medicine	Hwang J., Jeong Y., Park J.M., Lee K.H., Hong J.W., Choi J.	International Journal of Nanomedicine	39
4	2012	A model based on Biomimicry to enhance ecologically sustainable design	Gamage A., Hyde R.	Architectural Science Review	38
5	2017	How plants inspire façades. From plants to architecture: Biomimetic principles for the development of adaptive architectural envelopes	Lopez M., Rubio R., Martin S., Ben Croxford	Renewable and Sustainable Energy Reviews	35

## 5. NETWORK ANALYSIS USING CLUSTERING

The network analysis was performed using the VOSviewer software, which is an open source software. VOSviewer is a software that can be used for constructing and visualizing the bibliometric networks. A cluster may be termed as a set of closely related nodes, and a single network may consist of several thousands of nodes. In this section, an analysis of citations is carried out using cluster diagrams for citation statistics as per sources, authors and countries of publications.

## 5.1 Citations by sources

Fig. 8 shows the relationship between publication sources and citations in the form of network visualization. The size of the node represents the relative node, meaning that the largest node has the highest number of publications. The publication titled “Renewable and sustainable energy reviews” has the highest number of citations at around 61. The same publication has a total link strength of 5, indicating the total number of times the publication is cited by the 61 journals.

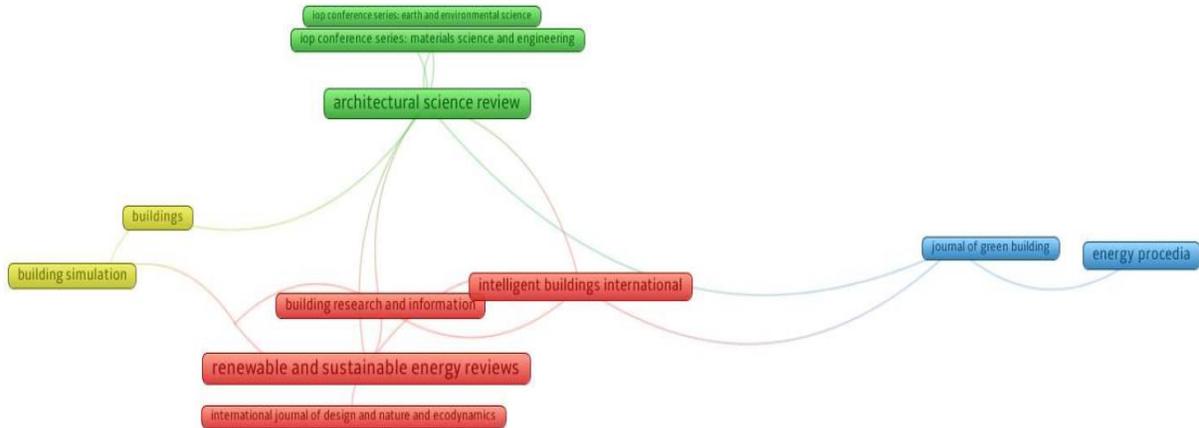


Fig. 8: Source-citation network visualization  
Source: VOSviewer software (created on 8<sup>th</sup> November 2020)

## 5.2 Citations by authors

Fig. 9 shows the relationship between publication authors and citations in the form of network visualization. The cluster network shows that Gamage, A. has the highest number of citations with 38, meaning that 38 different authors have cited publications by Gamage, A. The same author has a total link strength of 25, indicating the total number of times the author’s publications have been cited by 38 authors.

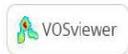
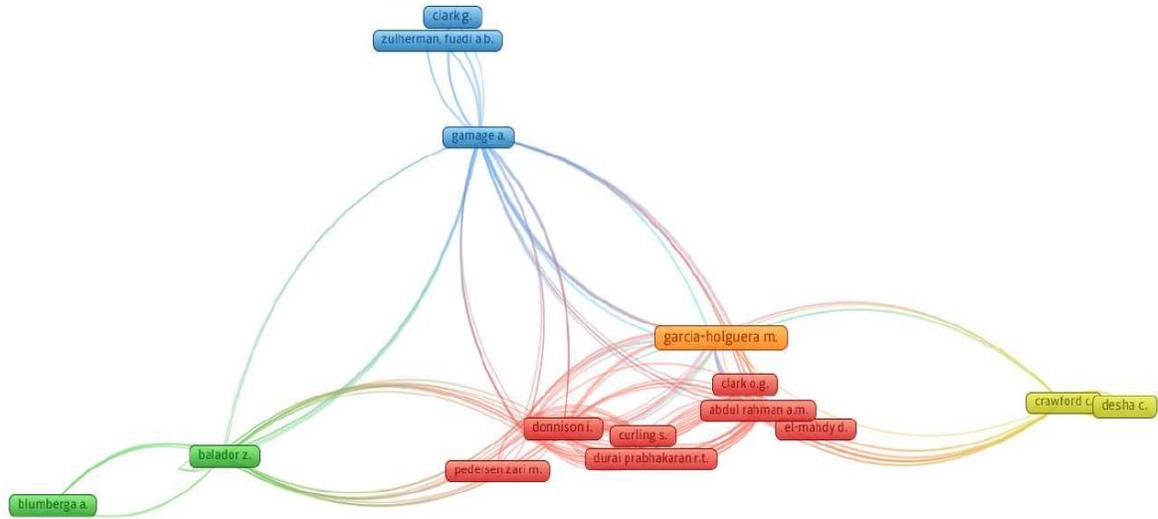


Fig. 9: Author-citation network visualization  
 Source: VOSviewer software (created on 8<sup>th</sup> November 2020)

### 5.3 Citations by countries

Fig. 10 shows the relationship between publication countries and citations in the form of an overlay visualization with the average publications per year by the countries. The color of the node is based on the year of citation, with a blue node representing publications cited in 2015 and yellow nodes representing publications cited in 2020. The United Kingdom has the highest number of citations of 175. The total link strength is 6, meaning that publications in the United Kingdom have been cited 6 times.

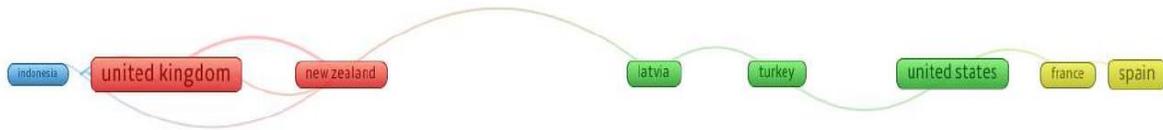


Fig. 10: Country-citation overlay visualization  
 Source: VOSviewer software (created on 8<sup>th</sup> November 2020)

## 6. LIMITATIONS OF THE PRESENT STUDY

For the purpose of this research, the main focus is given only to the Scopus database. Therefore, papers which are not part of the Scopus database have not been included in this analysis. This research paper includes publications only in English language. The study explores the Scopus database using a combination of various keywords, and the combination which yielded maximum results have been used for the analysis. The search has been restricted to keywords related only to article title, abstract and keywords; results outside this search field have not been included in this research paper.

## 7. CONCLUSION

The concept of biomimicry is a relatively new one, and there has been very limited research conducted in this field. However, the growing trend in number of publications in recent years does prove that there is considerable amount of research taking place in the field of study. This proves the necessity of biomimicry in the modern world, and because of the issues the world is facing, architects and designers are looking to nature as a model and a mentor. Analysis of the Scopus database showed that significant contributions to research in the field of biomimicry has taken place in countries such as the United States, United Kingdom and Australia, among others. The Victoria University of Wellington, in New Zealand, among other institutions, has the highest number of publications in the domain. It was also observed that maximum research was carried out in the engineering sector, followed by the materials science subject area.

With such limited results, it became clear that there is a need for more research in the field of biomimicry. Nonetheless, the growing trend since 2017 shows that there are positive results and research work in this field is increasing. Biomimicry, if implemented properly, can solve problems related to thermal regulation, energy efficiency and sustainable designs, and a number of research papers have proved this. For upcoming research work, there is a huge scope for studies in the field of biomimicry, especially in the engineering and materials science sectors.

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