Research trend on sustainable architecture: a bibliometric analysis emphasizing on building, material, façade, and thermal keywords

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Abstract. Studies about sustainable research remain increase recently due to the global trend and movement on greener lifestyles. Keywords on building, material, façade, and thermal represent the current issue in sustainable architecture. This study aims to trends in sustainable architecture research with specific keywords and periods. Publishing period between 1976-2020 with particular limitation applied to emerge 859 publication documents to be analyzed. Scopus’ on-site analysis system and VOSviewer were employed to generate graphical and visual analysis on research trends. The analysis results generate five significant research clusters: energy, façade technology, measurement, thermal, and climate. Besides groups, the analysis also indicates that most of the countries involved were from Europe. Hence, the conclusion of this study reveals potential research on a similar topic in tropical countries which demanding sustainable building encounters a humidity challenge. This study fills the gap in the bibliometric analysis regarding sustainable architecture with specific keywords and publishing period.

1. Introduction
The high demand for green building concepts brings a new environmentally-friendly culture to the construction industry. The government and stakeholders are expected to take this issue seriously and commit to everlasting sustainable construction to establish a better environment, social, and economic [1]. Complex decision yet thoughtful design to the environment is enormously required to address the sustainable living standards [2]. In research about the interpretation of sustainable building, Berardi [3] clarifies a building predicated as a sustainable building if it contributes whole sustainability domains holistically. However, the green building movement with all those promising benefits, in any case, finds difficulties in realizations, particularly in developing countries. Lack of information, unclear regulation, and insufficient marketing strategies for green products lead to sluggish green building movement in developing countries [4]. Hence, the government and the green building council should encourage stakeholders to promote the concept through certification, regulation, and reward [5].

Pertain to the green building; the material is the inseparable part that contributes to establishing sustainability. The research discussed the contribution of material to promote green building with earthy material usage [6]. The expedient in material usage also considerably reduce the waste material; thus, it is an addition to promote sustainability in material aside from earthy material [7]. The involvement of recent technology, Building Information Modelling (BIM), supports the sustainability in material usage [8] that comprises information on volumes and material selected for each element in building [9], and waste management support [10]. Materials are also entangling to the greenhouse effect, which
possibly caused increasing energy consumption and gas emission; thus, green roofs and facades are designated solutions to mitigate the building from harm impact to environment [11]. Glass as typical material for highrise building enveloped wall facade feasible contributes to causing waste energy effect. Some issues addressing glass envelope walls comprise poor insulation and rely on artificial ventilation [12].

Hence, the envelope wall as a highrise building façade is always appealing to research. To prevent the thermal transfer but remain the glass as envelope wall is a challenge for architects. Such tricky actions to obtain thermal comfort encompass double layer wall glass with sure angled sun blinds and air-circulated space between [13]. Meanwhile, wall materials remain updated with the latest technology and formula to prevent the thermal transfer, such as glazing and glass prismatic [14]. Research regarding building, material, façade, and thermal shown desired theme to study. Thermal comfort, heat transfer mitigation building, and pursuing a better environment are the purpose of those research, and the trend of this research will remain updated in the future. Bibliometric analysis is legal research using big data on Scopus, Web Science, Dimensions, or PubMed.

Keywords mentioned above in the title are about the architectural or construction industry. Li et al. [15] illustrated two-decade publications about green building sourced from the Web of Science core collection database. Their research revealed that thermal comfort and natural ventilation are appealing issues for green building themes [15]. Lima et al. [16] conducted a bibliographic analysis using VOS Viewer to generate potential future research regarding the construction industry. Analyzing big data from literature databases is fruitful to bridge historical gaps, understand the research evolution, and predict future research [15,16]. Then, this research aims to generate a mapping and visualized research regarding the keywords building, material, façade, and thermal in the Scopus database. Thus the outcome of the research enables future researchers to envision the potential and intense research theme.

2. Methodology

This study employs bibliometric analysis to provide knowledge mapping and visualize the maps graphically [17]. Bibliometric analysis likewise illustrated the geographical source and identified leading authors and affiliations involved in particular research keywords [18]. The supply of data uses in the study acquired from Scopus comprises citation information, abstract, and keyword. A preliminary step uses four keywords determined by authors during the colloquizing process and explores the Scopus database using the following keywords: building, material, façade, and thermal. The keywords utilized are explained in the introduction chapter, which are imperative keywords for current research in sustainability in the modern urban life of architecture. Scopus database reveal 984 document results in search of those keywords accessed on June 13, 2021. The number of documents exposed encompasses publications from 1976-2021, numerous subject areas, various source types, and two final publication stages.

The exclusion sets limit the documents before exporting the data for meta-analysis purposes. The limitation (L) encompass year (L1), subject area (L2), publication stage (L3), and language (L4) (table1). After searching and screening the document results, the data are exported to the CSV Excel file, including citation information and abstract & keywords. Thus, CSV Excel file extracted processed using VOSViewer to generate meta-analysis of 859 publications. The employment of VOSViewer allows the researchers to understand the meta-analysis visually by presenting label view, density view, cluster density view, and scatter view [19].

| Limitation criteria | Limitation | Information |
|---------------------|------------|-------------|
| L1: Year            | 1976 - 2020| Completed year |
| L2: Subject area    | Engineering, Energy, Material science, Environmental Science, Social sciences, Physic and astronomy, Computer Science, Earth and Planetary | Correlation to the keyword |

Table 1. Data exclusion.
3. Result and discussion

3.1. Publications: year, subjects, & publishers
Total 859 publications from 1976-2020 are selected to undergo analysis based on annual trends. Scopus Analysis program can generate graphics and charts based on annual publish trend, subject area involvement, most shown countries, and most active publishers pertain to that keywords. 1976 as the first year of publication based on the keywords, it shows a consecutively increase annually. The first two decades of research in this realm show stagnant numbers, then an increase in the third decade in 2006. In 2006, researchers began to consider the impact of material on the environment, and then the outcomes were material innovation, building skins, and climatic buildings [20,21,22]. Thus, 2018 was the peak of the curve and capped 118 publications with that four keywords. In the Year 2018, the researches went more complex and were argue specific material. It is exemplified by Bedon (2018) work, which revealed glass innovation for façade, and obtained the most cited document outright [23].

Nevertheless, in the following years, the number of publications was lessened insignificantly (figure 1). Actually, in the middle of 2021, the publications along 2021 capped 68 documents. TTt indicates that publications in the whole year of 2021 possibly reach a higher amount than in 2018. According to the area of the research publication with four keywords found in Scopus, table 2 indicates engineering possesses the most subject followed by energy, material science, and environmental science. Table 3 shows that Energy and Building is the journal most regarding this research area, looking at the screened documents.

![Figure 1. Documents by year.](image)

| Subject                        | Percentage |
|--------------------------------|------------|
| Engineering                    | 35.6 %     |
| Energy                         | 15.3 %     |
| Material Science               | 12.8 %     |
| Environmental Science          | 11.0 %     |
| Social Sciences                | 4.8 %      |
| Physics and Astronomy          | 3.8 %      |
| Computer Science               | 3.7 %      |
| Earth and Planetary            | 2.8 %      |

Table 2. Documents by subject area.
### Subject and Percentage

| Subject                  | Percentage |
|-------------------------|------------|
| Chemistry               | 2.3 %      |
| Chemical Engineering    | 2.2 %      |
| Other                   | 5.8 %      |

#### Table 3. Most published journals/proceedings.

| Journal/Proceeding Name                          | Total documents |
|-------------------------------------------------|-----------------|
| Energy and Buildings                             | 81              |
| Energy Procedia                                  | 40              |
| Solar Energy                                     | 31              |
| IOP Conference Series Material Science and Engineering Building and Environment | 22              |
| Advanced Materials                               | 20              |
| Applied Energy                                   | 18              |
| Sustainability Switzerland                       | 16              |
| Matec Web of Conferences                         | 15              |
| E3s Web of Conferences                           | 14              |

#### 3.2. Countries involvement in research

European countries dominated the ten most occupied countries in research about those four keywords. China and the US were the only country outside the European continent that belong to ten. Italy leads the highest involved country equipped with 121 research documents on Scopus. Researches in Italy are mainly focusing on the achievement of thermal comfort in building by the utilization of vegetation, natural ventilation, and material innovation [24,25,26]. Meta-analysis through VOSViewer presents the network between countries involved in research with keywords: building, material, façade, and thermal. Thresholds with a minimum of 5 documents of a country with no minimum number reveal 75 countries, and 44 meet thresholds (figure 3). The visual result (figure 3) of VOSViewer shows slightly similar data as a chart (figure 2). Italy holds the most prominent among 44 countries. Visualization in VOSViewer measures the strength of the link; hence the UK possesses the second most prominent, followed by Germany and Spain. This tool also visualizes countries’ entanglement in this research is broader, and various encompasses four continents. Analysis using VOSViewer correspondingly penetrate in period 2006-2020 (figure 4). The first period is set to 2006 due to the first milestone of higher documents in 3 decades since 1976. Blue dots indicate the participation of countries during 2006-2010. Germany leads this early research trend, followed by Brazil, Finland, and Saudi Arabia. Year-round 2015 indicated by the green dot, retained by most countries, comprises Italy, the UK, Spain, and the US. Thus recent countries involvement in the premise is Malaysia, Croatia, Canada, and Cyprus.

![Figure 2. Documents by country.](image-url)
3.3. **Keyword analysis**

Author keyword applies in this study to recognize the relation between keywords and indicates the clusters. This analysis requires five minimum number of occurrences of a keyword. Thus, VOSviewer visualizes 74 thresholds (figure 5). Meta-analysis of selected Scopus documents generates 9 clusters indicated by different colours. Manual labelling is required to designation the clusters based on the items contained (Table 4). Five clusters indicated the most influential cluster and have inter-cluster linkage. The prominent cluster is red, labelled as **energy**, possess the most keyword in the research area. Energy efficiency holds the hottest item in this label and broadest linkage area outright—energy efficiency is tightly associated with thermal concerns, façade, and material. The second cluster, the green dots labelled as **Façade Technology**, contains façade and shading innovations to mitigate heat transfer. The blue dots, the third cluster labelled as **measurement** because of assessment and simulation contained. Fourth, cluster the yellow dots labelled **Thermal** since they are closely associated with natural ventilation and thermal comfort. The fifth cluster is purple dots labelled as **climate** as a consequence of urban heat island is the main issue in this cluster.
Table 4. VOSviewer cluster indicators.

| No | Colour | Label name | Contain |
|----|--------|------------|---------|
| 1  | Red    | Energy     | Building façade  
|    |        |            | Buildings  
|    |        |            | Embodied energy  
|    |        |            | Experimental  
|    |        |            | Life cycle assessment  
|    |        |            | Moisture  
|    |        |            | Monitoring  
|    |        |            | Optimization  
|    |        |            | Phase change material  
|    |        |            | Phase change materials  
|    |        |            | Sustainability  
|    |        |            | Thermal energy storage  
| 2  | Green  | Façade technology | Computational fluid dynamics  
|    |        |            | Double skin façade  
|    |        |            | Etics  
|    |        |            | Façade  
|    |        |            | Facades  
|    |        |            | Heat transfer  
|    |        |            | Insulation  
|    |        |            | Shading devices  
|    |        |            | Thermal conductivity  
|    |        |            | Thermal insulation  
| 3  | Blue   | Measurement | Building simulation  
|    |        |            | CFD  
|    |        |            | Double skin façade  
|    |        |            | Energyplus  
|    |        |            | Numerical simulation  
|    |        |            | PCM  
|    |        |            | Thermal mass  
|    |        |            | Ventilated façade  
| 4  | Yellow | Thermal | Curtain wall  
|    |        |            | Energy consumption  
|    |        |            | Energy storage  
|    |        |            | Materials  
|    |        |            | Natural ventilation  
|    |        |            | Phase change materials  
|    |        |            | Simulation  
|    |        |            | Thermal comfort  
|    |        |            | Thermal energy storage  
| 5  | Purple | Climate | Building envelope  
|    |        |            | Building materials  
|    |        |            | Cool materials  
|    |        |            | Cool roof  
|    |        |            | Durability  
|    |        |            | Solar reflectance  
|    |        |            | Temperature  
|    |        |            | Urban heat island  

3.4. Documents & authorship.
This study includes the most cited documents on Scopus, indicating the most influential documents in this scope (Table 5). Of the 859 documents, this paper presents the 5 most influential documents about phase change material, green façade, ceramic material, life cycle assessment, and energy building simulation [27,24,28,29,30]. Several most influential authors are pointing to understand their expertise
for this research area. Scopus analysis indicates the top 10 authors in this research scope (Table 6). Authors belong to the list signify their frequent in this research area based on documents they published on Scopus.

**Table 5.** Most cited documents.

| Authors               | Document Title                                                                 | Cited by | Author Keywords                          |
|-----------------------|-------------------------------------------------------------------------------|----------|------------------------------------------|
| Huang et al. (2004)   | Thermal regulation of building-integrated photovoltaics using phase change materials | 299      | Building integration                     |
|                       |                                                                                 |          | Phase change material                    |
|                       |                                                                                 |          | Photovoltaics                            |
|                       |                                                                                 |          | Thermal control                          |
| Perini et al. (2011)  | Vertical greening systems and the effect on airflow and temperature on the building envelope | 237      | Airflow                                  |
|                       |                                                                                 |          | Energy savings                           |
|                       |                                                                                 |          | Façade greening                          |
|                       |                                                                                 |          | Living wall systems                      |
|                       |                                                                                 |          | Sustainability                           |
|                       |                                                                                 |          | Temperature                              |
| Martin-Marquez et al., (2008) | Effect of firing temperature on sintering of porcelain stoneware tiles | 157      | Sintering                                |
|                       |                                                                                 |          | Technological properties                 |
|                       |                                                                                 |          | Porcelain stoneware                      |
|                       |                                                                                 |          | Functional applications                  |
| Nemry et al. (2010)   | Options to reduce the environmental impacts of residential buildings in the European Union-Potential and costs | 154      | Environmental impacts                    |
|                       |                                                                                 |          | European Union                           |
|                       |                                                                                 |          | Improvement options                      |
|                       |                                                                                 |          | Life cycle assessment                    |
|                       |                                                                                 |          | Reduction potential                      |
|                       |                                                                                 |          | Residential buildings                    |
| Chan et al. (2009)    | Investigation on the energy performance of double skin façade in Hong Kong   | 127      | Building energy simulation               |
|                       |                                                                                 |          | Double skin façade                       |
|                       |                                                                                 |          | EnergyPlus                               |
|                       |                                                                                 |          | Payback period                           |

**Table 6.** Top 10 authors in the research area.

| Name                  | Documents | Most Published Topics                      |
|-----------------------|-----------|--------------------------------------------|
| Cabeza, L.F.          | 13        | Phase change material                      |
|                       |           | Heat storage octadecane                    |
| Cekon, M              | 10        | Zero energy building                       |
|                       |           | Refurbishment                              |
|                       |           | Renovation                                 |
| Castell, A.           | 9         | Phase change material                      |
|                       |           | Heat storage octadecane                    |
| Heim, D.              | 8         | Phase change material                      |
|                       |           | Heat storage octadecane                    |
| Zinzi, M.             | 7         | Heat Island                                |
|                       |           | Reflective coatings                        |
|                       |           | Albedo                                     |
| Athienitis, A.        | 6         | Solar collectors                           |
|                       |           | Phase change materials                     |
|                       |           | Photovoltaic system                        |
| De Gracia, A.         | 6         | Phase change material                      |
|                       |           | Heat storage octadecane                    |
| Gagliano, A.          | 6         | Zero energy building                       |
|                       |           | Refurbishment                              |
| Navarro, L.           | 6         | Phase change material                      |
|                       |           | Heat storage                               |
4. Conclusion

Admittedly, research regarding building, material, façade, and thermal attainment is familiar in current global warming issues. Those four keywords emerge as European countries as the countries most involved in this research area. Tropical countries correspondingly encounter the global warming issue but lack participation in these research areas. Meta-analysis refers to energy, façade, measurement, thermal, and climate as entitled clusters and consists of various items of research keywords. The cluster of energy focuses on less energy mitigation through material selection, energy storage and embodiment. Façade technology cluster represents research products to establish indoor comfort through eco-friendly façade material, shading device, and natural ventilation support. Measurement cluster highlighting building simulation program and direct indoor measurement. While thermal cluster emphasizes thermal comfort, and lastly, climate cluster stresses external building material and ecological issues. Unfortunately, none of the significant authors with high cited documents conduct their research in tropical countries. Hence, this study asserts the research gap and potential to research this scope in tropical countries where humidity is challenging to establish a sustainable building.

References

[1] Ortiz O, Castells F and Sonnemann G 2009 Constr Build Mater 23(1) 28
[2] Ding GKC 2008 J Environ Manage 86(3) 451
[3] Berardi U 2013 Sustain Cities Soc 8 72
[4] Wimala M, Akmalah E and Sururi MR 2016 Energy Procedia 100 469
[5] Berawi MA, Miraj P, Windrayani R and Berawi ARB 2019 Heliyon 5(3) 1
[6] Niroumand H, Zain M F M and Jamil M 2013 Renew Sustain Energy Rev 28 130
[7] Darko A, Zhang C, and Chan A P C 2017 Habitat Int Feb 1(60) 34–49
[8] Wong J K W and Zhou J 2015 Autom Constr 57 156
[9] Cheng J C P and Ma L Y H 2013 Waste Manag 33(6) 1539
[10] Wang J Y, Touran A, Christoforou C and Fadlalla H 2004 Waste Manag 24(10) 989
[11] Besir A B and Cuce E 2018 Renew Sustain Energy Rev 82 915
[12] Al-Kodmany K 2014 Buildings 4(4) 683
[13] Kong X, Liu S, Yang H, Zhong Y and Qi C 2016 Build Environ 97 166
[14] Sourek B, Jirka V, Shemelin V and Matuska T 2017 Sol Energy 158 440
[15] Li Y, Rong Y, Ahmad U M, Wang X, Zuo J and Mao G 2021 Environ Sci Pollut Res 28 46196
[16] Lima L, Trindade E, Alencar L, Alencar M and Silva L 2021 J Clean Prod 289 125730
[17] van E N J and Wältman L 2010 Scientometrics 84(2) 523
[18] Boquera L, Castro J R, Pisello A L and Cabeza LF 2021 J Energy Storage 38 102562
[19] Cobo M J, López-H A G, Herrera-V E and Herrera F 2011 J Am Soc Inf Sci Technol 62(7) 1382
[20] Mallick T K, Eames PC, and Norton B 2006 Sol Energy 80(7) 834
[21] Hasselaar B L H 2006 WIT Trans Ecol Environ 99 351
[22] Palero S, San J C, Enríquez R, Ferrer J A, Soutullo S, Martí J, et al 2006 Conf Proc (Geneva: PLEA)
[23] Bedon C, Zhang X, Santos F, Honfi D, Kozłowski M, Arrigoni M et al 2018 Constr Build Mater 163 921
[24] Perini K, Ottelé M, Fraaij A L A, Haas E M and Raiteri R 2011 Build Environ 46(11) 2287
[25] Ciampi M, Lecceese F and Tuoni G 2003 Sol Energy 75(6) 491
[26] Rossi F, Castellani B, Presciutti A, Morini E, Filipponi M, Nicolini A, et al 2015 Appl Energy 145 8
[27] Huang M J, Eames P C and Norton B 2004 Int J Heat Mass Trans 47(12) 2715
[28] Martín-M J, Rincón J M and Romero M 2008 Ceram Int 34(8) 1867
[29] Nemry F, Uihlein A, Colodel CM, Wetzel C, Braune A, Wittstock B, et al 2010 Energy Build 42(7) 976

[30] Chan A L S, Chow T T, Fong K F and Lin Z 2009 Energy Build 41(11) 1135