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# TREND OF SOUND ABSORPTION RESEARCH: A BIBLIOMETRIC ANALYSIS

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**Abstract**

The growing world population and urbanization have worsened noise pollution, driving the development of sound absorption (SA) research across the globe. This study aims to analyse the SA global research trends and discover the opportunities for future development or collaboration using systematic bibliometric analysis. A total of 2970 articles since 1913 were systematically retrieved. Results reveal that the most productive journal had taken 10.3 % of the total publications. A high correlation $r$ = 0.87 was found between the number of co-authorship and the h-index of a scholar. China has the highest number of publications 55.3 % and most research focused on porous materials. Present findings could be helpful to further develop SA from a global level perspective.

**Keywords:**

Acoustic absorber;
Bibliometric analysis;
Material parameters;
Sound absorbing materials;
Noise.

## 1 Introduction

Noise is generally known as an unpleasant sound that causes a disturbance or demonstrates psychological and physiological issues. Many types of ambient noise, such as industrial and traffic noises [1], are endangering the human body by causing hearing loss, stress, sleep disturbances [2], pain, mental disorders, cardiovascular disease and social cohesion [3]. In accordance with the universal call to action to achieve the Sustainable Development Goal (SDG) for good health and well-being, noise reduction is extremely crucial nowadays as the world's population grows and urbanization increases.

A well-known noise reduction method is the utilization of sound-absorbing materials, which is becoming increasingly popular among research community [4]. In particular, numerous studies have been conducted on developing more sustainable sound absorbing materials [5] and the identifying the of close related parameters to sound absorption for numerical simulation [6]. Sound absorption (SA) is achieved by transforming the kinetic energy of a sound wave into heat energy when it passes through a polymeric material. The process is schematically shown in Fig. 1 for better understanding. While propagating from air into an absorbing material, the sound wave could experience reflection or absorption, thereby loses energy.

Investigation on SA requires a systematic bibliometric analysis to obtain an overview of the field development, identify the research trend, discover the opportunities for future collaboration and reveal the gaps from past research work. In this sense, this study aimed to:

- assess the publication evolution on SA,
- classify the journals that published the most SA articles,
- identify significant authors and their collaboration network,
- display the global distribution of SA research and related factors,
- identify the most common SA materials and parameter measurements in SA research.

The findings of this study, when seen as a whole, are essential in the context of expanding research and development of SA.

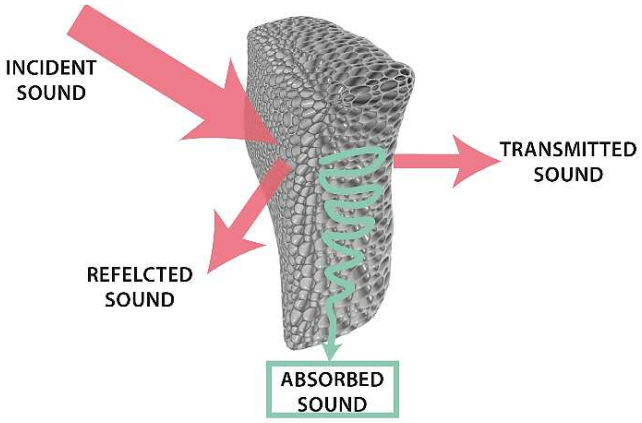


Fig. 1: Mechanism of sound absorption.

## 2 Methodology

### 2.1 Data source

Bibliometric analysis is a statistical and mathematical analysis of publications to present the state of art for a particular field. Generally, there are several popular databases including Scopus, Web of Science, Google Scholar and PubMed applied for bibliometric analysis. Among all, Scopus was claimed the “largest single abstract and indexing database ever built”, comprising 27 million abstracts with citations back to 1966 [7]. Researchers also stated that Scopus contains the largest collection of quality peer-reviewed papers with broader bibliometric reach and the most up-to-date information than Web of Science [8]. As a result, the dataset applied in this study was Scopus in regard to its broadest coverage of any interdisciplinary abstract and citation database.

### 2.2 Search strategy

The search field of Scopus consists of author, article title, abstract, keywords, affiliation, funding information, reference, etc. Note that the present study focuses on sound absorption research thus the search field - keywords - was mainly utilized. The keywords that were identified closely related to sound absorption are “noise* absor*” OR “sound* absor*” OR “acoustic* absor*” OR “sound absorption coefficient*” OR “noise reduction coefficient*”. These keywords were applied with Boolean operators, quotation marks, wildcards, and query sets in three search fields, i.e. title, abstract, and keyword. This was done to avoid omissions and to cover as many documents as possible related to SA. As a result, a total of 10,273 publications had been identified from 1913 up to 13 March 2021. To ensure the quality of the article and prevent further analysis on secondary data such as review paper, the result was refined to 6,367 by limiting to only journals as source type and only primary data research article as the document type. Proceedings or conference papers which are not secondary data are included in this study as well to overview the trend more accurately.

The results were further screened to restrict the output to only primary data research articles. Additional phrases such as “recent, progress, review, critical, revisit, advance, highlight, perspective, prospect, trends, bibliometric, and scientometric” were added in the title query string whilst “progress, review, bibliometric, and scientometric” were added in the abstract query string to exclude all concealed review articles. The abstract and full-text screening were also done manually to assure high accuracy. Eventually, a total of 159 review articles were identified and removed. The data was then limited to only ten years from 2011 to 2020 to focus on the trendiest SA research development trend since there was a dramatic increase over the ten years period. Overall, the systematic flow of collecting and screening data is illustrated in Fig. 2.

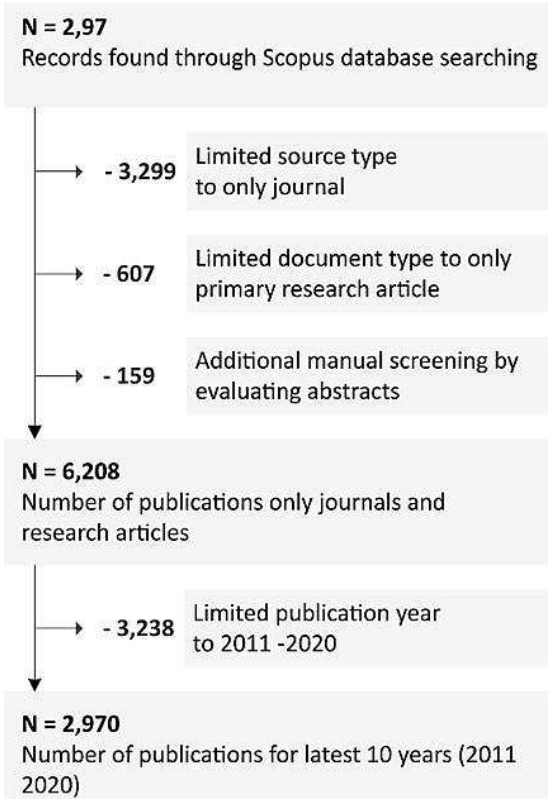


Fig. 2: Systematic flow of data collection and screening.

### 2.3 Principle of data interpretation

The research trend of SA with the year of publication for each article was analyzed based on the 6,208 results retrieved from 1913 to 2020. The results were further analyzed by comparing the year of publication for the top ten most cited articles. Afterwards, the finalized 2,970 articles were investigated and extracted desired information to achieve the specific objectives as follows:

a) To determine the leading journals in the SA field with their number of articles published in each journal. Additional information for selected journals such as citations number of selected articles, journals' Scopus CiteScore 2019, publishers and the most cited article were discussed.

b) To identify the top ten highest contributing researchers with most publications on SA. Related information that had been extracted included the year of first publication, total publications, total citations, h-index, current affiliations, countries, and co-authorship numbers. Pearson correlation test was conducted to determine the mutual relationship between publication numbers and relevant information. Additionally, the collaborations among the ten most productive authors were illustrated in a bibliometric map using VOSviewer and the connecting links for selected authors were discussed.

c) To investigate the performance of SA research based on the number of publications by country. For multiple countries' publications, only the first author's country was considered. Continents, multiple countries publication ratio, gross domestic expenditure on R&D (GERD), R&D personnel numbers, publication growth from 2011 to 2020 were extracted from additional sources. To examine the factors affecting publication numbers on SA, the Pearson correlation test was conducted. Besides, a bibliometric map was also plotted to elucidate explicitly the countries' collaborations based on the co-authorship of shortlisted articles.

d) To study the recent research trend on SA using 6,041 extracted author keywords from the Scopus database in which 220 (3.64 %) keywords with at least five re-occurrences. A bibliometric map was plotted via VOSviewer based on the selected keywords. In order to examine the trend specifically, the author keywords have been filtered into two significant groups: materials and parameter measurements that are often associated with SA study. A comprehensive discussion was made to investigate further the relationship between the most encountered keywords and sound absorption.

## 3 Result and discussion

### 3.1 Publication growth

A plot of publication number versus year in SA research is shown in Fig. 3. Over 108 years since 1913, a total of 6208 research articles had been published in the SA field. The exponential growth can be segregated into three phases:

- phase 1 (1913 - 1969),
- phase 2 (1970 - 2005),
- phase 3 (2006 - 2020).

In phase 1, the growth was considerably slower, with only 374 publications in 57 years (8 publications averagely per year). The average number of citations to papers was only 12.7. The oldest publication, "A direct method of finding the value of materials as sound absorbers," was dated 1913 [9], which mainly emphasized the theoretical basis of the sound absorption coefficient for different materials. The slow development during this period was mainly attributed to low demand for SA material in general.

From 1970 to 2005 (phase 2), the number of publications reached 2108 within 36 years (58.6 publications averagely per year). The trend is undoubtedly a sudden increase, although the annual number of publications fluctuated between 35 and 91. Among all SA articles, “Transfer function method of measuring in-duct acoustic properties. I. Theory” [10] was cited the most (cited by 715 articles). This paper proposed a mathematical method to decompose random acoustic waves into the incident and reflected waves. In addition, among the top ten most cited articles (Table 1) between 2011 and 2021, 70 % were published between 1970 and 2005. This increment is evident that a breakthrough had been achieved at this period to develop impactful fundamental knowledge.

A steep climb in SA publication can be observed from 2006 to 2020 (phase 3) in Fig. 3a. Within 15 years, a total of 3608 publications had been published (240.5 publications averagely per year). Compared to the previous phase, the recorded annual publication has increased more than 400 % and is expected to increase further after 2020 due to more emphasis on SA. This scenario has been attributed to the growing population and increasing awareness of a more comfortable and healthier living environment free from noise pollution. This emerging trend has become even more prominent after the introduction of Sustainable Development Goals (SDGs) by the United Nations.

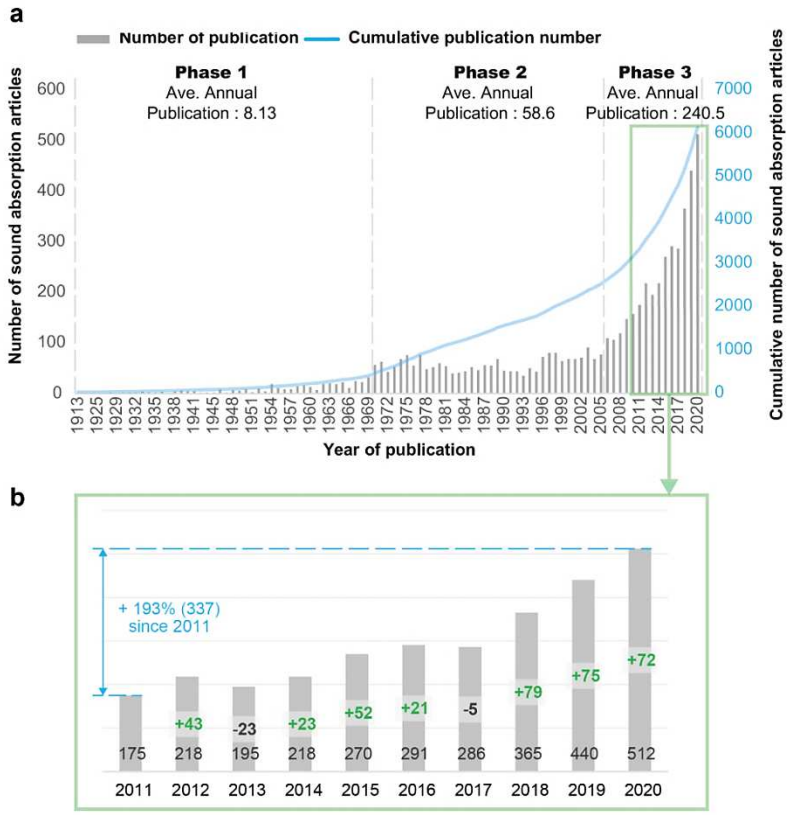


Fig. 3: Publication trend per year for SA from: a) 1913 – 2020; b) 2011 – 2020.

Since the primary intention of this study is to analyze the trendiest research development, a total of 2970 trendiest articles from the year 2011 to 2020 were shortlisted from 6208 articles. As an overview in Fig. 3b, the increase in publications was 193 % from 2011 to 2020 and peaked in 2018. This trend has been associated with an improvement in the standard of living, evident through a GDP growth of 2.9 % [11] and an increase in urban population (The World Bank, 2018) that emphasizes sustainable development [12]. This period is undeniably the most interesting in SA research development. As such, the following section will focus on the research that was conducted between 2011 and 2020.

Table 1: Top 10 most cited articles in SA research.

| Rank | Citations | Year | Title |
|---|---|---|---|
| 1st | 715 | 1980 | Transfer function method of measuring in-duct acoustic properties. I. Theory |
| 2nd | 680 | 1998 | Potential of microperforated panel absorber |
| 3rd | 527 | 2014 | Ultralight nanofiber-assembled cellular aerogels with superelasticity and multifunctionality |
| 4th | 465 | 1972 | On the ultrasonic attenuation in glasses at low temperatures |
| 5th | 385 | 1997 | Dynamic compressibility of air in porous structures at audible frequencies |
| 6th | 377 | 1982 | Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption |
| 7th | 359 | 1992 | Interaction of soft modes and sound waves in glasses |
| 8th | 352 | 2008 | Mechanical properties of concrete containing a high volume of tire-rubber particles |
| 9th | 304 | 2016 | Acoustic metasurface-based perfect absorber with a deep subwavelength thickness |
| 10th | 304 | 1986 | Laser generation of acoustic waves in liquids and gases |

### 3.2 Distributions of articles fields and top journals ranking

Based on the latest 10 years data, the selected articles have been published in 26 fields, as shown in Fig. 4. The most popular research fields are “Physics and Astronomy”, “Engineering” and “Materials Science”, which took up 25.4 %, 24.7 %, and 18.2 % respectively. These three topics covered 68.3 % of the total publications, while the remaining publications 31.7 % were evenly distributed among 23 fields, with each taking less than 5 %. These articles were published in 160 different journals. The top 10 journals with the highest number of publications based on the selected articles were summarized in Table 2. Out of the ten journals, three journals were published by Elsevier while the rest were the Acoustical Society of America; the American Institute of Physics; the Polish Academy of Sciences; the Institute of Noise Control Engineering; the Hirzel Verlag, Multidisciplinary Digital Publishing Institute (MDPI); and the Zhongguo Zhendong Gongcheng Xuehui.

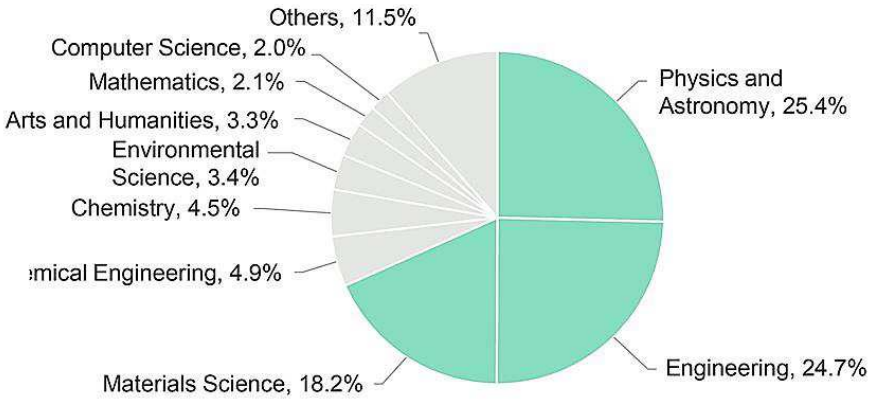


Fig. 4: Distribution of academic discipline that involved SA.

Table 2: Top 10 most productive journals in SA research with their most cited article.

| No. | Journal | No. of SA publications P | P/Total [%] | No. of citations | CiteScore 2019* | The most cited article | Times cited | Publisher |
|---|---|---|---|---|---|---|---|---|
| 1 | Applied Acoustics | 307 | 10.3 | 4012 | 4.9 | Acoustical and fire-retardant properties of jute composite materials | 164 | Elsevier |
| 2 | Journal of the Acoustical Society of America | 129 | 4.3 | 2015 | 3.2 | Electroacoustic absorbers: Bridging the gap between shunt loudspeakers and active sound absorption | 78 | Acoustical Society of America |
| 3 | Journal of Sound and Vibration | 73 | 2.5 | 1006 | 6.5 | Optimization of locally resonant acoustic metamaterials on underwater sound absorption characteristics | 62 | Elsevier |
| 4 | Construction and Building Materials | 60 | 2.0 | 957 | 7.4 | Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement | 62 | Elsevier |
| 5 | Applied Physics Letters | 53 | 1.8 | 1926 | 7 | Acoustic metasurface-based perfect absorber with a deep subwavelength thickness | 277 | American Institute of Physics |
| 6 | Archives of Acoustics | 38 | 1.3 | 254 | 1.8 | Improving sound absorption property of polyurethane foams by adding tea-leaf fibers | 56 | Polish Academy of Sciences |
| 7 | Noise Control Engineering Journal | 36 | 1.2 | 180 | 1.4 | An assessment of the performance of impedance tube method | 27 | Institute of Noise Control Engineering |
| 8 | Acta Acustica United with Acustica | 35 | 1.2 | 220 | 2.2 | Random-incidence absorption and scattering coefficients of vegetation | 37 | Hirzel Verlag |
| 9 | Materials | 33 | 1.1 | 125 | 3.5 | Characterization of sheep wool as a sustainable material for acoustic applications | 17 | Multidisciplinary Digital Publishing Institute (MDPI) |
| 10 | Zhendong Yu Chongji Journal of Vibration and Shock | 32 | 1.1 | 60 | 1 | Acoustic analysis for a sound-absorbing structure with a multilayered porous material | 8 | Zhongguo Zhendong Gongcheng Xuehui |

*Calculated on 6 May 2021

The most productive journal was Applied Acoustics 10.3 %, followed by Journal of The Acoustical Society of America 4.3 %, Journal of Sound and Vibration 2.5 %, Construction and Building Materials 2.0 %, and Applied Physics Letters 1.8 %. Among these journals, articles in Applied Acoustics had been cited the most, 4,012 citations for 307 papers, followed by the Journal of The Acoustical Society of America, 2015 citations for 129 papers. There was a high correlation between the number of publications and their citation number $r = 0.92$; $p = 0.0001$.

Although the Applied Acoustics and Journal of The Acoustical Society of America had the highest publications, their CiteScore in 2019 was considerably lower at 4.9 and 3.2, respectively, compared to the Construction and Building Materials 7.4, the Applied Physics Letters 7.0, and Journal of Sound and Vibration 6.5. Nevertheless, there seemed to be no correlation between the CiteScore based on the number of published articles and the CiteScore of a journal $r = 0.24$, $p = 0.49$.

### 3.3 Leading authors and collaborations

Table 3 lists the top ten authors with the most publications. These authors are affiliated with eight countries: Taiwan, Japan, Italy, Canada, China, Bucuresti, France, and Japan. There was no significant difference in the publication numbers, but all had published between 17 and 28 papers. The most active researcher was Lin Jia Horng from Feng Chia University, Taichung, Taiwan, who published 28 articles with 589 total publications and 493 co-authorships. Subsequently, Lou Chongwen from Asia University Taiwan, Wufong, Taiwan (TP = 522, co-authorship = 280) and Lu Tianjian from Xi'an Jiaotong University, Xi'an, China (TP = 655, co-authorship = 600) held similar records. A strong correlation was also found between the total publication number of an author and their co-authorship $r = 0.94$, $p = 0.00005$.

The author, Lin Jia Horng has collaborated with 40 authors 127 times to publish articles in sound absorption. As the author with the highest co-authorships, he has often collaborated with Lou Chongwen and Li Tingting as shown in Fig. 5b. From the bibliometric map, there is 25 links strength between Lin Jia Horng and Lou Chongwen and 18 links strength in between Li Tingting and Lin Jia Horng. Li Tingting also has 18 links with Lou Chongwen.

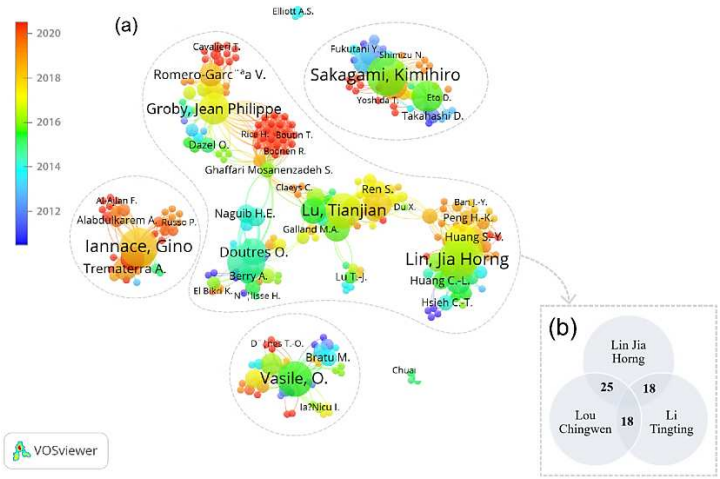


Fig. 5: a) The bibliometric map based on co-authorships, b) cross-team collaboration among three leading authors with strong co-authorships.

Table 3: Top 10 most productive authors in SA research.

| No. | Author | TP in SA | Year of 1st publication* | TP | h-index | TC | Current affiliation | Country | Co-author |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Lin, Jia Horng | 28 | 1998 | 589 | 28 | 3906 | Feng Chia University, Taichung, Taiwan | Taiwan | 493 |
| 2 | Sakagami, Kimihiro | 27 | 1993 | 120 | 22 | 1365 | Kobe University, Kobe, Japan | Japan | 82 |
| 3 | Lou, Chongwen | 26 | 2002 | 522 | 25 | 3086 | Asia University Taiwan, Wufong, Taiwan | Taiwan | 280 |
| 4 | Iannace, Gino | 25 | 1999 | 108 | 14 | 1034 | Università degli Studi della Campania Luigi Vanvitelli, Naples, Italy | Italy | 60 |
| 5 | Atalla, Noureddine | 24 | 1994 | 150 | 19 | 2166 | Université de Sherbrooke, Sherbrooke, Canada | Canada | 150 |
| 6 | Lu, Tianjian | 24 | 1989 | 655 | 65 | 18438 | Xi'an Jiaotong University, Xi'an, China | China | 600 |
| 7 | Vasile, O. | 21 | 2005 | 72 | 10 | 362 | University Politehnica of Bucharest, Romania | Romania | 94 |
| 8 | Groby, Jean Philippe | 18 | 2005 | 126 | 23 | 1725 | Laboratoire d'Acoustique de l'Université du Maine, Le Mans, France | France | 205 |
| 9 | Li, Tingting | 18 | 2011 | 164 | 14 | 802 | Tiangong University, Tianjin, China | China | 124 |
| 10 | Toyoda, Masahiro | 17 | 2004 | 63 | 12 | 511 | Kansai University, Suita, Japan | Japan | 53 |

### 3.4 Leading country and R&D development

The selected articles in this study were from 79 countries. Among these articles, 55.3 % were from Asia, 31 % from Europe, 8.5 % from North America, 2.1 % from South America, 1.8 % from Oceania, and 1.4 % from Africa. The article distribution is shown in Fig. 6. To further investigate the interdependence of a nation to publication output, the 15 most productive countries (see Fig. 7) contributing to the growth of SA research were examined. Asia and Europe have taken up 86.3 % of total publications. China was leading far ahead in SA research, which accounted for 1046 publications, equivalent to 35.2 % of total publications from 2011 to 2020 and comparable to the total publications in European countries 1130. The United States was the second most productive country with 199 publications, followed by South Korea 165, France 156, Japan 141, etc.

China's publications have grown exponentially within ten years, with an average publication of 104.6 per year while other countries recorded between 7.4 and 19.9. The gross domestic expenditure on research and development might be the potential factor affecting publication output. Based on the available data from World Bank [13], the United States, China and Japan have respectively allocated 3.9 trillion US$, 2.85 trillion US$, and 1.3 trillion US$ of gross domestic expenditure on research and development from 2011 to 2018. Among the surveyed countries, these were also the highest expenditure. Meanwhile, the Pearson correlation test showed a moderate correlation between publication numbers and total investment $r = 0.58$, $p = 0.022$. On the other hand, a high correlation was found between the number of publications and the number of personnel in the research and development field $r = 0.96$, $p = 0.00000005$. Therefore, this means that professional human resources primarily determine the productivity or efficiency of research output.

In terms of multi-country publication (MCP), countries with more than half of their publications in MCP are the United States at 52 %, followed by France 51 %, United Kingdom 58 %, Canada 60 %,

Germany 52 % and Hong Kong 65 % as shown in Table 4. This could indicate a strong inter-country collaboration. On the contrary, the rest of the countries listed in Table 4 had an average of 22 % of international collaboration in publication. India had the lowest MCP, with only 13 % of the publication collaborated with other countries. Overall, the percentage of MCP did not affect the publication number but possibly limited the research development to focus on country-specific problems only.

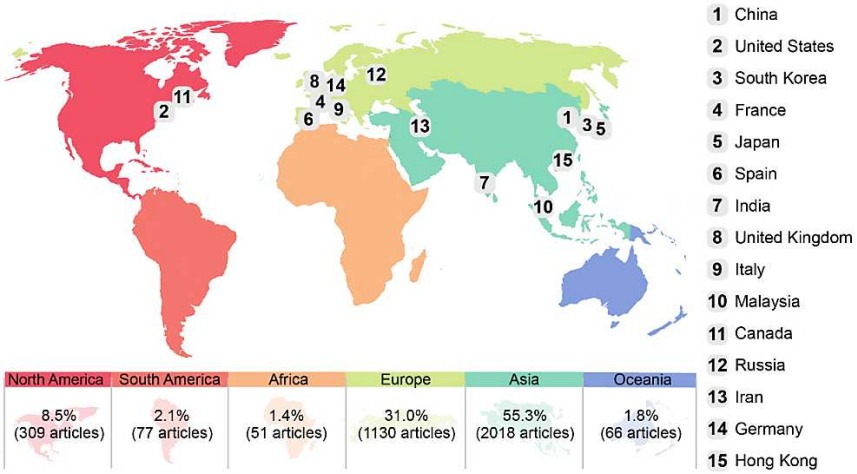


Fig. 6: World continents and countries distribution of SA research articles.

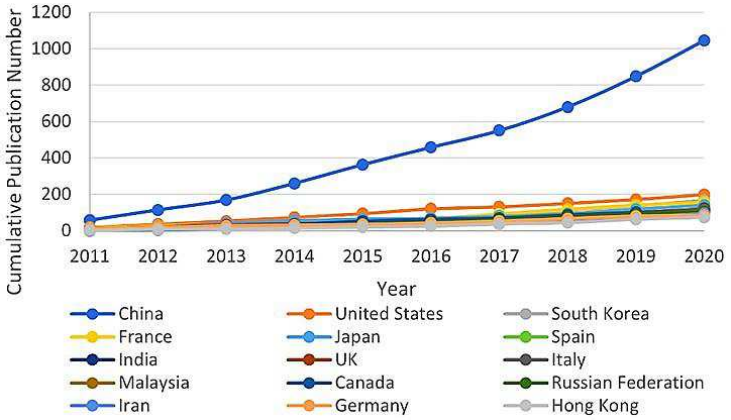


Fig. 7: The trend of SA research articles for the top 15 most productive countries.

Table 4: The top 15 most productive countries in the SA field and their R&D related statistics.

| Rank | Country | TP in SA | MCP [%] | GDP on R&D | R&D personnel |
|---|---|---|---|---|---|
| 1 | China | 1046 | 20.0 | 2,850,375,806 | 9,425,085 |
| 2 | United States | 199 | 51.8 | 3,937,644,000 | N/A |
| 3 | South Korea | 165 | 15.2 | 611,144,513 | 3,451,487 |
| 4 | France | 156 | 50.6 | 487,430,401 | 3,408,682 |
| 5 | Japan | 141 | 25.5 | 1,301,243,024 | 7,016,760 |
| 6 | Spain | 123 | 42.3 | 164,094,382 | 1,675,624 |
| 7 | India | 121 | 13.2 | 396,817,036 | 1,081,188 |
| 8 | United Kingdom | 119 | 58.0 | 360,563,586 | 3,211,773 |
| 9 | Italy | 115 | 26.1 | 245,179,309 | 2,143,073 |
| 10 | Malaysia | 108 | 28.7 | 52,956,826 | 450,575 |
| 11 | Canada | 105 | 60.0 | 220,570,811 | 1,643,169 |
| 12 | Russia | 103 | 13.6 | 309,371,070 | 6,496,095 |
| 13 | Iran | 94 | 16.0 | 20,956,182 | 436,457 |
| 14 | Germany | 83 | 51.8 | 921,219,491 | 5,051,543 |
| 15 | Hong Kong | 74 | 64.9 | 25,145,034 | 236,232 |

Fig. 8 shows the distribution of countries by publication collaboration. Bigger circles indicate a higher number of publications, while the collaboration with other countries is shown via the linkage lines; in this regard, the stronger the collaboration, the darker and thicker the line. It clearly demonstrates that the United States, the United Kingdom, and France are the most affiliated countries. These countries are collectively linked to 33 countries with their co-authorship recorded at 136, 111, and 109, respectively. This is followed by China 29 links, 234 co-authorships, Germany 26 links, 63 co-authorships, and Canada 25 links, 85 co-authorships. In general, one-third of the countries have collaboration with more than 10 countries. Co-authorship is also found to be strongly correlated to publication output $r = 96$, $p = 0.00000005$. The possible reasons for different collaborations among the countries might be the diversity of research partners, a high percentage of foreign researchers, and substantial research funding. Furthermore, a flexible and stable research policy also plays an important role in sustaining international collaboration.

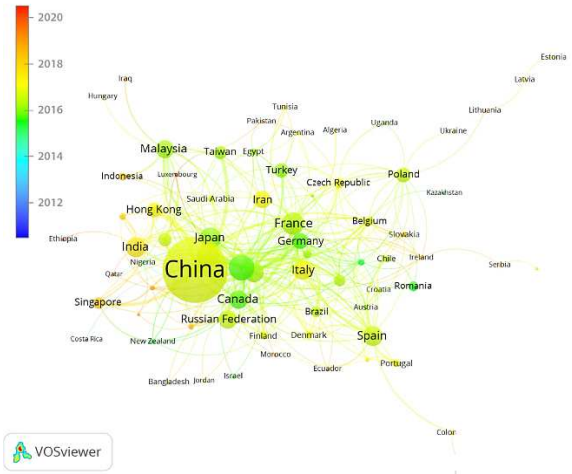


Fig. 8: The bibliometric map on co-authorships among countries.

### 3.5 Author keywords

A close look at author keywords showed that, out of a total of 6041 keywords, only 220 (3.64 %) had appeared more than five times. Fig. 9 shows the bibliometric map of the author keywords. Without a doubt, the phrase “sound absorption” is the most encountered keyword with 633 occurrences and 176 links to other keywords. The majority of keywords were encountered from 2016 to 2018. The following sections shall discuss the keywords segregated based on the type of material and measurement parameter since numerous studies have been conducted on developing a more sustainable sound absorbing materials [5 and the identifying the of close related parameters to sound absorption for numerical simulation [14].

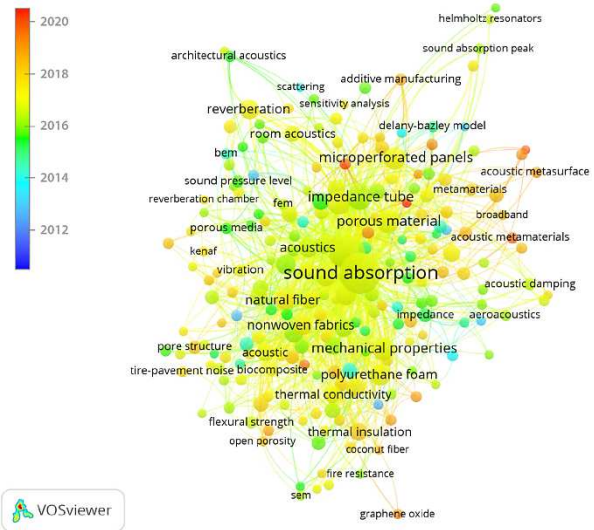


Fig. 9: The bibliometric map of author keywords with at least five occurrences.

### 3.5.1 Materials

Fig. 10 depicts the segregation based on the type of material. Most keywords were encountered from 2015 to 2018. Table 5 shows the top five keywords in this category. The phrase “porous material” had the highest citations recorded at 99 occurrences, Table 5. Porosity is highly associated with sound absorption or sound attenuation [15]. Based on the conversion of sound energy to heat energy in the irregular pore structures, porous materials are endowed with high and mid-frequency sound absorption ranges [16]. Due to its cost-effectiveness and simplicity of manufacturing, the material seemed to gain popularity in 2016 [17].

With 77 occurrences, the second most common keyword was "microperforated panels." A perforated panel is a kind of sound-absorbing material that absorbs resonance [18] that is not the same as a porous material. These resonance sound absorbers function based on the internal resonance effect [19] to absorb low-frequency noises (100 Hz - 500 Hz) [20]. The applicable frequency band is narrow [21], hence, perforated plates have been used with various porous materials in experiments to expand the absorption frequency range [22], elastic [23] or permeable materials [24]. According to a recent research, perforating numerous sub-millimeter diameter holes in a thin panel increases viscous and thermal losses, leading to the desired acoustic resistance and mass reactance reduction [25]. Microperforated panels, on the other hand, are gaining popularity as their citation effect grows (average citation = 12).

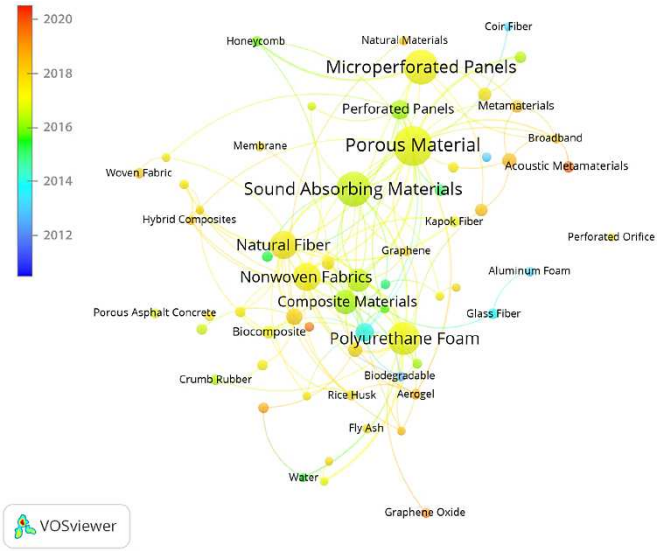


Fig. 10: The bibliometric map of author keywords based on sound-absorbing material.

The term "polyurethane foam" was used 67 times, with a publication year of 2016.8. Polyurethane foam is a porous, lightweight material that is less expensive and simpler to use [26]. Polyurethane foam is made up of interconnected polymer cellular structures. It absorbs sound waves with frequencies higher than 1600 Hz very well [27], typically caused by engine noises. Recent research has focused on changing the cavity size of polyurethane to enhance sound absorption effectiveness [28].

"Nonwoven textiles" was the fourth most popular keyword (48 occurrences). Nonwoven textile materials are soft, flexible, and have a high tensile strength [29]. It is a relatively new material with its average publication year of 2017.1. The impact of nonwovens' structural and physical properties, such as thickness [30] and flow resistivity [31], has been the subject of numerous experimental or computational [32] research studies. Recent research has focused on sound absorption characteristics using a variety of bonded methods, including thermally bonded, chemically bonded, and hybrid bonded materials [33], particularly for post-consumer fabric waste. Nonwoven fabric articles have a relatively low citation impact, with an average of 8.8 citations. Nonetheless, since it simultaneously handles trash recycling and reuse, it may be the material of future potentials.

"Natural fiber" is the trendiest sound absorption materials. With an average publication year of 2017.3 and a citation frequency of 13.5 for each article, this term has been cited 48 times. It is also known as lignocellulosic fiber, and it's grown more popular as the need for fresh natural fiber to replace synthetic fiber has increased [34]. Currently, the commonly researched natural fiber materials

include bamboo fibers [35]; coconut coir fibers; hemp fibers [36]; jute fibers; and kenaf fibers [37]. Continuous filaments or staple fibers [31] can be bonded using different binders to form a highly porous material with numerous interconnected pores [38]. A recent study compared the natural fibers to synthetic porous materials (straw, hay, plant litter, and wood chip). It concluded that natural fiber has similar sound absorption coefficients performance with synthetic materials [39]. With increasing awareness of sustainability, the publication and citation of natural fiber material for sound absorption publications may increase over the years.

Additionally, other than the most popular material keywords, there are some keywords mentioned in recent sound absorption publications (average publication date ranged from 2018 to 2019) worth to be highlighted, such as “graphene oxide” (2019), “acoustic metamaterials” (2018.4), “aerogel” (2018.6), “coconut fiber” (2018.2) and “3D printing” (2018.2). These keywords are indicating the insights and trends for sound absorption research.

Table 5: Types of sound-absorbing material as keywords.

| Types of material | Occurrences | Avg. pub. year | Avg. citations |
|---|---|---|---|
| Porous material | 99 | 2016.8 | 10.2 |
| Microperforated panels | 77 | 2017.0 | 12.0 |
| Polyurethane foam | 67 | 2016.8 | 11.5 |
| Nonwoven fabrics | 48 | 2017.1 | 8.8 |
| Natural fiber | 48 | 2017.3 | 13.5 |

### 3.5.2 Measurement parameters

Based on the selected articles, there are several corresponding parameter measurements associated frequently with sound absorption material. Therefore, this section aims to investigate the correlation of those parameters systematically to sound absorption performance. Out of 6041 author keywords from selected articles, 25 keywords are the parameter measurements that have been extracted via VOSviewer for further analysis. Fig. 11 demonstrates the ten major classified results based on 25 popular parameter measurements versus their occurrence frequencies. The following discussion shall focus on the common parameter terminologies, including “mechanical properties”, “thermal properties”, “permeability properties", and "porosity". All of these parameters have been encountered more than 50 times.

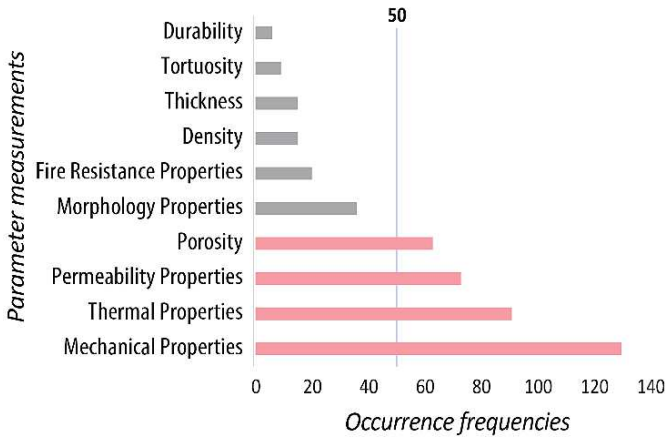


Fig. 11: 10 major parameter terminologies and their number of occurrences.

“Mechanical properties” (130 occurrences) was the most frequently encountered keyword. The sound absorption performance of a material is indirectly correlated with mechanical properties. Generally, sound absorption effectiveness depends on the porosity and pore structure [40]. In most cases, sound absorbers have poor mechanical stability [41]. Thus, numerous research studies have emphasized finding the balance between mechanical strength and sound absorption [42, 43].

“Thermal properties” (91 occurrences) was the second most popular keyword that has a strong correlation with sound absorption [44]. The vacancy content of thermal insulating materials is comparable to most sound absorbers because it reduces heat convection and the high porosity adds

to a material's thermal insulation [45]. Numerous studies have been performed to develop materials with both thermal and acoustic insulation characteristics, particularly in metropolitan environments, due to the necessity to meet both energy-saving and human comfort goals [46, 47].

"Permeability" (73 occurrences) is also an important parameter in assessing the sound absorption performance of materials [48]. This is measured in terms of the material's airflow resistance and water permeability. Previous research based on non-acoustical characteristics simulated the sound absorption performance of several materials and found that airflow resistivity is an essential parameter [49]. However, permeability values vary greatly depending on the type of material (such as foam, fiber, granular, and meta-materials) [50] and pore properties [51].

"Porosity" (63 occurrences) is the quantified measurement of pores amount. Two types of pores contribute to different properties of a material. The first type is known as "closed pores", which is easily identifiable via an investigation of the material's macroscopic properties such as bulk density, mechanical properties, and thermal properties. The second type is known as "open pores", which entails the continuous contact channel with its external medium. Open pores are important for sound absorption [52], permeability [53], and tortuosity [54]. Generally, the general pore ratio is embedded in the sound absorption coefficient [55]. Some SA studies have investigated specimens of different pore sizes [56], pores shape [57], and pores distribution [58] to improve the stability and accuracy of the sound absorption simulation result.

### 3.5.3 Correlation between top author keywords and their efficiency

Fig. 12 depicts the associations between the top 5 material keywords and the top 5 measurement parameters. Both keywords are associated to each other with difference occurrence frequency. Porous material, the highest occurrence among the material keywords, is highly correlated with measurement parameter porosity, followed by thermal insulation properties and mechanical strength. On the other hand, microperforated panel study mostly focuses on mechanical and porosity properties. Polyurethane foam and natural fiber display similar trend, which have the highest occurrences on mechanical and thermal properties. Generally, among the top 5 materials in SA study, mechanical, thermal and porosity properties are the three crucial properties researchers focused on from 2011 to 2020, while fewer studies are investigating morphology properties. Porosity is the determining factor of sound absorption performance yet high porosity generally leads to the deterioration of mechanical. Therefore, these two correlated parameters are commonly discussed together in SA studies. Some studies on the type of materials are summarized in Table 6 as well, It is observed that porous materials, microperforated panels and polyurethane foam are commonly applied in aviation industry with significant reduction on noise intensity, Meanwhile, nonwoven fabric is mostly utilized in reverberation room or building machine for better sound-absorbing, The application of natural fibers as construction material is also worthy noted/attention-grabbing, demonstrating the trend of sustainable materials and cities.

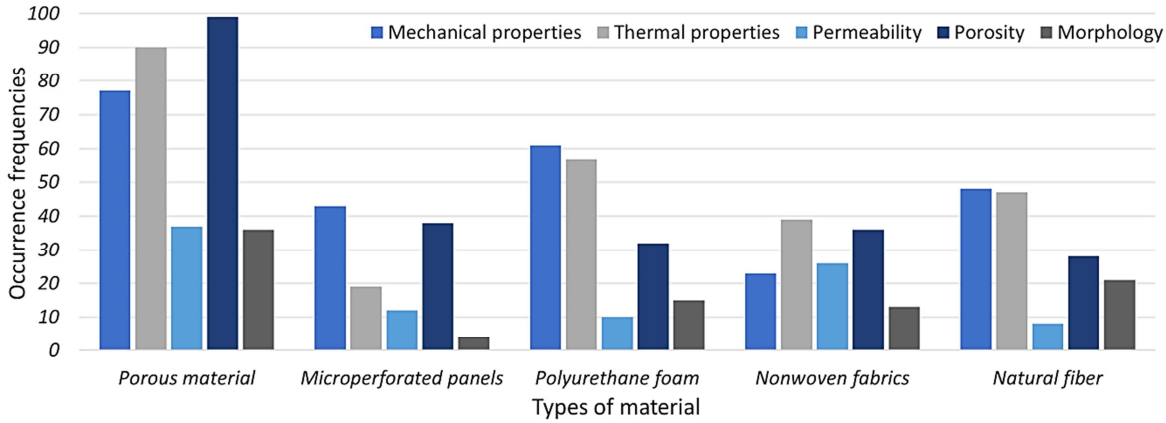


Fig. 12: Correlation between the top keywords (types of material and its measurement parameters).

Table 6: Studies on sound-absorbing materials and their efficiency on noise intensity reduction.

| Type of material | Treatment/Material/Fabrication method | Application | Reduction of noise intensity | Reference |
|---|---|---|---|---|
| Porous materials | Porous surface on trailing-edge | Trailing-edge | 4 dB | [59] |
| | Porous trailing edge | Trailing-edge | 11 dB | [60] |
| | Porous aerofoil leading edges ($d$ = 1 mm) | Leading edges | 1 dB - 5 dB | [61] |
| | Poro-serrated trailing-edge | Trailing-edge noise | 1.5 dB | [62] |
| | Rubberised double layer porous asphalt | Pavement | 2.2 - 3.2 dB | [63] |
| | Porous asphalt | Pavement | 59 % | [51] |
| | Alantum NiCrAl open-cell metal foams | Trailing-edge noise | 11 dB | [64] |
| Microperforated panels | Microperforated-panel casing treatment over the rotor | Small-sized contra-rotating fan | 0.7 dB | [65] |
| | Short microperforated panel covered with shallow cavity backing | Ducted fan | 10 dB | [66] |
| | Infinite-sized microperforated panel backed by cavity and thin plate | Capplications | 20 dB | [67] |
| | Microperforated panel backed by cavity filled with anisotropic fibrous material | Aero-acoustic applications | 30 db | [68] |
| Polyurethane foam | Magnesium hydroxide filler in polyurethane composite foams | Automobile industry | 70 % | [69] |
| | Polyurethane-urea/rice straw waste (PUU/RSW) biofoam | Noise reducing acoustic panel | 27 % | [70] |
| | Polyurethane foam under 30 % vacuum condition | Urban noise | 8 dB | [71] |
| | Aluminium fuselage with polyurethane foam | Vibroacoustic phenomenon in aviation industry | 8 dB | [72] |
| Nonwoven | 3.24 mm thick sandwich (recycled nonwoven-nanofiber-recycled nonwoven) | Reverberation room | 50.4 % | [73] |
| | Nanofiber web-reinforced nonwovens sandwich structures | Reverberation room | 57.4 % | [74] |
| | Windmill palm fiber/polyvinyl alcohol coated nonwoven mats | Reverberation room | 38 % | [75] |
| | Electrospun PAN hollow nanofibers on the PP nonwoven with a thickness of 1.5 cm | Building machine | 59 % | [76] |
| Natural fiber | Cellulose nanofiber and melamine composite foam | Rail transportation, industrial, residential building | 80 % | [77] |
| | Incorporating 33 % hemp fibre into concrete | Construction material | 59 % | [78] |
| | Hemp fibre mixing with hydrated lime and 30 % GGBS with 0.5 % methyl cellulose | Construction material | 50 % | [79] |
| | Oil palm wood with hot press method | Noise insulation board | 33 % | [78] |

## 4 Conclusion

The global research trend of sound absorption had been analyzed based on 2970 relevant articles. The number of SA publications peaked in 2020 and is expected to grow further. The cumulative publications soared 84 % from 2011 to 2020 in 26 fields. The majority (68.3 %) of the publications were in Physics and Astronomy 25.4 %, Engineering 24.7 %, and Materials Science 18.2 %. The most productive journal was Applied Acoustics 10.3 %, while the rest of the publications were evenly distributed among 160 journals, with less than 5 % of the total publications for each journal. By comparing the 10 most published authors, there was no apparent difference in the publication numbers, and all published within a range of 17 to 28 papers. Author Lin Jia Horng from Taiwan had the most collaborations 127 with another 40 authors. A high correlation $r$ = 0.87 was determined between the number of co-authorship and the h-index of a scholar. 55.3 % of the total publication was published in Asia, where China was leading far ahead among the 79 countries in sound absorption research 1046 articles, 35.2 % of total publications. A high correlation $r$ = 0.96 was found between the publications number and research and development personnel number. Most researchers focused on porous materials, microperforated panels, polyurethane foam, nonwoven fabrics, and natural fiber. Nonetheless, mechanical, thermal, permeability and porosity properties were commonly examined for sound absorption materials. Overall, these findings can be helpful for researchers to develop SA from a global level perspective further

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