



UNDERSTANDING EMISSION OF FORMALDEHYDE THROUGH PRESSED WOOD PRODUCTS IN CONTEXT TO INTERIOR SPACE- A LITERATURE REVIEW ANALYSIS

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Abstract

In order to comprehend the work done for wood-pressed material and its emission consequences, the current study maps the academic literature. The research uses bibliometric approaches to highlight important aspects of the literature data on formaldehyde emission from pressed wood. By the use of keywords and reference searches, the study was able to locate 165 research publications in the Scopus database. The literature on pressed wood has been enriched by the identification of significant journals, prolific writers, nations, and associations thanks to analysis tools. An overview of the key information and analyses of the authors, nations, universities/institutions, and publications were included in the analysis. Findings of the research indicate that several different areas have been working on a variety of issues like formaldehyde emission, and health issues have been undertaken, but its relation to pressed wood and its application for Interior Space, does not have any defined strategies worked out for its further delimitation or reduction policy understanding in this domain. The results of this study will give academics a thorough grasp of present research projects as well as a direction to reinterpret them in relation to the subject of interior Spaces.

Keywords: Pressed wood products, Indoor Space, Formaldehyde emission, Scopus, Biblioshiny.

1. Introduction

Buildings in India are largely cooling-dominated, due to their hot and arid weather climate. 31% of the energy used by commercial buildings is for space cooling. There has been a sharp increase in related carbon emissions as a result of deeper market penetration of air conditioning systems, rising income levels driving higher comfort standards, and expanding floor space (Manu et al., 2016). The material choice affects thermal performance, air quality and outgassing, fire toxicity, cancer-causing fibers, and mould, all of which have an impact on the respiratory and digestive systems, eyes, and skin as stated by Danoff 1990 (Loftness et al., 2007). 90% of the time, people stay indoors, according to the Confederation of Industry, which was noted by the Indian Green Building Rating Council (IGBC) in a 2019 update addendum. These locations are

suitable for living in or working in that indoor volume. From the same angle, the user's health and safety are intimately tied to the interior volume. Measurements show that the probability of interior pollution is ten times greater than that of outside pollution (Ye et al., 2017). Our building interiors, once thought of as providing safe havens from the pernicious effects of outdoor air pollution and harsh climates may actually be more polluted than the surrounding ambient environment (Spengler & Chen, n.d.2000). The persistence of healthy lives and fostering well-being for everyone have been prioritized in attitudes towards wellbeing. The same thing is being witnessed in creating interior spaces for a person's well-being. The framework for healthy building standards, which was first developed by Fange in 1996, stated that- in 1800 -1975, the standard pattern for living was oriented towards –“comfort & Health”. This shifted in 2000-to present, which is as “Productivity + Comfort.” But predicting as in 2025-2050, the concern will be to personal aesthetics + Health (Spengler & Chen, n.d.2000). Health is no longer just considered to be the absence of sickness. The World Health Organization (“WHO Guidelines for Air Quality,” 1998) has made significant contributions to the advancement of a concept of health that includes both physical and emotional well-being, as well as access to safe and clean settings and medical treatment. Also, this sharp rise in unfavorable health impacts is a recent phenomenon that has been linked to the observed symptoms in buildings.. A focused look into the use of the material in an influential context-role of material palette is to execute safe, healthy, productive, and enjoyable environments as stated by the national Council of Interior Design Qualification (NCIDQ). Understanding material becomes crucial in addressing new technical, social, and cultural reactions, rather than being conventional to its surface or product beauty alone. The scientific transformation of material is related to its long-term or economical environmental concern. A modification or innovative design cannot be achieved simply by using new materials. Interior material application has evolved into a "one-size-fits-all" mentality. Materials are used without first considering how they should be used. Before using a material, one must first comprehend it. In this study, pressed wood goods including plywood, medium density fibre (MDF), veneer, etc., which are typically used for either manufacturing or covering the space or furniture interior volume, are examined in relation to the definition of health in interior space vs. material application. Volatile organic compounds, an organic chemical pollutant, are linked to the majority of these contaminants (VOC). The substance mentioned previously primarily emits formaldehyde (HCHO), which is an airborne chemical. Most indoor panel products are bonded using urea-formaldehyde resin (UF), which releases free formaldehyde more or less. This causes customer dissatisfaction and health-related complaints. These emissions have caused various symptoms, the most common of which are irritation in the eyes and the upper respiratory tract and prolonged exposure to formaldehyde in high doses can lead to chronic toxicity and even cancer (Aydin et al., 2006; S. Kim, 2010; Que et al., 2007; Uchiyama et al., 2007).

1.1 Research Questions

RQ1: What are the publication trends in the area of emission through pressed wood?

RQ2: Who are the most prolific authors, journals, organizations, and countries contributing to the topic of emission through pressed wood?

RQ3: What are the mature and emerging themes in the area of formaldehyde emission from pressed wood products?

RQ4: What are the directions for future research to bridge its use in Interior Spaces?

The bibliometric approach is used to analyze a sample of articles from the Scopus database in order to respond to these research questions (RQs). It is well known that bibliometric analysis has the ability to quantitatively summarise the body of knowledge related to a specific study topic. (Bhatt et al., 2020). Using the well-known, dependable software Visualization of Similarities (VoS viewer) and R Bibliometrix 3.0, the data was analysed and the results were presented.

2. Research Methods

In reference to the Research Question, the study complies with the criteria for the scientific mapping workflow, which include a clear research strategy, data collection, analysis, visualization, and further interpretation (Zupic, 2015). After compiling the Scopus data, a platform for information visualisation is chosen in order to make conclusions about the future study's breadth of usage of pressed-wood goods in relation to Interior Space. The study used the systematic literature review (SLR) approach to locate the literature for the bibliometric analysis. SLR is carried out according to established standards, examining databases using a predetermined search strategy to improve for transparent, scientific, and thorough data (Williams et al., 2021). The most popular technique for bibliometric analysis is full counting (Perianes-Rodriguez et al., 2016). Fractional counting is preferable when full counting of bibliometric linkages may occasionally result in biases (van Eck & Waltman, 2017). However, it is extremely improbable to get different results whether utilizing full or fractional counting methods for relatively tiny data sets, like the one used in this study (Perianes-Rodriguez et al., 2016). Bibliometrix 3.0 is also used in the study using the Biblioshiny interface. Bibliometric analysis utilizing Bibliometric and Biblioshiny has been done in a number of earlier research in a variety of fields (Hafeez et al., 2019, Syed & Bawazir, 2021)

2.1 Data Analysis criteria

The Scopus database is famous for its wider, all-encompassing, and comprehensive coverage of material, according to (Pranckutė, 2021, Caviggioli & Ughetto, 2019), and other scholars. It is the largest online database with over 24,000 peer-reviewed articles, higher citation records, and the capacity to manage data (Borrett et al., 2018). The analytical job is also made easier, as it ensures that each publication's institutional addresses and author profiles are available (Mongeon & Paul-Hus, 2016). Because of this, the Scopus database was used in the current inquiry to locate the relevant literatures. The database was exhaustively searched using words related to the literature and words associated with the field (Bartolini et al., 2019). The formaldehyde volatile organic compounds in pressed wood are the subject of the literature review in this work. Although the search was done using the Scopus database on May 3, 2022, the study's sample period is just 1975 to 2021 in order to minimise any potential bias brought on by the ongoing updating of Scopus data. Scopus is one of the comprehensive databases that are used for reclaiming literature on the stated keywords. The authors found

195 research publications during their initial search. The study complies with (Zupic, 2015) criteria for the scientific mapping workflow, which include a clear research strategy, data collection, analysis, visualization, and interpretation. The program for information visualization is selected after the data has been compiled in order to draw conclusions that are useful. Through Prisma guidelines the data has been extracted as put in figure 1.

The suitable papers were chosen using inclusion and exclusion criteria in order to make the study thorough and concentrated on its objectives. The exclusion criterion lists the characteristics of a document that, if present, would disqualify it from the investigation. The requirements a document must meet in order to be included in the sample are outlined in the inclusion criterion (Bhatt et al., 2020). According to the objectives of the study, the inclusion and exclusion criterion aids in separating relevant information from important data. Visualization of Similarities (VoS viewer), a well-known and dependable application, was used to evaluate the data and present the findings graphically.

Given that full counting is the most popular method for bibliometric analysis (Perianes-Rodriguez et al., 2016), the current study built bibliometric networks using full counting. When full counting of bibliometric links can occasionally lead to biases, fractional counting is better (van Eck & Waltman, 2017). However, for relatively small data sets, like the one utilised in this study, it is incredibly unlikely to obtain different results using full-counting or fractional counting approaches (Perianes-Rodriguez et al., 2016). The study also made use of R Bibliometrix 3.0 using the Biblioshiny interface.

Flowchart of selected studies using PRISMA guidelines

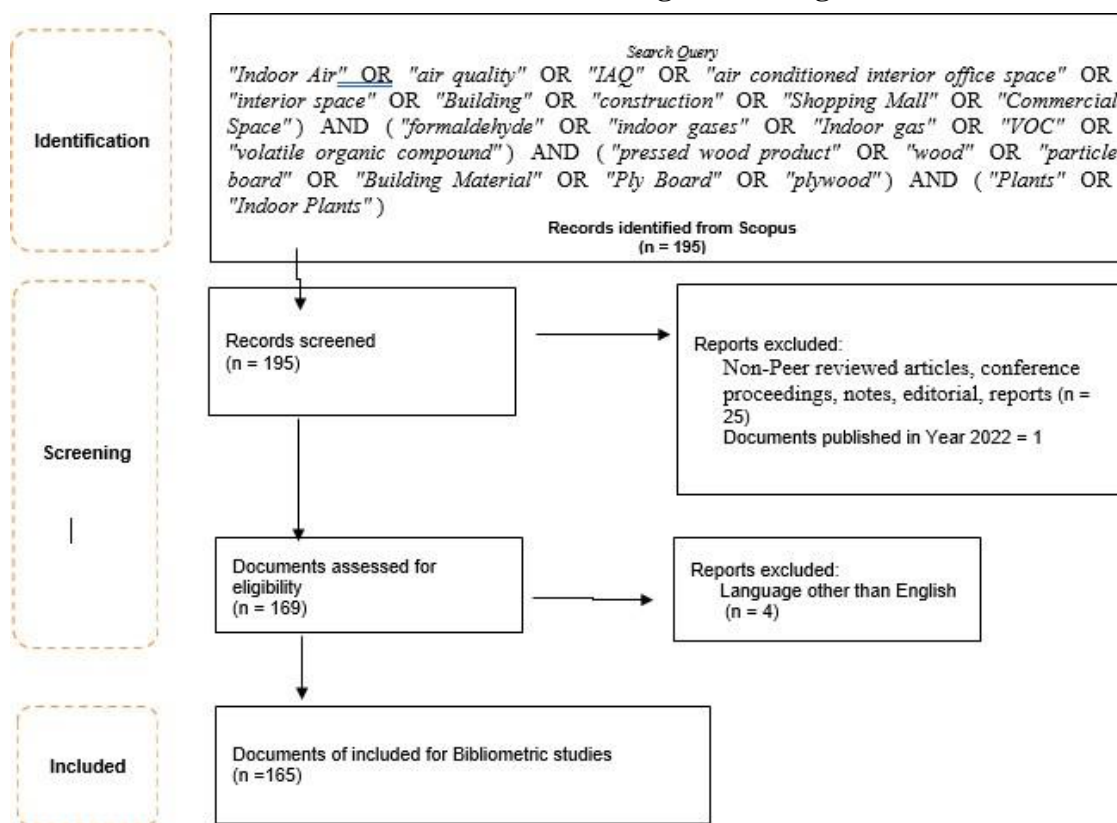


Figure 1 Methodological approach- identification of studies via Scopus database

2.2 Selection of Software

To perform a justifiable bibliometric analysis, appropriate software becomes a priority. Bibliometrix is an open-source tool developed by (Aria & Cuccurullo, 2017) that facilitates quick analysis and creates a data matrix for scientific mapping of the obtained data. No coding skills are necessary to utilise Biblioshiny, a web-based utility available through R-studio. Also, VOSviewer which also is a bibliometric analysis tool has also been used for visualization analysis.

2.3 Analysis

Both quantitative and qualitative assessments were taken into consideration for this paper's study. The quantitative analysis included information on the study (authors, countries, universities/institutes, and publications), the publication year, the writing style, the distribution of the journals, and the language used in the writing. The theme domains and keyword/term mapping were taken into account in the qualitative analysis. The current study, which takes into account the importance of bibliometrics and the analysis of keywords, gives a thorough analysis of the authors' keywords in the area of formaldehyde emission. The analysis was then finished, and the results were provided, as may be seen in Section 3.

3. Results and Discussion

3.1 Outline of retrieved data

Table 1 shows the results of the descriptive analysis of the bibliographic data from the 165 included studies. The included articles were published in 89 different journals, books, etc. during the period 1975-2021.

Table 1 Overall Scopus data referred under keyword's findings.

MAIN INFORMATION ABOUT DATA	Results
Timespan	1975:2021
Sources (Journals, Books, etc.)	89
Documents	165
Annual Growth Rate %	2.42
Document Average Age	16.5
Average citations per doc	20.18
References	2112
DOCUMENT CONTENTS	
Keywords Plus (ID)	1644
Author's Keywords (DE)	346
AUTHORS	
Authors	494
Authors of single-authored docs	16
AUTHORS COLLABORATION	
Single-authored docs	18
Co-Authors per Doc	3.58
International co-authorships %	18.18

The annual scientific production in the field has on average grown is 2.42 percent. This is substantially low. Although, the keywords for calculating the annual growth percentage research publication till 2021 are considered in the searched field. The keyword search goes to 1644, and authors working on the topic are a count of 494. Co-authoring is also quoted low as 3.58%. 153 are journal articles, reviews Editorial and Data Papers, the conference proceedings make up the remaining 12. Fewer (only 13%) were having conference reviews. The annual growth rate identified is just 2.42%.

3.1.1 Chronological publications trend

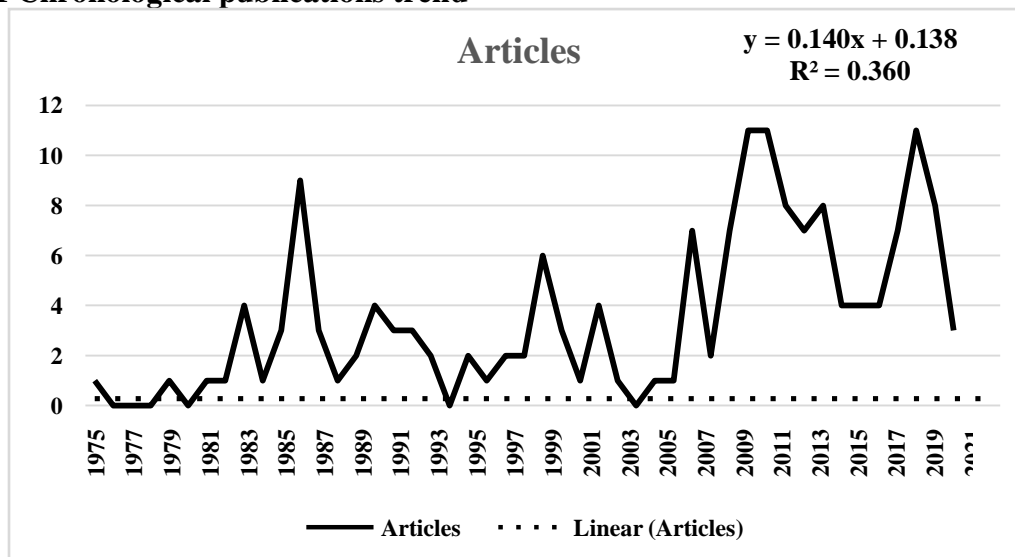


Figure 2 Chronological publication trend in the field of health-related concerns in the use of press-wood products

Between 2012-2018, the number of publications was again moving towards single-digit numbers. 2019-2020, which globally was a pandemic phase of covid-19, had again caught up with the pace of research. The indoor stay was also prolonged during this time, which might have influenced the research to go in its rise. Also, the regression line was fitted, and the R squared determination coefficient was discovered to be 0.3603. According to these statistics, the number of publications has grown statistically very modestly throughout the review period. Hence, study on the subject of formaldehyde volatile organic compound emission may be relevant to interior space.

3.1.2 Countries and Regions

According to the [World Economic Outlook Database April 2022 -- WEO Groups and Aggregates Information \(imf.org\)](#), the classification of individual authors' countries has been done into three categories— Developing Economy, Developed Economy, major developed Economy, to examine the research dependency on the kind of economy.

As per Table 2, though the trend started in developed countries, in 1975, the grade of publication is consistent in the major developed countries till 2020. Developing countries research contribution is seen since the mid-21st century. Compared to other construction materials like concrete or steel, wood is a preferred choice because of its availability, affordability, adaptability, and environmental sustainability. Wood is an important business and its usage in building is well-established in several industrialized nations with considerable wooded areas, such as Canada (US), Finland, and Sweden. As per IMF's world economic report, these countries stated in the list, have cold climatic conditions, their association and understanding towards basic building material of wood can be seen with respect to their publication period starting from 20th century. Material consciousness signifies the health concern towards these developed countries at an early span to time. In the middle of the twenty-first century, research data on health outcomes in underdeveloped nations is anticipated to be available. Due to a lack of resources, basic essentials like food, water, and shelter sometimes take precedence in these nations over healthcare.

As a result, rather than emphasizing the promotion and maintenance of good health, the emphasis is frequently placed on satisfying these fundamental requirements. Health is a secondary goal in poor nations.

Table2 Leading countries by documents and Citation

Rank	Country	No of Articles	Citations	Type of Economy
1	United States	29	832	Advance economy
2	China	21	272	Developing Economy
3	Sweden	8	121	Advance Economy
4	Austria	7	167	Advance Economy
5	France	6	127	Advance Economy
6	Turkey	6	49	Developing Economy
7	Germany	5	70	Major Advanced Economy
8	Poland	5	85	Developing Economy
9	Czech Republic	4	165	Advanced Economy
10	Spain	4	93	Advanced Economy

According to the number of papers and citations for the documents published on health issues associated to the use of press-wood products, Table 2 provides data from the top 10 nations. The number of articles published from different nations in the top 10 positions ranges from a minimum of 4 in Spain to a high of 29 in the United States. The United States is also to its credit for receiving the most citations. Although Turkey, Germany, and Poland have contributed to it, the Czech Republic and Spain have produced a smaller number of documents in the same field. Only three of the top 10 contributor countries are emerging economies or developing economies, while seven are advanced economies. This frames the finding that work in developing nations has been initiated and has scope further take it as research.

To further understand the economy groups, the chronology of publication in these three defined Economy groups provides insights into the evolution of interest in Press wood emission by presenting the yearly distribution of the analyzed 162 of 165 documents.

Table 3 Annual Publications by economy groups

Year	Emerging & Developing Economy	Developed Economy	Major Developed Economy	Total
1975		1		1
1979		1		1
1981			1	1
1982			1	1
1983		1	3	4
1984			1	1
1985			2	2
1986		2	6	8
1987			3	3
1988			1	1
1989			2	2
1990	2		2	4
1991		2	1	3
1992	1	2		3

1993		2		2
1995			2	2
1996			1	1
1997		1		1
1998		1	1	2
1999	1		5	6
2000			3	3
2001			1	1
2002	1		3	4
2003			1	1
2005			1	1
2006		1		1
2007	1	3	3	7
2008	1		1	2
2009	2	3	2	7
2010	8	1	2	11
2011	4	5	1	10
2012	5	1	2	8
2013	3	1	3	7
2014	5	2	1	8
2015	2	1	1	4
2016	1	3		4
2017	3	1		4
2018	5	1	1	7
2019	6	1	4	11
2020	4	3	1	8
2021	3			3
Total	58	40	63	165

Supporting further to Table2, it became important to understand the chronology of publication respectively year wise development in the economy verticals. Although an advanced economy released the initial research report in 1975, majorly advanced countries began to show interest in the concept of formaldehyde emission behavior in 1981. Despite the fact that these developed nations have consistently contributed to the research, few publications are still being made. It is noticeable from Figure-3, that formaldehyde emission expanded admiration in underdeveloped nations in 2010, and ever since, some work has been continuously started. The research subject has been seen as a node of interest since the mid-21st century, in developing, advanced, and major advanced economy.

Figure3 gives a holistic idea of the changing trends from its start seen in Major Developed Economy countries but, in the 21st century Emerging & Developing Economies are showing a conscious effort in the proximity of the emissions related to indoor air quality.

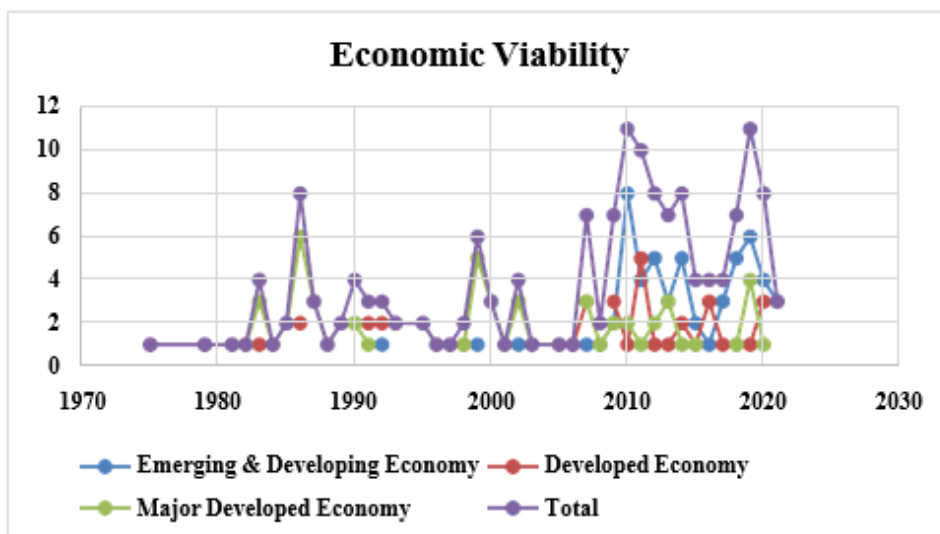


Figure 3 Trend development in respect to Economy viability

3.1.3 Journal quality analysis

165 papers were published in 89 Journals between 1975 and 2021. The top 10 journals with the most formaldehyde and volatile organic compound-related papers over this time are listed in Table 4. The table also includes some substantive inputs, such as the Scopus Q rankings and the Scimago Journal Ratings (SJR) score. The most publications were found in the NC State University journal "Bio-Resources," which had 11 papers, a Q rating of 3, and an SJR score of 0.39. With 7 and 6 documents, respectively, the journals "Building and Environment" from Elsevier and "Advanced Materials Research" from Trans Tech Publications took second and third positions. These indicators help researchers choose high-caliber publication platforms.

Table4 Leading 10 journals and Q rating list

Rank	Sources	Publisher	Articles	SJR Score SCImago Journal Rank	Q rating
1	Bio-resources	NC State University	11	0.39	3
2	Building and Environment	Elsevier	7	1.5	1
3	Advanced Materials Research	Trans Tech Publications	6	Discontinued in Scopus as of 2014	
4	Environmental Science and Technology	American Chemical Society	4	2.7	1
5	Forest Products Journal	Forest Products Society	4	0.25	3
6	Indoor Air	Blackwell Munksgaard	4	1.13	1
7	Bulletin of the Institute of Maritime and Tropical Medicine in Gdynia	Conference Proceedings	3	Conference Proceedings	
8	Composites Part B: Engineering	Elsevier	3	2.12	1

9	European Journal of Wood and Wood Products	Springer Verlag	3	0.5	1
10	Industrial Crops and Products	Elsevier	3	1	1

Source: Authors calculation form VOSviewer output and Scimago web portal.

3.1.4 Citation analysis

Assuming that citations can be used as a measure of influence (Zupic, 2015), the citation analysis reveals that though Bio-resources contributes the most to the field of research of our interest with 11 articles, the journal is as that influential as the total citations of the journal in the aforementioned topic is just 58 against the citation of 267 achieved by Environmental Science And Technology with first rank in citation. The journals, having high citations, accommodated works related to product manufacturing, materials identification for quality variation and identification of physical properties and mechanical procedures. The Journals “Environmental Science and Technology”, “Building and Environment”, “Indoor Air” rank 1, 3, and 5 respectively shown in Table- 5, had highlighted more on the strategies of environmental concern in their published works. However, hardly any journal in the list accommodated research work related purely to Space Planning or building design.

Table 5 Top Influential journals based on citations.

Rank	Source	Documents	Citations	Total link strength
1	Environmental Science and Technology	4	267	1
2	Forest Products Journal	4	230	4
3	Building and Environment	7	216	62
4	Composites Part B: Engineering	3	177	20
5	Indoor Air	4	160	6
6	Journal of Environmental Management	1	153	0
7	Atmospheric Environment (1967)	2	131	0
8	Industrial Crops And Products	3	123	28
9	Journal of Cleaner Production	2	94	0
10	Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering	1	72	11
11	International Journal of Cancer	1	70	0
12	Atmospheric Environment	1	67	0
13	Holz Als Roh - Und Werkstoff	2	62	0
14	Bioresources	11	58	94
15	Polymer Degradation and Stability	1	57	0
16	Environment International	1	55	0
17	Wood Research	3	40	26

3.1.5 Author and Organization

As shown in Table 6, the top two organizations in terms of their contribution to the field research focusing on the manufacturing of particle boards using formaldehyde are the College of Material Science and Engineering affiliated with Northeast Forestry University, China, and the Timber Research and Development Institute, Czech Republic.

Due to the lack of research in this area, we can observe that the third, fourth, and fifth-ranked organizations each provided two research documents. Therefore, when examining the top contributing organization, we only considered the top five organizations rather than the top ten. All of the top 5 organizations have one of the following three focuses: 1) manufacturing, 1) environment, 3) agriculture, or a combination of any two of the three. Shen J, Liu Y, and Shen X, who are in the top three ranks, have respectively cited 10, 6, and 4 research articles in the fields of formaldehyde and VOC emission. They were able to make a significant contribution to this field of study as a result. Both Shen J. and Liu Y.'s study is regarded as influential and has received a sizable number of citations. However, with three research pieces published in the field, Matthews T.G., Böhm M., and Salem M.Z.M. have received far more citations than the first three contributing authors, as shown in table-6 (A) & Table 6 (B). All three research documents of Matthews T.G. are on different experimental models which help to understand indoor air pollution of formaldehyde. Sitko E, Wiglusz R, have majorly elaborated their concerns for effect of environmental factors related to volatile organic compounds. While the research by Shen J and Liu Y, which has been authors working the mid-21st century has shown their scope of research to investigate the VOC emission of particleboard under different processing conditions. This research, which focused solely on residential typology, also indicated the health concerns associated with exposure to formaldehyde and benzene.

Table 6 (A) Top 10 contributing Authors and their citations

Rank	Author	TP	TC
1	Shen J.	10	41
2	Liu Y.	6	42
3	Shen X.	4	10
4	Sitko E.	4	28
5	Wiglusz R.	4	28
6	Böhm M	3	44
7	Jarnuszkiewicz I.	3	13
8	Matthews T.G.	3	67
9	Salem M.Z.M.	3	44
10	Zhu X.-D.	3	12

*TP= total papers, TC=total citations

Table 6 (B) Top 5 contributing Organizations and their citations

Rank	Organization	TP	TC
1	College Of Material Science and Engineering, Northeast Forestry University, China	10	49
2	Timber Research and Development Institute, Czech Republic	3	44
3	USDA Forest Serv., Forest Prod. Lab., United States	2	174
4	Gorgan University of Agricultural Sciences and Natural Resources, Iran	2	155
5	State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, China	2	136

*TP= total papers, TC=total citations

The top 5 organizations which have their total citations on the highest are related to fields of Production(3), Agriculture(4), and Environment Pollution(5). Though the total number of papers is just 02, but major citations can be seen in them. This concludes that the interest in the topic is seen though the quantum of research done is still less. Material Science organizations are the favorites doing their work in analysis, as well as easily be cited. Figure – 4 shows the research chronology of the authors that reveals the consistency of the authors in this research. During the mid-20th century, researchers utilized various experimental models to study indoor air pollution, specifically related to formaldehyde emissions from pressed-wood buildings.

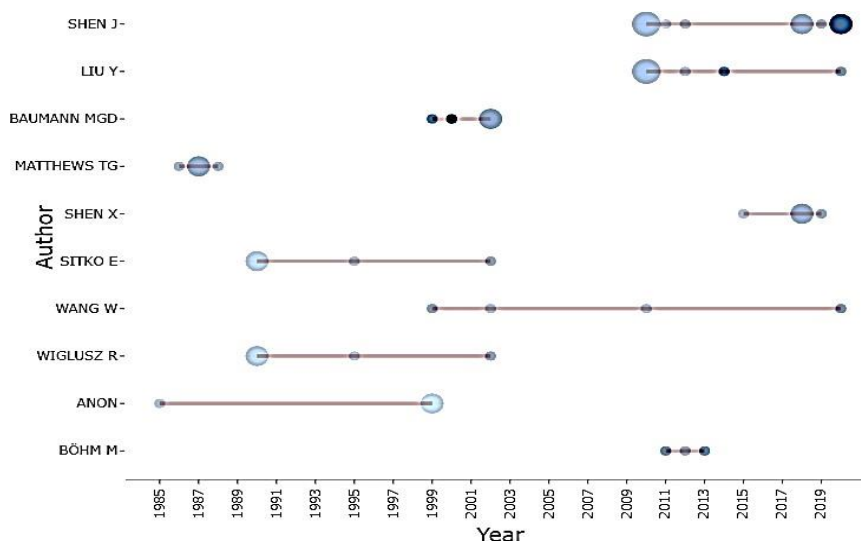


Figure 4 Research chronology in reference to research involvement by authors.

Detailed laboratory and research house studies helped identify the health effects and sources of volatile organic compounds (VOCs), such as formaldehyde. (Gammage & Matthews, 1988). Mathematical models and analytical methods were developed to classify particle boards according to their formaldehyde emission levels and predict formaldehyde concentrations in indoor environments. In the 21st century, researchers continued to investigate the effects of different manufacturing conditions on surface finishing and VOCs' impact on indoor air quality. Studies used climate chamber tests or small-scale chamber methods to identify odors and evaluate the removal efficiency of air-cleaning materials on particleboard. (Chi et al., 2016)(Zhu et al., 2010)(Liu et al., 2010). Researchers identified that VOCs with low concentrations, even below the detection limit, can have negative effects. (Liu et al., 2010)(L. Jiang et al., 2018). Studies evaluated the pressing parameters' effect on total volatile organic compound (TVOC) emissions from particleboard, sorption and desorption for gypsum board, and formaldehyde emission from wood-based panels based on different types of resin used in bonding, from organic materials configuration. (Liu et al., 2010)(Xu et al., 2013)(Salem et al., 2011)(W. Wang et al., 2010). Early Studies in the 21st century concentrated on the diversity in panels' mechanical properties and formaldehyde emissions. The research was also conducted on bio-resources and their impact on particle board manufacturing. (Salem et al., 2011). Referring to these top authors will help in formulating to understand, (a) in experimentation method in reference to Interior space and (b) interior environment variables to be noted in context to the volume of space.

3.1.6 Co-word analysis

Co-word analysis is a method for analyzing keyword co-occurrences as well as for finding connections and interactions between the study topics and new research trends. Keywords are the authors' frequently used words and phrases in the articles' titles, abstracts, and bodies. In the current paper, co-word analysis is utilized to explain the interactions that occur across various innovation process phases as well as to demonstrate whether fundamental or applied research is the driving force. Figure -5 shows the four clusters of authors keywords co-occurrence resulting from R-Biblioshiny tool that describes the major four themes of research based on the keywords analysis.

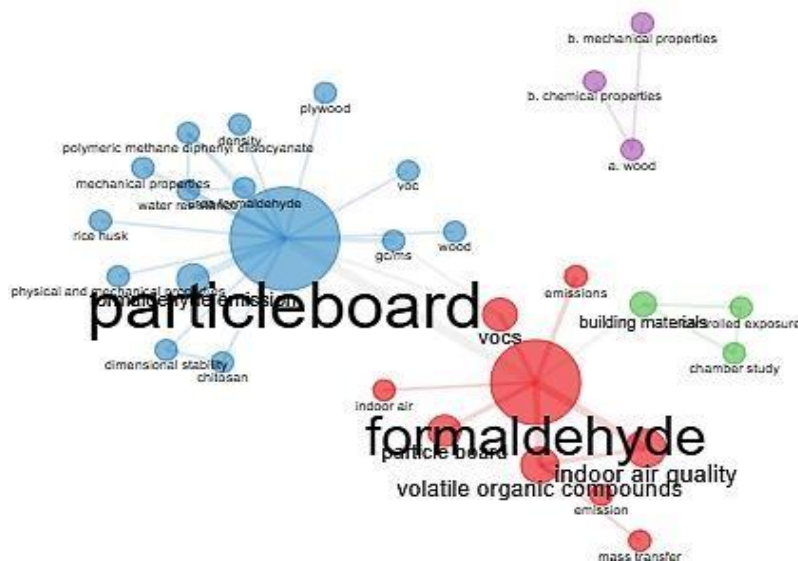


Figure 5 Clusters of Authors Key Word

The top 8 keywords often used by writers include formaldehyde (22), particle board (27), indoor air quality (8), volatile organic compound (7), building material(8), voc (5), emissions (5), and formaldehyde emission (6). This list is based on a keyword mapping of 346 author keywords in Figure-5. Based on the authors' keywords' co-occurrence, we identified four clusters: each cluster as particle board, formaldehyde, building materials wood has a consolidated group each working in four domains individually as process, impacts, usage, and properties/characteristics. The impacts of the formaldehyde employed in the manufacturing process of particle board were followed by it in terms of co-occurring keywords. The words co-occurred, VOCs, VOC emissions, mass transfer, and effect on indoor air quality are used to describe formaldehyde. The connection between the two simultaneous terms is represented by the network, while the frequency of a particular term is represented by its bubble size. A high frequency is indicated by the vicinity to the center of the figure and the font size. (Rawal et al., 2020) For instance, "particle board" and "formaldehyde" are the terms that are most frequently used in the cited literature's body text, followed by "building material" and "wood" in other clusters.

Figure 6 displays the keyword mapping and word usage frequency for the author. In comparison to the other keywords, research on building materials in relation to formaldehyde and VOC had taken place in the analyzed document from 1991 to 2009. These are the new themes in this context since research on "indoor air," "mechanical properties," and "particleboards" has increased recently. The term "emission" is not relevant when discussing particle board. The number of times the word "Particleboard" was used grew from 10 in 2009–2011 to 30 in 2016–2017.

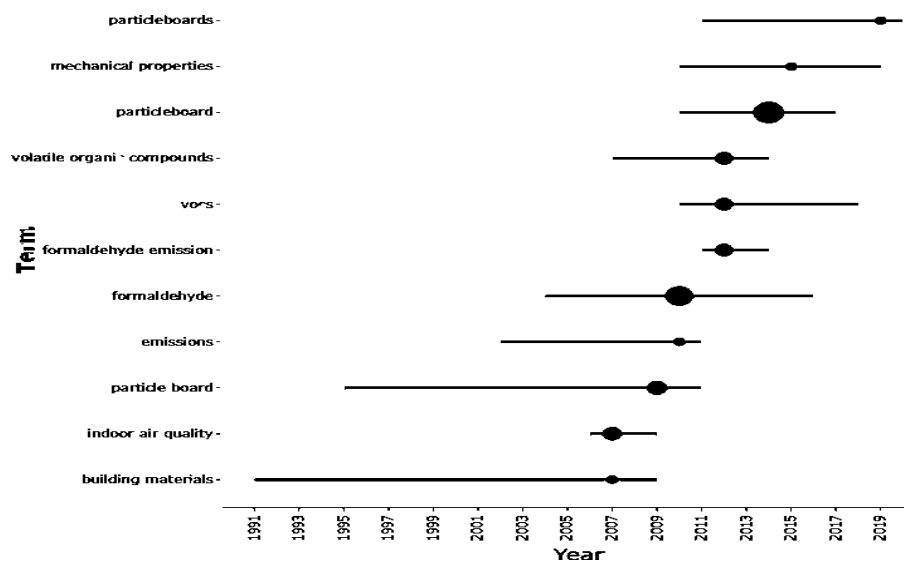


Figure 6 Word Dynamics-Trend Topics

Formaldehyde emission, VOCs, particle boards, and mechanical characteristics have emerged as the top co-related terms from 2010 to 2021.

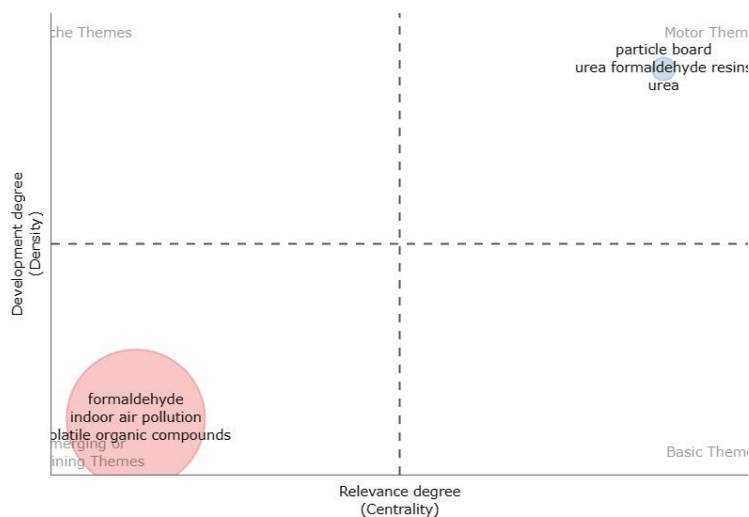


Figure 7 Relevance degree to the development degree of the theme

The conceptual framework of a certain study field is represented by thematic maps, which are a component of scientific mapping approaches. A thematic map identifies four typologies of themes based on the quadrant in which they are placed. Due to their high centrality and density, subjects in the upper-right quadrant are taken into consideration as developing and important issues for the research area. Themes located in the upper-left quadrant are thought to be exceptionally developed and isolated themes or niche themes because of their high centrality and low density. Emerging themes are those that are located in the lower-left quadrant and have a low density and low centrality.

Basic themes are those that are located in the lower-right quadrant and have a high density but low centrality. As shown in figure-8, volatile organic compounds, indoor air pollution, and formaldehyde are some of the modern study topics in the field of health in indoor spaces. Several research have sought to monitor and enhance indoor air quality using cutting-edge technology like smart sensors and machine learning algorithms. Interior professionals can rethink these technological advancements as a sub-theme for future

research, exploring their potential applications and benefits in creating healthier indoor environments.

4 Thematic Mapping

A useful method for displaying and interpreting spatial data is thematic mapping. It entails the mapping of information on a certain theme or issue. Thematic maps may be used to spot trends, correlations, and patterns in space that are not immediately obvious from raw data. There are various reasons why thematic mapping is significant. Thematic maps make it easier to study and comprehend geographical data. Data visualization on a map makes patterns and linkages more obvious, which makes it simpler to find trends, outliers, and hotspots. These maps are a powerful tool for disseminating geographical data to a wider audience (Yang et al., n.d 2012.) They may be used to convey complicated information in a simple, direct, and understandable way. In disciplines like urban planning, environmental management, and public health, thematic mapping is particularly crucial. It is simpler to spot regions that need attention, prioritize activities, and allocate resources more effectively when data is shown on a map. Planning and resource management can be facilitated by using thematic maps. In general, thematic mapping is an effective method for managing, evaluating, and sharing geographical data. It may be applied in a variety of areas, including urban planning and environmental management, to assist in decision-making and deepen our comprehension of the environment. By leveraging bibliographic coupling, the thematic mapping may be used to identify and display groups of linked research topics based on how frequently their references appear together in academic literature (Jain et al., 2021). Thematic mapping employing bibliographic coupling's underlying technique entails locating pertinent academic papers or articles and connecting them to the publications they were cited in. We did that by bibliographically connecting the papers using VOSviewer (Yan, & Ding, 2012). A measurement of the degree to which two articles have the same references is called bibliographic coupling. Publications with several citations are probably connected to the same area of study. VOSviewer groups articles with a high degree of bibliographic coupling using clustering methods such hierarchical clustering or modularity-based clustering, and then visualizes the results through clusters.

4.1 Bibliographical coupling

Based on common references, bibliographic coupling creates connections between diverse entities including authors, papers, journals, organizations, and nations. This method compares the amount of references that two publications have in common as a sign of shared intellectual property and a gauge of similarity (Zupic, 2015) A stronger link or relationship is shown by more instances of reference overlapping. The total link strength of the links indicates the extent of the connection or relationship. A greater relationship between the entities is indicated by a higher link strength numeric number. Influence measured using this approach does not change over time since references do not change (van Eck & Waltman, 2017). Related research topics are represented by these clusters. The number of papers and degree of bibliographic coupling are indicated by the size and colour of the nodes on the map, respectively.

Figure 8 displays the degree of bibliographic coupling between authors, documents, sources, organisations, and nations.

The figure displays bibliographic coupling of 437 most cited papers on pressed wood emission. The publications are highlighted on the basis of the number of common citations. The different node colors represent the effects of the Louvain group identification algorithm applied to the bibliographic matrix. (Jain et al., 2021).

Cluster 7 (orange colour) Scientists have directed their attention towards examining

the adhesives employed in particle boards. They have carried out a sequence of experiments using modified rubber derived from *Rhizophora* spp. wood to achieve a match with the mass attenuation coefficient. This coefficient is a significant parameter in the fields of radiation and medical physics, particularly for the detection of Stage 1 Breast Cancer.(Tousi et al., 2014).

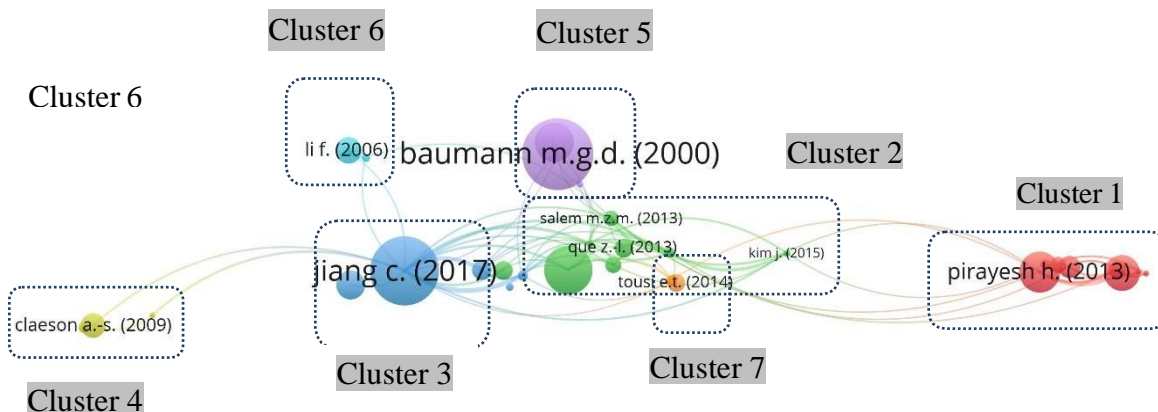


Figure 8 Bibliographic coupling of documents

Cluster 6 (Turquoise colour) has research that is concerned with indoor air quality and gas emissions. Real substrates like particle board would act like a "sponge," which lowers the peak concentration but prolongs the presence of VOCs from the applied paint, according to studies on the possibility of reducing formaldehyde emission, policy framework, and small chamber tests (Li et al., 2006). In relation to indoor parameters, the cluster is seen to have identification for comprehending the absorption of the emission through building materials, which occasionally act as sponges. Through the use of various manufacturing variables, the artificial neural network (ANN) approach, a form of artificial intelligence, is used to predict. This study may help the wood industry predict formaldehyde emission with less taxing experimental procedures, resulting in shorter experimental times, and lower experimental costs(Akyüz et al., 2017).

Cluster 5 (magenta colour) focuses on different emission from particle board. Terpene emission and Aldehyde emission experiments were conducted in the same 4-day condition stay. Terpene test and Aldehyde test were conducted in Gas Chromatography chamber. The Aldehyde test showed differences in VOC composition and emission factors by product and tree type. While Terpene test emissions were largely related to the extractive content of the wood species. The terpenes were almost completely absent in emissions from MDF samples, which indicates that differences in the manufacturing of MDF compared with the manufacturing of particleboard may have considerably affected emissions. (ZHANG, 1999)(BAUMANN et al., 2000) Wood-Plastic Composite (WPC) study was conducted in a Laboratory test to determine the release of formaldehyde, phenol, and ammonia from flat pressed WPC. Emissions from flat-pressed WPC were much lower than steady-state emission. This study recommended the use of WPC in Interiors as well as Outdoor applications.(Lyutyet al., 2017)

Cluster 4 (lemon green) Look into doing an experiment for air quality within a space of 2mx2m. The experimental set-up with and without nose-clip for 10 mins with the participants was carried out to understand the symptoms of exposure to dampness of the material selected. This was done to understand the base of poor air quality and to conclude understanding of nasal chemosensory part which enhances chemical symptoms from dampness in material(Claeson et al., 2009). A 1m³ climate chamber test was conducted to understand the effects of different Volatile Organic Compounds emitted from decorative

particle boards. Time span was one of the variable used in the experiment(L. Jiang et al., 2018). Use for the detection and monitoring of Microbial volatile organic compounds (MVOC) was conducted using ChemPro100i sensor machine. Detector responses were monitored before and after air sampling and data was analyzed by means of multivariate data analysis (MVDA) Basically it was related more to understanding the equipment to be used to monitor emission pattern of MVOC(Räsänen et al., 2010).

Cluster3(Blue):Formaldehyde contributes insignificantly to odor at room or higher temperatures. Emissions of HCHO and 44 VOCs were identified with their dependence on temperature(C. Jiang et al., 2017).The manufacturing of material from formaldehyde with hot pressing temperature and time are detected factors in influencing of VOC (Matthews, T.G. et al.,1987). Different chemical composition analysis for different types used as adhesives and their total and VOCs emissions of the particleboard manufactured under different conditions were investigated, for manufacturing. Increasing and decreasing density and time were variable factors experimented on.

Cluster 2(green):Resin was the major factor considered for reducing the pollutant emission rate of particle board during the production process (J. Kim et al., 2015).Surface coating plays an important part in specially formaldehyde emission (Pibiri et al., 2020). The wood composite products can also be ranked in the decreasing order of formaldehyde emission as follows: Chipboards > MDFs >Plywood ... (Plaisance et al., 2014). In field study of formaldehyde in homes were studied, the paper highlights, the evidence of presence and risk related to cancer and needed policy framework to govern it further.(Rovira et al., 2016)Cluster 2, can be identified as the base for the research to be undertaken. Experiments can be conducted with finished and unfinished material which can be the research gap understanding for use of a material purely in context with the interior spatial arrangement. Broadly understanding it further,

Cluster 1(red), has major focus on Physical and Chemical Properties of chip board focuses on walnut/almond shells as alternative raw material or filler in manufacturing particleboards used in indoor environment(Pirayesh et al., 2013). Also on adhesive based on renewable resources that is formaldehyde free is of great interest, such as wheat gluten (WG)-based adhesives(Khosravi et al., 2014).The cluster talks about fiberboards made by the dry method were stronger and tougher than fiberboards made by the wet method. The only shortcoming of the former was their low water resistance as samples dissolved in water(Kallakas et al., 2018). Experimental tests were conducted to determine the physical, mechanical, thermal, and fire-resistance properties(Ferrandez- Villena et al., 2020).This research can be diverted to material and space relationship.

6 Conclusion

The conclusion is derived by framing answers for the shortlisted Research Questions.This can further guide to decide the best possible route in understanding the scientific analysis of Space to Press wood Products.

RQ1: What are the publication trends in the area of emission through pressed wood?

During the period between 2012 and 2018, the number of publications related to formaldehyde volatile organic compound emissions decreased and was heading towards a single-digit figure. However, the global pandemic phase of COVID-19 in 2019-2020 caused research in this area to pick up the pace again, possibly due to prolonged indoor stays.

Therefore, there is potential for further research in the domain of interior space relevance regarding formaldehyde volatile organic compound emissions as inferred through figure 2. Table 2 & Table 3 clarifies the economic chronology of the publication

identifies the rise and concern in Developing countries, though at a snail's pace (Goletto et al., 2020).

RQ2: Who are the most prolific authors, journals, organizations, and countries contributing to the topic of emission through pressed wood?

Table 4 & Table 5 highlight the journals and documents having major citations. Bioresources and Building Environment tops the list in influential contents. This justifies to the authors engagement as seen in Table 6 with their engagements In Material Science (Shen J., Zhu X.-D, Liu Y.), Health, Medicine and Safety (Liu Y. Matthews T.G, Jarnuszkiwicz I.), Forest Services (Shen X., Salem M.Z.M.), Agricultural Science (Sitko E). Wiglusz is the only one in Environmental and Pollution Control. This clearly highlights the research done for improving the material at the grass root level. Figure 4 helps to understand the most consistent work by Wang (Goletto & Wang et al., 2020) (W. Wang et al., 2010) (D. Wang & Sun, 2002), who has the focused growth of work. Mapping the keywords in figure 5 & figure 6, further clarifies the connecting link of Formaldehyde, Indoor Air Pollution, Volatile Organic Compound.

RQ3: What are the mature and emerging themes in the area of formaldehyde emission from pressed wood products?

Bibliographic couplings connecting different entities including authors, papers, journals, organizations, and nations. The seven clusters identified through VosViewer. Cluster 7 examines authors and their elaborate understanding towards adhesives emission. Cluster 7 and Cluster 6 look into the mechanical and physical properties of particle board. Abridging with the health-related issues and elements of Interior which emits gases. Artificial Intelligence (AI) has been explored to control Formaldehyde emissions.

To thematically exploring the concern, it can be seen that if explorations for its emission control is done with the recent future ventures in AI, can't it be a start to give thought to the material itself at Interior Planning and Material Selection stage in Professional field of Interior Design?

Cluster 5 precisely shows the available variable for particle boards as Wood- Plastic Composite (WPC) (Lyutyy et al., 2017) (Wi et al., 2020). But as it is not economically viable, its usability in commercial spaces is not seen much. (<https://www.houzz.in/magazine/marine-plywood-vs-wpc-wood-plastic-composite-which-is-better-stsetivw-vs~113804609>). This again orients the study towards commercially acclaimed pressed wood products as Plywood, Medium Density Fiber boards, Particle Boards

Cluster 4 helps to create the model for conducting the experiment for this research. It also identifies that time is one of the variables in emitting VOC. There are many VOC's which can be detected and studied through different equipment and sensor machines (Räsänen et al., 2010)

Cluster 3 makes temperature one of the main contributors of formaldehyde, which can be studied at different levels.

Cluster 2 looks into the application part of the material products from wood by cross checking and analyzing the certified standard limits of the chemical profiles in the material products from wood.

Cluster1 focuses more on the concentration of the product manufacturing with sustainable materials and testing the necessary physical, chemical properties. The cluster1 focuses more on the production of the material of wood or wood particles or wood waste mixed with another organic or sustainable or eco-friendly material. The above papers are by authors working from the middle of 21st century for manufacturing only. The direction can also be continued as Cluster 2 and Cluster 6 focus to the Indoor Air Quality with the existing circumstances as is.

RQ4: What are the directions for future research to bridge with its use in Interior Spaces?

In the future, the scope of research and understanding of formaldehyde VOC within the interior design profession could expand in several ways. For example:

- Development of standards and guidelines: Research in this field could lead to the development of standards and guidelines for formaldehyde exposure levels in indoor spaces, by- quantification of the material to be used within the defined volume, or, by absorption-desorption factors to reduce or neutralize the formaldehyde exposure within the guideline framed work by certified organizations.
- Increased focus on sustainability: As the focus on sustainability and environmental impact continues to grow, research on formaldehyde VOC could also focus on identifying and promoting alternative, eco-friendly materials that have low VOC emissions.
- Advancements in technology: Advances in technology, such as sensors and monitoring systems, could be used to more accurately measure and track formaldehyde exposure levels in indoor spaces, providing valuable data for designers and building managers to make informed decisions.
- Collaboration with other fields: Interior design professionals could collaborate with experts in fields such as medicine, engineering, and chemistry to gain a deeper understanding of the impacts of formaldehyde VOC on human health, and to develop effective strategies for reducing exposure.
- Education and awareness: The awareness of Formaldehyde VOC should be increased in Interior design education and in the industry, in order to empower designers to make informed decisions about materials selection and to promote healthier indoor environments.

Overall, future research and advancements in the understanding of formaldehyde VOC within the interior design profession, could lead to the development of safer and healthier indoor environments for building occupants.

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