Chapter 37
Bibliometric Study on Particle Emissions of Natural and Alternative Building Materials

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37.1 Introduction

Pollution characterised by building construction material emissions has become a hot spot of study due to its accompanying environmental and health complexities. This research aims to conduct a structured literature review on the subject of particle emissions of natural and alternative building materials. The high demand for construction materials is dependent on consumption of raw materials (Lassio and Naked, 2016). The difficulty of determining the pattern of toxins emitted from the use of building construction materials by the built environment professional has led to the use of several toxic materials which are worthy of attention. Some of these materials are legally accepted, yet they contain some form of toxicity (Levin, 2016; Pacheco-Torgal & Jalali, 2011). Thus, there is the need for environmental assessment of building materials so as to substitute those prone to health ramifications with more environmentally friendly ones in the delivery of sustainable building construction projects (Farahzadi et al., 2016).

In their study of building material emissions through regression, He et al. (2005) argued that emission parameters have a causal connection between the molecular structure of compounds and material properties. Their study explained that the two most widely accepted physical models for emission determination are (1) the diffusion coefficient [D] and (2) the partition coefficient [K]. Thus, many researchers use Fick's law to interpret the mass transfer inside the material due to the concentration difference. The argument by He et al. (2005) was affirmed by the research carried out by Zhang et al. (2018, p.3) – through material efficiency by separation and

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dematerialisation. The material efficiency measurements 'include all changes that result in decreasing the number of materials used to produce one unit of economic output or to fulfil human needs'.

To be able to assess the emission characteristics of building construction materials, there is a need to determine the emission factors and the taxonomy of chemicals emitted concerning the materials' health intricacies. Analysing the search results from a bibliometric review, an overview of natural and alternative material emissions is presented in this paper with discussions and pathway for future research.

The procedure involved a detailed literature review of building construction materials to provide a summary of existing studies of particle emissions. The literature is relative to the health implications of the materials in question that apply to the built environment. The study depended on those building construction materials available on the market with emission quality deductions and consisted of three stages.

Stage 1 consisted of articles retrieved from reputable databases from a list of publications using the keywords as the benchmark. Further, articles from each database were grouped and sorted based on their relevance to the objectives of the study. In stage 2, a systematic review of the articles (peer-reviewed journals, original industry reports) and books to solicit for the data of particulate matter emissions of building construction materials and their health benefits and/or challenges was carried out. Critical reading was carried out to obtain evidence and to provide a useful evaluation of the text. Stage 3, the final stage, considered the impact of emissions on human health from literature.

37.2 Search Strategy

The scope of the literature search was within the confines of the widely academically recognised databases, namely, Google Scholar, ScienceDirect, ResearchGate and Web of Science. The literature was then sorted according to their background, for example, *Journal of Cleaner Production* (*JCP*), Multidisciplinary Digital Publishing Institute (MDPI), ResearchGate and Original Industry Reports and Letters. The studies that did not connate to the objectives of the review were removed. The literature retrieval was done using the keywords and Boolean logical operators – for example, natural and alternative building material emissions. Sources of literature that had strong affinity to the study theme were used as a foundation for the review (Ramdhani et al., 2014). Also, particulate matter emissions, factors affecting material emissions and building construction material efficiency were included in the search plan as text words. To ensure that high-quality literature was used, refereed journals and original documents were selected for the study (Wallace & Wray, 2013).

37.2.1 Frontline Literature

A total of 127 journal articles, industry reports, letters and unpublished articles were retrieved from various databases. Following Sun et al. (2020) and Chan et al. (2020) study, a scrutiny of all the articles was carried out. Repeated articles were removed and those articles with the required relevance to the study were selected. After this consideration, a total of 107 articles remained. With the need for more relevance, a comprehensive examination of abstracts, conclusions and full-text analysis was carried out. After the examination of the abstracts, conclusions and text analysis, 53 of the articles found to be relevant to the research were collected for further studies. Seven out of the 53 publications were deemed to be most relevant to the study and were captioned 'frontline literature', and they were used as the basis for the literature synthesisation. Table 37.1 shows the keywords setting used for the search. Table 37.2 shows the spread across various search results of the final literature. Table 37.3 clarifies the synthesised matrix organised by frontline literature (Fig. 37.1).

37.3 Family of Construction Materials

37.3.1 Natural Materials (Traditional)

In their study of building material emissions for the construction of classrooms, Moulton-Patterson et al. (2003) classified 'commonly used building products containing low or no recycled content' as standard or natural materials. When the working life of construction material is increased, the eco-friendliness of the content is improved (Edwards and Bennett, 2003; Hertwich et al., 2019). In their study of material efficiency, Ruuska and Häkkinen (2014, p. 267) argued that the use of natural materials supports the quality of life of the occupiers of the building. They posit that the 'natural building material that has the required emission stipulations provides a better construction option and also reduces emission'. Natural materials are found as either renewable or non-renewable. The renewable materials are those that

Table 37.1 Keywords setting used for the search

Parameter	Setting
Keywords	Natural material and particulate matter emissions
	Alternative material and particulate matter emissions
	Natural material emission factors
	Alternative material emission factors
	Particulate matter emission factors

Table 37.2 The spread of literature search relevant to the study

No.	Database/ background	Initial retrieval	Final retrieval relevant to study	References
1	Google scholar	50	21	Maoeng et al. (2020), Had and Brain (2020), Milner et al. (2020), Aisyah et al. (2019), Huang et al. (2019), Keita et al. (2018), Souza and Borsato (2016), Gonçalves de Lassio and Naked Haddad (2016), He et al. (2005), Upstill-Goddard et al. (2015), Doroudiani et al. (2012), Glass (2011), Reed (2011), Ghumra et al. (2011), Holton et al. (2008), James and Yang (2005), Magee (2005), Moulton-Patterson et al. (2003), Edwards and Bennett (2003) and Bellis (1998)
2	ScienceDirect	19	11	Xia et al. (2020), Jung et al. (2019), Nwodo and Anumba (2019), Harb et al. (2018), Martínez-Rocamora et al. (2016), Wille and Boisvert-Cotulio (2015), Azari (2014), Ramesh et al. (2010), Haapio and Viitaniemi (2008), Aoki and Tanabe (2007) and Wegener et al. (2007)
3	Original industry reports and letters	16	11	Raifman et al. (2020), Greenstone and Ryan (2020), IISD (2019), Chin et al. (2019) Hertwich et al. (2019), SimaPro Library Database Manual Colophon, M. (n.d.), Meng et al. (2015), Hillman et al. (2015), United States Environmental Protection Agency (2013), Baetens et al. (2010) and Järnström (2007)
5	Multidisciplinary digital publishing institute	9	5	Shi et al. (2020) Kong et al. (2020), Sun et al. (2020), Mohajerani et al., 2019) and Ruuska and Häkkinen (2014)
6	*Journal of cleaner productions*	7	4	Cheriyan and Choi (2020), Silva et al. (2019), Khoshnava et al. (2018) and Gmelin and Seuring (2014)
7	ResearchGate	10	5	Zhang et al. (2018), Levin (2016), Farahzadi et al. (2016), Jalali (2015) and Zhang (1997)
	Total	111	57	

can be replenished after harvesting, while the non-renewable material resource is those that can only be gathered once. The theory of durability concerning material efficiency was corroborated by Lifset and Eckelman (2013) and Levin (2016). In his plenary architecture lecture, Levin (2016, p.15) explained, 'selecting natural building materials that are durable has sufficiently environmental benefits than the one that must be substituted more than once in the life of the building'. For example, when the concrete cover is doubled from 10 mm to 20 mm, the service life of

Table 37.3 A synthesised matrix organised by frontline literature

Author and date	Purpose	Finding	Background
Kong et al. (2020)	To evaluate the carbon emissions during the construction process of a prefabricated concrete slab	The carbon emission from prefabricated concrete slab is 35% less than cast in place (p. 12)	MDPI
Hertwich et al. (2019)	To address the current state of knowledge in reducing emissions through material efficiency focusing on product groups: Building, vehicle and electrical	A considerable potential exists to decrease abundant emissions connected to material production used in buildings and vehicles. Evidence for emission reduction in the electrical group is limited (p. 13)	*Environmental research letters*
Farahzadi et al. (2016)	To examine the similarities in energy efficacy and emissions of using traditional materials with proposed alternative ones (p. 187)	Using eco-friendly materials in building construction reduces energy consumption and promotes emission reduction	ResearchGate
Levin (2016)	To exhibit analysis to assist design alternatives in reducing harmful impact on indoor and general environments	'Durable materials are less likely to emit contaminants into the atmosphere, will require less toxic chemicals for the maintenance and refurbishing and, by definition, will be longer lasting' (p. 17).	ResearchGate
Pacheco-Torgal and Jalali (2011)	To discuss the effects of toxic building materials	'Several building materials that comply with regulations remain toxic to human health' (p. 5)	ResearchGate
He et al. (2005)	To use emissions data to provide information on emission parameters (p. 60)	Compound molecular structure and material properties affect diffusion and subsequently affect emissions	Google scholar
Moulton-Patterson et al. (2003)	To compare emissions data of traditional materials with that from no or low recycled products (standard) and those with high recycled content, rapidly renewable and/or products containing low or no VOCs (alternative)	Many products tested emitted chemical concentrations exceeding the allowable concentration limits used in the study	Google scholar

reinforcement – 'defined as the time it takes carbonation to reach the reinforcement', Levin (2016, p. 63) – is increased by 400% but increases concrete consumption by only 5–10%. Farahzadi et al. (2016) proposed a variety of conventional construction materials: viz. standard bricks, oil paint, aluminium frames, polystyrene thermal insulation and air-filled double glazed windows.

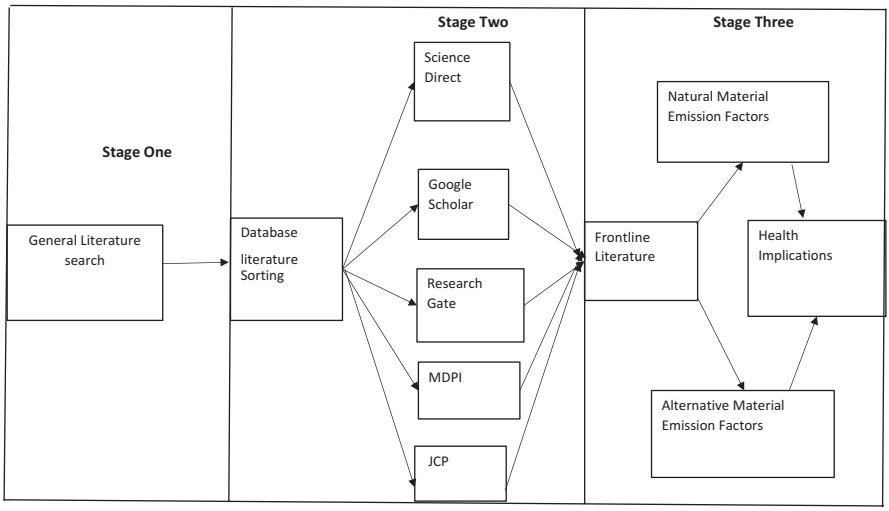

Fig. 37.1 Literature search process after Sun et al. (2020)

37.3.2 Alternative Materials

Moulton-Patterson et al. (2003) carried out an extensive study on material emissions for the construction of schools in the United States. During their study, they classified alternative materials as those with 'higher amounts of recycled content, rapidly renewable materials, and/or products containing no or low volatile organic compounds – VOCs' (p. 1). However, in their study of the assessment of alternative materials, Farahzadi et al. (2016) also established the following materials as being alternative construction materials, thus clay blocks, glass wool thermal insulation, acrylic paint, wooden frames and argon-filled double glazed windows. In his study of building ecology (design alternatives), Levin (2016, p. 7) characterised building materials as one of the essential primary criteria for classifying a building as either healthy or not. The trade-offs in using alternative building construction material are to accomplish the expected results. The optimum way of doing this is 'to select low emitting products, to condition or treat the product before installation or to ventilate the building after installation before occupancy'.

To this effect, the most prudent way of reducing environmental pollution from building construction materials and thus raise its efficiency is to use them again at the end of their useful life to prevent them from going through the processes of extraction to processing (Hertwich et al., 2019) (Table 37.4).

After Farahzadi et al. (2016)

Table 37.4 Conventional and alternative building construction materials

No	Conventional materials	Alternative materials
1	Brick	Clay block
2	Petrochemical insulation (polystyrene)	Mineral-based insulating (glass wool)
3	Synthetic and petrochemical paints (oil base)	Natural paints (acrylic)
4	Aluminium window frames	Wooden window frames
5	Double glazed 6 mm spacing (air-filled)	Double glazed 6 mm spacing (argon-filled)

37.4 Natural and Alternative Material Selection

In their study of validating a set of empirically weighted sustainability indicators for construction products, Ghumra et al. (2011) posit that pollution from the use of the construction materials was highest on the ranking of all indicators. Life cycle assessment (LCA) has the most significant attention based on the indicators' respective weightings used in their study. Even though LCA is a widely accepted criterion in the promotion of sustainable material selection, the process is intensive and difficult to handle. Upstill-Goddard et al. (2015) argue that those responsible for material selection may choose other methodology and still aim for higher performance. To this effect, Upstill-Goddard et al. (2015) suggest that LCA methodology should be carried out and promoted as a separate entity.

Khoshnava et al. (2018) conclude that the action of building material selection involves a complex challenge which usually looks at quality, performance, beauty and cost to reveal the main serviceability functions. In selecting building materials, whilst the focus is usually on the environmental impact reduction, it is imperative to consider the economic and social impacts as well. The emission characteristics which contribute to human health efficiency are considered under social impact.

37.5 Particulate Matter (PM) Emissions

Particulate matter emissions are characterised by the presence of small particles and liquids.

Depending on their size, particles can be inhaled deeper into different parts of the respiratory system causing serious health challenges.

Doroudiani et al. (2012, p. 264) investigated the toxic release from construction materials during fire. The authors reported in their study that 'particle size larger than 5μm are filtered in the upper respiratory system while the smaller ones can travel to bronchial and alveolar areas'.

In their study on cities' ambient particulate matter source contribution Karaguliana et al. (2015) and Bylone (2019) clarified that as of year 2015, PM was judged to be the core function for health effects of pollution.

37.5.1 Emissions and Human Health

Pacheco-Torgal and Jalali (2011, p. 2) substantiated that a large number of building construction materials exhibit some form of toxicity, 'thus causing several health-related problems such as asthma, itchiness, burning eyes, skin irritations or rashes, nose and throat irritation, nausea, headache, dizziness, fatigue, reproductive impairment, disruption of the endocrine system, impaired child development and birth defects, immune system suppression and cancer'. Table 37.5 shows some cancer-causing agents and their likely sources from paints used in the building industry.

The global burden of disease (GBD) reported in 2015 that air pollution is the fifth-ranked mortality factor (Burnett et al., 2018).

During a fire, significant toxic chemicals are emitted from building materials. These chemicals released are very harmful to human health (Doroudiani et al., 2012). Considering Doroudiani et al. (2012) study and GBD (2015) report, it is imperative that emissions from both the usage of materials and their combustion properties are taken into account during selection of natural and alternative materials for construction projects.

37.5.2 Factors Affecting Building Material Emissions

The detailed study carried out by Moulton-Patterson et al. (2003) outlined certain critical factors that affect the emissions from materials. Examples of these factors include:

- Quantity of material used in a particular operation.
- The assumed average ventilation rate.
- The time between completion of construction and occupancy.
- Building ventilation rate before and during occupancy.
- Age of material between manufacturing and installation.
- Storage, delivery and construction practices.

Table 37.5 Carcinogenic properties in paint

Property	Likely source
Chromates	Primers
Cadmium	Pigments
Benzene	Solvents
Nickel compounds	Pigments
Tetrachloroethylene	Organic solvent
Lead	Primers, dryers
Methylene chloride	Paint strippers

Source: Pacheco-Torgal and Jalali (2011)

These factors critically affirm that material efficiency has a larger role to play in terms of emissions. This means emission of a material is a direct function of the quantity of material and its concentration present in a product which affirms Fick's law.

37.6 Material Efficiency

Holton et al. (2008) emphasise the role of responsible material sourcing leading to enhanced material selection through material efficiency to provide an avenue to unlock opportunities to improve competitiveness.

In this perspective, Glass (2011) argued that responsible sourcing in industrial procurement practice is a challenge to selecting sustainable efficient materials. The study explains that for selecting an efficient construction material, there is the need to be proactive rather than reactive. 'The construction industry's fragmented supply network is a fundamental problem' (Glass, 2011, p. 169). Zhang et al. (2018) established that eco-friendly indicators emphasise the environmental reduction of resource use. The study by Ruuska and Häkkinen (2014), Edwards and Bennett (2003) and Hertwich et al. (2019) corroborates to the assertion that the durability and longevity of a material contribute to its eco-friendliness and thus its efficiency.

37.7 Conclusion and Future Research Direction

Motivated by building material emissions and their accompanying health complexness, this study concentrated on the need for insight into particle emissions of both natural and alternative building materials as directions for sustainable built environment achievement. The literature was sorted and categorised to help understand the pathway to the study of material emissions in the academic fraternity. A list of the important databases with their brief research engagement helped to outline the scope of this review. Durability and longevity of construction materials appear to be very significant in the study of construction material selection as corroborated by the study carried out by Ghumra et al. (2011).

The problem of selecting good quality material with emission-free health challenges stems from the fact that the built environment professionals have little clue of knowing about the toxicity of building materials. Throughout the review, literature has been quiet on the emissions of PM_{10} and $PM_{2.5}$ released from the use of both natural and alternative materials. This calls for concern, and a more significant research direction is required towards the study of this phenomenon to yield the required data that is essential for analysing the health complexities accompanying the use of these construction materials. Alternatively, the review confirms several studies on emissions relative to carbon and volatile organic compounds on building materials.

The study has been limited because to ascertain a more in-depth theoretical account, detailed analysis and discovery are paramount to bring forwards the boundary of emissions between natural and alternative materials.

Future research pathway(s) should provide more information on particulate matter emissions (PM_{10}, $PM_{2.5}$) of building construction materials with various quantitative emission factors of both natural and alternative materials.

Responsible material sourcing has also been found as an enhanced methodology to promote the mitigation of challenges associated with material selection. To this effect, even though life cycle assessment methodology is cumbersome, it provides a better inclusion in responsible sourcing (ethical management of sustainability issues within the construction supply chain) to demonstrate transparency with regard to the materials within a particular product, and thus aids in their selection.

When this is done, the confidence for material selection will be expanded to enable the built environment professional to make bold and knowledgeable decisions in this direction.

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