

Innovation of Environmentally Friendly Building Materials Based on Waste: Literature Review

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Abstract

This study explores the Innovation of environmentally friendly building materials, focusing on using Waste as a raw material for bricks as an alternative in the construction industry. This study aims to analyze organic and inorganic waste-based building materials to support the practice of environmentally friendly brick concepts with resistance to concrete compressive strength and reducing energy consumption. Using the Systematic Literature Review (SLR) method, this study focuses on the topic of using natural fiber waste, Cigarette Butts, RCF, Plastic PET, Pleurotus Florida, and Empty Oil Palm Fruit Bunches, which have been identified as potential solutions. Overall, the study results show two main aspects in making environmentally friendly building materials, namely the element of raw materials and production procedures. Raw materials from organic waste fibers and inorganic Waste have become of interest and have experienced significant development in various countries; this Waste can be used as raw materials for making bricks, which help reduce environmental impacts, support sustainable practices, increase energy efficiency by reducing energy use by 9.5%, having a concrete compressive strength of 7-20 Mpa. the use of environmentally friendly building materials provides long-term ecological benefits

Keywords: *Bricks, building materials, waste*

A. INTRODUCTION

A sustainable environment is a concept that emphasizes the utilization of resources without disturbing the ecosystem so that it is maintained for the future. This concept has become an exciting and widely discussed topic, especially regarding the construction industry (Effendi et al., 2018) In addition, this concept is one way to reduce the negative impact of development on the environment and as a form of justice between generations (Cahyani, 2020) Significant interest in sustainable development has increased in various developed countries. This is because the depletion of raw materials and resources has become widespread and almost uncontrollable, causing significant environmental impacts and concerns. Sustainable development aims to optimize the use of natural resources without harming the standard of living of society and communities (K et al., 2016)

The construction industry sector is one of the primary users of natural resources and carbon emitters worldwide. Building materials such as sand, cement, bricks, and steel are commonly used in the construction industry. These materials come from natural resources that will damage the environment if used significantly due to their depletion. In addition, during the manufacturing process, various building materials can contribute high carbon dioxide to the atmosphere (Al-Tameemi & Al-Kadhim, 2023) The extraction of raw materials for construction often hurts the ecosystem and reduces biodiversity. The need for building materials will increase due to the growth of cities and infrastructure development worldwide.

To answer this challenge, environmentally friendly buildings are one of the efforts to support lower carbon development through policies and efficiency of energy, air, and building material programs. Using environmentally friendly buildings is beneficial to the environment and economically beneficial by reducing operational and maintenance costs (Pradana & Hariyani, 2021). In this case, the role of civil engineers and architects is needed to explore more environmentally friendly and durable building materials because most of the damage to the ecosystem comes from building materials (Ul Haq et al., 2023). One of the innovations in building materials is to utilize Waste, which appears to be a promising solution for sustainable development. Mixing certain building materials with waste materials can provide reasonably good results; besides that, the use of waste materials as renewable resources in building materials can be a way to minimize pollution by reducing soil contamination at the final disposal site. However, it must be able to consider all negative processes from the production process (Bories et al., 2014)(Alam et al., 2021). **This study aims to analyze** organic and inorganic waste-based building materials to support the practice of environmentally friendly brick concepts with resistance to concrete compressive strength and reduced energy consumption.

B. Method

Systematic Literature Review (SLR) is used in this study to identify, review, evaluate, and finally interpret each existing study. Articles in accordance with the research topic are then reviewed based on the subject or theme of the research question. At the review stage, it is carried out in a structured and systematic manner in each predetermined process; the next step is to conduct an in-depth study of the reviewed articles.

Techniques

There are five stages in this systematic literature review technique, namely: 1) building research questions, 2) mapping articles that are by the research questions, 3) including/classifying and excluding/evaluating to select articles that have been obtained, 5) data is presented and processed, 5) the findings contained in each article are then interpreted to draw conclusions.

Identification

Identification is carried out to choose a theme by the research subject, then look for words synonyms with keywords, namely, Innovation of environmentally friendly building materials based on Waste. The process of searching for literature study data is carried out through the www.scopus.com database using the keywords 'brick, AND eco-friendly, AND Waste AND buildings AND material.

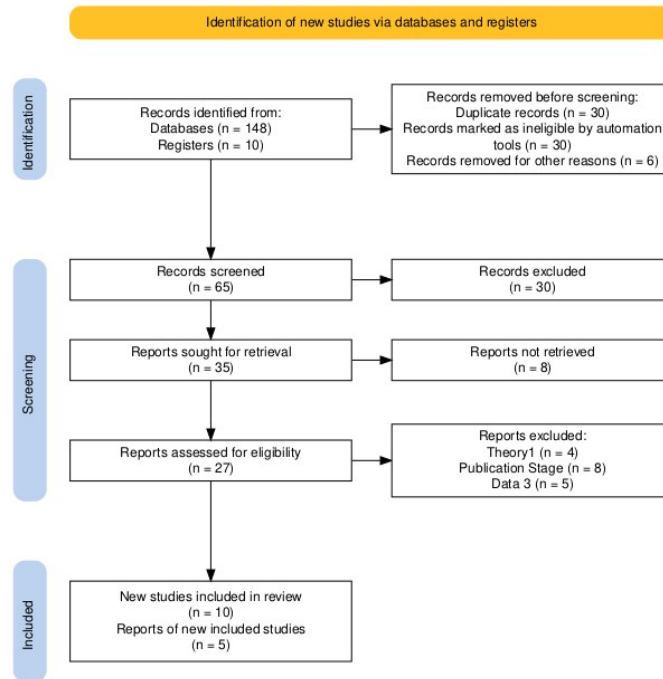


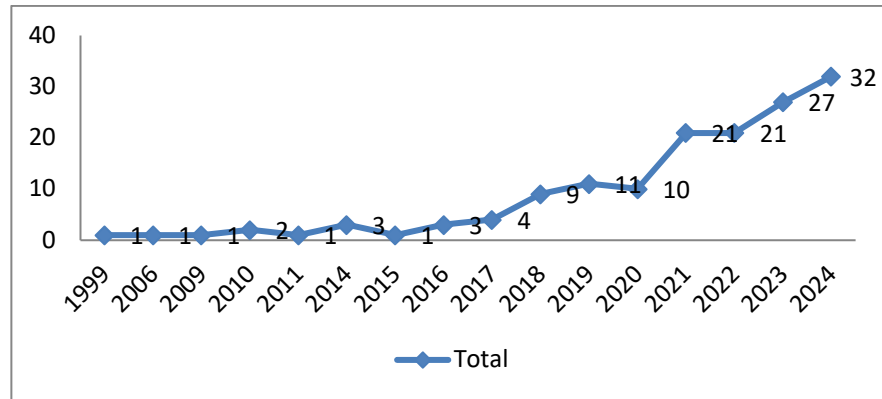
Figure 1: Identification flow (Source: Analysis By Author. 2024)

From the process of searching for relevant articles, 148 articles were initially found that appeared according to the keywords used; then identification was carried out based on several criteria to reduce articles that did not match the established criteria, namely, year of publication (2019-2024), open access, type of document, from this reduction process the number of articles was reduced to 134. The filtering process was carried out again by looking at the title, and the contents of the article were then analyzed, 10 articles were found that met the criteria, and from these results, 5 articles were selected to be analyzed and reviewed in depth according to the theme being studied

C. Results And Discussion Publication Trends

Topics related to environmentally friendly building materials have become an interest and have experienced significant developments to be studied and used as a focus of research from various fields; in recent decades, the use of Waste as raw materials in buildings for industrial construction can minimize the negative impact on the environment. Many studies have been developed to process Waste into valuable materials, especially organic Waste and inorganic Waste. The purpose of all these studies is to obtain sustainable building materials.

Judging from the publication trend from the Scopus database, there are many studies related to Waste that can be recycled into more efficient building materials and, if supported by appropriate technology, can be an alternative building raw material. Figure 2 shows the rate of publication trends from research that has been published in the last period. This proves that science is broad and continues to innovate



Gambar 2. Publication Trends
(source.scopus.com. 2024)

In Figure 2, research on environmentally friendly building materials started in 1999 and will continue until 2024. This trend recognizes the possibility that it will continue to grow. The data displayed from 1999 to 2018 contains a total of 17 studies. In 2019, 9 studies were published; this data shows a significant increase from the previous year, only around 0.89 per year. Meanwhile, in 2021, there was a decline compared to 2020; the spike occurred quite high in 2021, while in 2022, it was stable and rose again in 2023, continuing to grow until, in 2024, there were 32 studies. The upward trend in the last five years shows that many factors are driving the growth of studies related to waste utilization innovations, such as the number of campaigns related to climate change.

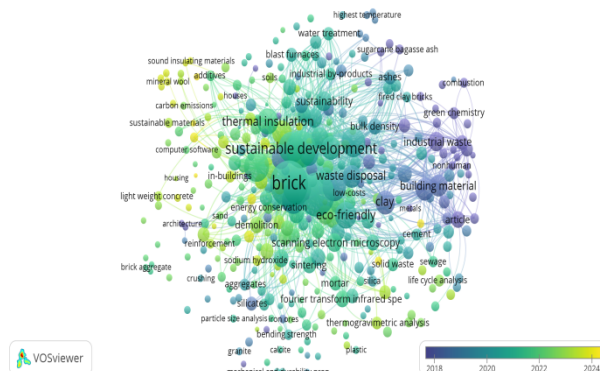


Figure 3 VOSViewer Visualization of Time Range of Research Topic Distribution
(Source: Analysis by Author. 2024)

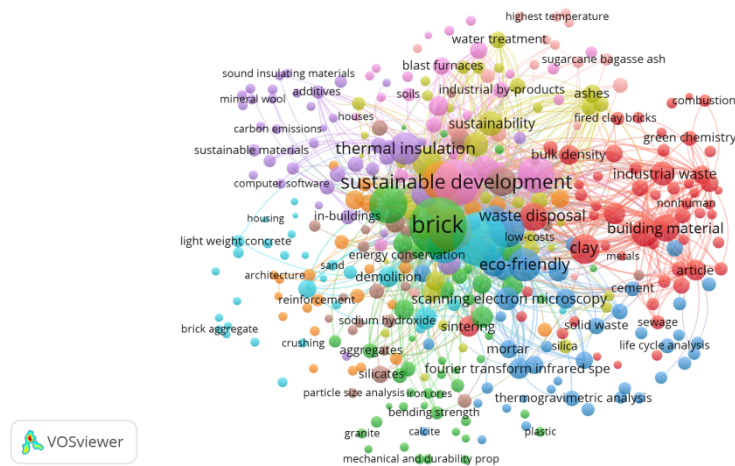
VOSViewer network visualization Figure 3 with the addition of a time scale element, indicated by a color gradient from blue to yellow, indicating the period from 2018 to 2024. This shows the change in focus or popularity of research topics over time in the analyzed dataset. Here is a detailed analysis based on the available information

Blue (2018): Blue topics are more concentrated on the left and right sides; this can indicate dominant or previously researched topics. For Green (around 2020-2021): its distribution almost throughout the network, it can be assumed that this topic is exciting and developing during that period. Yellow (2024), with a focus on the keywords "sustainable development" and "eco-friendly," approaching 2024, there is an increase in research focus related to these topics

Both keywords, sustainable and brick, are central to the network and show sustainability as the center of this research. Thermal insulation and waste disposal indicate interest in the new topics indicated by the more yellow color, showing an increased focus on energy efficiency and sustainable waste management; Fourier Transform Infrared Spectroscopy and Thermogravimetric Analysis are analytical methods that appear in the more yellow color, indicating that they have become more relevant or frequently used in recent studies to evaluate sustainable materials.

Color Categories, Relationships, Clusters and Connections

Green: Related to building and construction materials, such as lightweight concrete and demolition. Red: More focused on environmental and sustainability aspects such as eco-friendliness, waste disposal, and sustainability. Blue: Includes scientific techniques and methods such as Fourier transform infrared spectroscopy and thermogravimetric analysis. The close interaction between brick and eco-friendly and low-cost building materials shows that the research focuses on developing building materials that are not only sustainable but also economical. The link between waste disposal, industrial Waste, and recycling indicates vital research in processing industrial Waste as valuable materials in construction, contributing to sustainable development.



**Figure 4 VOSViewer visualization of research topic distribution
(Source: Analysis by Author, 2024)**

Visualization of VOSViewer in Figure 3 shows the relationships between topics in a particular study, usually based on word frequency or co-citation in the scientific literature. Here is the visualization analysis: Main Focus Point Sustainable Development: This is the most significant point in the center, indicating that this is the main or most frequently discussed theme in the analyzed data set. Bricks and Eco-friendly Look very close to "sustainable development," suggesting that environmentally friendly building materials such as bricks are a relevant topic in sustainable development.

Sustainable and environmentally friendly Brick concept

In conventional bricks, such as red bricks, the burning process can produce black carbon and other pollutants because the production process uses wood as fuel. In addition, the local ecosystem is also affected and contributes to climate change because carbon absorption is reduced. (Kumar et al., 2024) In the construction industry, building materials should be switched to sustainable and environmentally friendly materials.(Moazzem et al., 2022) To support sustainable development, the use of environmentally friendly building materials is

essential so that it can reduce the impact of environmental damage. Because its design considers the impact of ecological balance and life cycles.(Saghir Hussain, 2023) In recent years, the construction industry should have switched to an environmental approach to use natural materials. This material can come from Waste, natural fibers, rocks, plants, or animals (Nowotna et al., 2019) It is time for the construction industry to use environmentally friendly and sustainable building materials.

To make environmentally friendly and sustainable building materials, it is worth paying attention to raw materials and manufacturing procedures. There are several alternatives to the use of raw materials, such as utilizing other materials such as Waste, natural fibers, or other natural materials such as zeolite tuff rocks. The use of bricks from cigarette butt waste and zeolite rocks directly encourages construction practices to be less dependent on conventional raw materials and can also reduce environmental impacts (Ibrahim et al., 2024) Zeolite material is a pyroclastic rock material that can absorb cations (Lia Nazmi Aida, Wawan Budianta, 2020) Zeolite tuff material on earth is quite abundant and naturally available. Because it has good absorption, it can be used as a mixture for making bricks with recycled fiber waste materials. Cigarette butts are one of the most abundant types of Waste and can contribute to environmental pollution. Recycling into bricks helps reduce Waste disposed of in landfills or burned. This method can reduce the use of conventional raw materials so that environmental impacts are controlled, which is part of sustainability efforts (Mohajerani et al., 2020)

Using PET waste to produce clay-cement bricks supports sustainable practices by reducing the amount of plastic waste dumped into the environment. This study shows that by utilizing PET waste, the construction industry can contribute to a circular economy and reduce the environmental impact of plastic Waste. Making clay-cement bricks, unlike traditional bricks, which do not require firing, can reduce greenhouse gas emissions. By reducing the need for firing, this study contributes to reducing the construction industry's carbon footprint. There is also PET waste with a mixture of cement and soil; this step is to make the construction of building materials sustainable and economically feasible because, in general, this Waste is not utilized and is simply thrown away; the recycling carried out practices the concept of a circular economy (Rodrigues et al., 2021)

Brick Durability

Adding bricks with Waste can provide concrete strength and durability of 20%, and 12.5% is the smallest concrete compressive strength. Based on the provisions for raw materials from Waste, it can be used as a mixture of bricks. 13](Putra et al., 2023). Compressive strength is an important property for construction materials. Bricks made by meeting the important compliance requirements outlined by national standards indicate their suitability for use in construction (Xin et al., 2023) Bricks with a higher percentage of water cement have higher compressive strength. Bricks with 14% cement can achieve a compressive strength of more than 3.5 MPa, and bricks with 20% cement can achieve more than 7 MPa. Each class of brick tested has a water absorption of less than 20%, which meets the minimum criteria of IS 1077:1992.(Alam et al., 2021)

Energy Efficiency

Conventional bricks require relatively high energy compared to bricks made from Waste because the production process uses high temperatures and causes a carbon footprint.(Kumar et al., 2024).Bricks made from zeolite waste and cigarette butts show excellent thermal insulation properties, which can significantly increase the energy efficiency of buildings. Innovation in raw materials for making bricks continues to occur, especially raw

materials from Waste, but Waste alone is not enough if not mixed with other materials. In several studies, the use of Waste from cigarette butts can minimize the use of heating machines and also air conditioning machines. This gives hope that environmental damage caused by climate change and greenhouse gases can be reduced. In addition, this Innovation presents new building materials from other Waste that are more efficient in terms of energy waste (Mohajerani et al., 2020)(Ibrahim et al., 2024)Waste has many benefits if managed properly; it can become a renewable resource in the construction industry, especially in the preservation and practice of environmentally friendly construction. Plastic Waste, which has been widely developed for building materials, is Waste(Aneke & Shabangu, 2021) from the results of the study of the utilization of RCF waste in the production process during burning, there is a decrease in temperature by 9.5%, and reduced CO2 emissions by 471 tons. The use of a brick mixture using RCF waste produces quite significant thermal properties (Xin et al., 2023)

Biodegradability

Fiber is a natural, easily decomposed material; therefore, it can be used as a solution as a mixture of raw materials for making bricks. Natural fibers offer the last diversion for traditional bricks, which are much stronger in reducing ecology. Several biotechnology methods stimulate the production of various materials, including bioplastics, bendable edge membranes, and bio-fungal composites. Fibers have been used as raw materials for making modular elements and as panels for thermal insulation systems, soundproofing, and furniture.(Almpani-Lekka et al., 2021)

Application of Waste-Based Building Materials in Various Countries

Building construction that implements sustainable concepts is a process that starts from the stage of raw material utilization, planning, infrastructure, implementation, and use of environmentally friendly building materials and waste management (Imran, 2019).Waste is the remains of human and industrial activities. The use of Waste is one of the efforts to reduce the accumulation of waste materials that can potentially damage the environment. In many countries, waste has become a study and building material. Based on the results of the bibliometric analysis related to Waste, articles were selected from five countries that utilize Waste as raw materials for brick-making mixtures, which can be seen in Table 1.

Table 1: Comparison of Selected Countries' Research Focus Related to Waste

Country	Article Title	Type Of Waste	Author	Source
India	An investigation of various properties of hybrid bricks using Natural fibers and waste fiber-based aterials	Abaca fiber, Pinus-Roxburghi leaves, fiber, wood, wheat straw, animal dung, sand, cement, phenolic resin and gypsum	(Kumar et al., 2024)	Journal of Engineered Fibers and Fabrics
Hungary	Transforming Zeolite Tuff and CigaretteWaste into Eco-Friendly Ceramic Bricks for Sustainable Construction	Cigarette waste	(Ibrahim et al., 2024)	Construction and Building Materials
Australia	Utilizing rejected contaminants from the paper recycling process in fired	Paper, Glass, aluminium, plastic	(Xin et al., 2023)	Buildings . MDPI

	clay brick production	and Stone		
Brasil	Technological Characterization of PET Polyethylene Terephthalate Added Soil-Cement Bricks	Plastic PET	(Rodrigues et al., 2021)	Materials. MDPI
Egypt	Enhancing the Thermal and Energy Performance of Clay Bricks with Recycled Cultivated Pleurotus floridaWaste	Pleurotus florida	(Fahmy et al., 2024)	Buildings MDPI
Indonesian	Utilization of Oil Palm Empty Fruit Bunch (EFB) Waste as a Mixing Material for Interlocking Brick Production	Empty Oil Palm Fruit Bunches	(Marini et al., 2024)	Journal of Studies in Science and Engineering

Table 1 Describes countries that utilize various types of Waste, both inorganic and organic, as one of the solutions in building material innovation, especially bricks. In developing countries, there is no clear waste management system; Waste is managed by burning or dumping it in landfills. However, Waste is no longer a new thing to use as a building material, especially bricks. Because of its characteristics, bricks are the easiest building materials to adapt and innovate, including using natural fibers and Waste as raw materials. .(Micheal & Moussa, 2022). Table 1 shows countries that utilize Waste as raw materials for making bricks. In research conducted in India, the natural fibers used are Abaca fiber, Pinus-Roxburghi leaves, fiber, wood, wheat straw, animal dung, sand, cement, phenolic resin, and gypsum. It has long been known that natural fibers are a suitable alternative to traditional building materials. Because they have good thermal and acoustic insulation, they can also be used as cement mortar reinforcement fibers, composite materials, panels, and bricks (Liuzzi et al., 2017). In Hungary, the Waste developed for raw materials is from Cigarette butts and cigarette ash. Cigarette waste is the most easily found Waste, especially filters and cigarette ash; the filter part is the part that is not used up and leaves residue (Qamar et al., 2020) The primary material of bricks with a mixture of cigarette butts is no different from bricks in general. However, it is still weak in strength where only 25.65 Mpa when added with a mixture of CB (Cigarette butts) 10%, then there is a decrease of 58% mPa strength (Mohajerani et al., 2016).

A developed country such as Australia has utilized widely rejected waste, also called RCF, such as paper, glass, aluminum, plastic, and stone. The use of this material is to reduce the use of clay and other solid waste. Besides, waste can meet good thermal needs and can be used as an alternative sustainable brick industry (Xin et al., 2023)While PET plastic waste is Waste that cannot be stopped and continues to increase and takes a long time to decompose, in Brazil, it is used as an additive for sand because the characteristics of PET have sand particles and optimal humidity (Rodrigues et al., 2021) but from the inside use as an additive should not be more than 5% of its use because it can affect the strength of the brick (Akinyele et al., 2020). If PET plastic waste is Waste that is not easily decomposed, then there is also Waste that is easily decomposed and can be used as brick material, namely organic Waste such as Pleurotus florida and Empty Oil Palm Fruit Bunches Waste.

Pleurotus florida waste in Egypt shows that the results of waste utilization can reduce thermal conductivity and also reduce the ratio of this Waste by 15%. In addition, the findings of this study can connect the gap between sustainable material mixing, thermal performance, and optimal architectural design so as to provide a blueprint for architects to utilize Waste from organic materials and save energy without sacrificing material integrity (Fahmy et al., 2024). Indonesia is known as one of the countries that produce palm oil to be processed into palm oil; therefore, the management of palm oil can generate waste. Therefore, from the results of the study, fiber from TKKS can be used as a raw material for bricks but must be combined with other materials (Ramadhana, 2021). In addition, TKKS has the ability to become a brick reinforcement to bond together so that it can be lighter, have good compressive strength, and have high water absorption (Marini et al., 2024). To get hollow bricks, the size of TKKS fiber that can be used is 1-10 mm, the composition of 30-40% waste, and TKKS can produce concrete compressive strength of 3.23 mpa -5.49 mPa and tensile strength of 20-34 Mpa. If you want a greater concrete compressive strength, the composition of the TKKS mixture must not be more than 25% (Fitriadi & Fatahillah, 2017).

D. Conclusion

The brick industry sector is one of the world's major users of natural resources and carbon emitters. Climate change requires this industry to consider the use of more environmentally friendly raw materials. Bricks are characteristic of being the easiest building material to adapt and innovate. To make environmentally friendly and sustainable building materials, it is worth considering the aspects of raw materials and manufacturing procedures. There are several alternatives in the use of raw materials such as utilizing other materials such as Waste, natural fibers, gypsum, cigarette butts, RFC PET Plastic, Pleurotus florida, Empty Oil Palm Fruit Bunches directly encourage construction practices to be less dependent on conventional raw materials, reduce environmental impacts, contribute to a circular economy, meanwhile. The use of bricks using waste can reduce energy consumption by 9.5% and CO₂ levels by 470 tons. On the other hand, the durability of adding bricks with wastewaste can provide a strong concrete resistance of 12.5% - 20%. Besides, it also has good thermal insulation properties and significantly increases the energy efficiency of buildings.

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