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Environmental Management and Construction Waste Strategies in Malaysia: An Overview of Green Materials and Waste Management Challenge

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ABSTRACT: This review provides an overview of Malaysia's environmental management practices, with a focus on construction waste management, to address the country's growing waste generation in the construction sector. The paper highlights key challenges Malaysia faces in implementing effective environmental practices and offers potential solutions to overcome these hurdles. Additionally, it examines the use of green materials, such as recycled concrete aggregate and bamboo, which have demonstrated significant potential in reducing resource consumption and carbon emissions. The challenges of adopting these materials are analyzed, along with a discussion of their advantages and limitations. Ultimately, the review underscores the importance of environmental management and the role of sustainable materials in transforming Malaysia's construction industry, while calling for stronger regulatory frameworks and industry collaboration to address these challenges. The objective of this review is to provide insights into the current environmental management efforts in Malaysia and to explore the potential of green materials in mitigating environmental impacts.

KEYWORDS: Environmental management practices; construction waste management; green materials; recycled concrete aggregate; sustainable construction in Malaysia

1. Introduction

Global sustainability is a pressing concern, especially in light of climate change and environmental damage. The G20 has recognized this urgency, prioritizing sustainability in their 2030 agenda and developing action plans to achieve these goals. This emphasis on sustainability is reflected in various sectors, notably in construction, where there's a growing demand for eco-friendly materials [1–3]. Green materials, designed to minimize environmental impact, are gaining prominence as sustainable alternatives. The USGBC defines them as materials derived from renewable, recyclable, or reusable sources that can be used indefinitely without harming the environment. Examples include bamboo, recycled concrete aggregate, recycled steel, recycled glass, and hempcrete. Replacing non-renewable materials with these green alternatives offers several benefits. Kuppusamy et al. highlights that using green

materials can enhance indoor air quality and overall building performance. This improvement stems from the reduction of harmful chemicals often associated with conventional materials. Furthermore, using low-toxicity materials for building finishes can further improve indoor air quality and mitigate the risk of Sick Building Syndrome [4, 5].

Aside from that, there are additional benefits to using GBM. For example, glass reinforced concrete (GRC) is a popular, stable mineral-based material that, unlike traditional reinforced concrete, requires less time and energy for crushing due to the absence of coarse aggregate recycling. GRC products also offer a clear advantage in terms of their manufacturing carbon footprint, as they are often thin-sectioned and use less material compared to traditional precast equivalents. In contrast, cement manufacturers produce 10 billion tonnes of cement annually, contributing to 10% of global emissions and representing a significant source of greenhouse gases. Therefore, adopting green materials can potentially reduce environmental impact. This essay provides a detailed overview of the current state of green materials in Malaysia. It will use recycled concrete aggregate and bamboo as examples of green materials being adopted in the country. The discussion will cover environmental management practices (EMPs) in Malaysia, the prospects and challenges of adopting green materials, and relevant government policies in the industry. Finally, the advantages and disadvantages of these green materials was also compared [3–5].

2. Sustainable Construction and Green Materials in Malaysia.

In Malaysia, EMPs play a crucial role in advancing the use of green materials across construction and other sectors by promoting sustainability. These practices, which are regulated by national laws and policies, aim to minimize the environmental impacts of construction activities, including air and water pollution, waste generation, and soil erosion, while fostering the adoption of sustainable products and technologies. Malaysia is progressing towards a more sustainable future by enhancing resource efficiency and implementing regulations such as the Environmental Impact Assessment (EIA). This section outlines some of the EMPs relevant to Malaysia’s construction industry. Four key areas where environmental management in the construction sector can reduce negative impacts are resource consumption, carbon emissions and solid waste generation, interaction with the external environment, and the inherent quality of the construction site [6]. To effectively implement these practices, it is essential to establish guidelines and strategies for resource management and waste minimization [7]. The adoption of green materials represents a significant EMP with considerable potential. Due to their eco-friendly attributes, green materials have been gaining traction. Examples in Malaysia include recycled concrete aggregate, bamboo, hempcrete, and other natural materials. Additionally, other EMP techniques involve designing energy-efficient buildings and ensuring proper waste management practices within the industry. The Green Building Index (GBI) and the Low Carbon Cities Framework (LCCF) are two major initiatives by the Malaysian government that underscore its dedication to sustainable construction and environmental management [8, 9]. These frameworks actively promote the integration of green materials and environmentally friendly construction practices in building design, aiming to reduce the industry's environmental impact and support the nation's broader sustainability objectives.

3. Challenges and Solutions in Construction Waste Management in Malaysia

Proper construction waste management is a key environmental management practice (EMP). Within the construction sector, concrete is one of the most widely used materials [10]. Due to the sector's high demand, the majority of construction waste is generated from this industry, as concrete production relies heavily on raw materials such as natural aggregates [11]. The growing population in developing countries has further driven an increase in infrastructure and residential construction, resulting in significant amounts of construction and demolition (C&D) waste [12]. In 2014, global aggregate production reached 40 billion tonnes, double the amount produced in 2007 [12]. Malaysia is among the countries experiencing rapid growth in the need for waste recycling, producing 28.6 tonnes of construction waste daily in 2015. The rise in waste production has also led to an increase in illegal dumping, negatively impacting the environment. A previous study found that up to 42% of the waste in over 40 illegal dump sites was construction waste, reflecting its prominence as a common waste disposal method [7]. Furthermore, Ummi Kalthum Shuib, director of Federal Territories SWCorp, reported incidents of illegal dumping in Kuala Lumpur, Malaysia's capital [7]. It has also been observed that contractors in Selangor often dispose of construction waste in the early morning hours [7].

With the anticipated growth of the construction industry in Malaysia, future development and construction activities are expected to generate even more waste [14]. Lachimpadi et al. estimate that up to 60% of Malaysia's construction waste is concrete waste, heightening public concern about its environmental impact in rural communities [9]. To address these challenges, the Construction Industry Development Board (CIDB) has established the Construction Waste Management Plan (CWMP). This initiative aims to improve waste management practices in the Malaysian construction sector through the Construction Industry Master Plan 2006–2015 and the deployment of the Industrialised Building System (IBS) under the "IBS Roadmap 2003–2010" program [15].

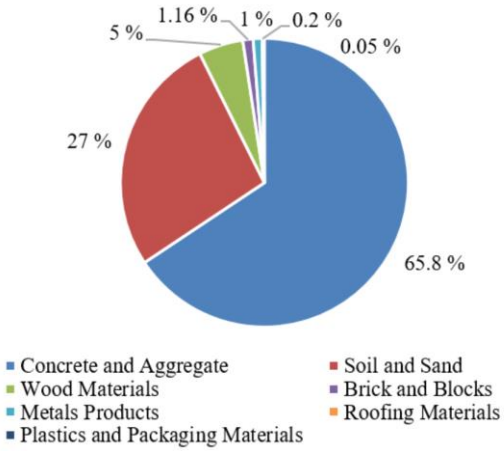

Figure 1. Composition of construction waste from site [7].

According to Wong et al. [16], up to 27,000 tonnes of waste is generated from a construction project site, with concrete and aggregate accounting for the largest portion of the total waste from a construction site, as shown in Figure 1. Therefore, construction companies have been encouraged to employ and implement the 3R concept (reduce, reuse, and recycle) to minimize the generation of waste, like prefabricated materials, concrete, wood, and steel. Malaysia government has been actively promoting this concept to the construction industry to

encourage the completely utilize the resources before discarding them. Nonetheless, this concept is still at the infant stage in the country, meaning that there is only 5% implementation of this concept across the nation [16]. The reason behind the lack of implementation of the 3R concept has been identified due to several reasons. Previous study conducted that the implementation of environmental practices by contractors in Malaysia has discovered the reasons for this poor implementation include the lack of involvement, awareness, understanding, and enforcement. Some other factors include contractors' attitudes, time, money, and space limit. Law and regulations must be enforced as part of the EMPs so that negative impact on the environment can be mitigated or minimized [17]. The relevant legislation and regulations for managing construction waste, controlling water quality, and monitoring management in Malaysia are shown in Table 1.

Table 1. Legislation and regulations for water quality control, solid waste management, and environmental monitoring in Malaysia.

No.	Law and Regulations	References
1	Environmental Quality (Compound of Offences) Rules 1978	[18]
2	Environmental Quality (Scheduled Waste) (Amendment) Regulations 2007	[19]
3	Environmental Quality Act 1974 (Act 127) -Section 25: Restriction of pollution on inland water	[20]
4	General waste (industrial, commercial and domestic waste) is controlled under the Local Government Act 1976	[21]
5	Local Government Act 1976 -Sec. 69: Committing nuisance in streams	[21]
6	The effluent criteria for the parameters shall adhere to the Environmental Quality Act 1974 and the Environmental Quality (Sewage) Regulations 2009	[20]
7	The National Water Quality Standards for Malaysia (NWQS)	[22]

Apart from regulations, it is also recommended to revise government policy in the Malaysian construction industry, particularly the Green Building Index rating system and Malaysian Standard (MS1525) [5]. In addition, a tax break is also suggested to be implemented for companies who conduct constructions with the practice of energy efficiency, low carbon emission, recyclable raw material, and recyclable waste [5]. Additionally, education plays a vital role in advancing the industry towards a sustainable future. The Malaysian government can implement policies in the education sector to strengthen students' understanding of sustainability and the urgency of addressing the waste crisis (Table 2).

Table 2. Challenges of implementing EMPs in Malaysia.

Challenges	References
– Fragmentation within Malaysia's construction sector hinders the adoption of EMPs, particularly for small and medium-sized enterprises (SMEs) that operate in numerous, dispersed segments. This fragmentation complicates the enforcement of EMPs across the industry. – A lack of knowledge among industry stakeholders about sustainability poses another challenge for EMP implementation. Without awareness of environmental regulations and sustainable practices, stakeholders may not fully grasp the serious consequences of non-compliance and inefficient resource use. – Construction waste management in Malaysia is still developing, resulting in significant waste generation, including potentially hazardous materials that can harm the environment. There is a pressing need for more effective waste management strategies. – The construction sector's reliance on natural resources such as timber, water, and energy is problematic due to their scarcity. To ensure long-term sustainability, there is an urgent need for more sustainable alternatives that reduce the industry's dependence on these limited resources.	[23–25]

As an illustration, by integrating environmental awareness and sustainability practices into the curriculum, future generations will be better equipped to drive innovative solutions and promote a greener, more responsible approach to industrial development. Another potential

and effective practice is to introduce knowledge of green materials in education, such as implementing a mandatory training course on green materials and sustainability practices for final-year graduates who are studying in the construction field [5].

4. Proposed Strategies for Enhancing Sustainability in Construction Industry

To address the challenges in implementing EMPs, several strategies are proposed. First, adopting advanced technology can significantly enhance sustainability in the industry. For example, renewable energy sources such as solar panels and wind turbines can reduce reliance on non-renewable energy sources like fossil fuels, which currently dominate Malaysia's energy generation. Additionally, tools like Building Information Modeling (BIM) can optimize building design, facilitating more efficient resource use and minimizing excess, which helps to reduce waste generation. Second, adhering to green building standards such as the Green Building Index (GBI) and the Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST) is recommended. These standards encourage the adoption of eco-friendly building practices and offer guidelines and incentives to mitigate environmental impacts. Another key strategy involves collaborating with governmental agencies, non-governmental organizations (NGOs), and other stakeholders. Such partnerships can provide valuable insights into industry issues and help identify solutions for the waste management crisis. By working together, stakeholders can access expertise and resources to improve EMP implementation. Finally, using green materials is a promising approach to enhance sustainability in the construction industry. Green materials, which often require fewer natural resources or are derived from recycled waste, can help address the issue of construction waste. Examples include recycled concrete aggregate and bamboo, which will be explored further in the next section.

5. Adoption of Green Materials

Green materials are gaining popularity in Malaysia due to government initiatives, increasing the demand for sustainable products, and the awareness of environmental issues. In this section, recycled concrete aggregate and bamboo are discussed regarding their current adoption status and prospects in Malaysia, as well as any potential challenges in implementing them. Lastly, the advantages and disadvantages of the materials are summarized.

5.1.Recycled concrete aggregate (RCA).

The introduction of RCA has been gaining momentum in the construction industry to address the huge amount of concrete and aggregate waste and to encourage sustainability in the sector. Since aggregate makes up 70% of a concrete mix, the amount of natural aggregate required can be greatly decreased by substituting sustainable alternative materials for the aggregate [11]. This has led to the discovery of the use of RCA in Malaysia’s construction sector when the aggregates in concrete waste are recaptured and recycled by crushing the concrete waste lumps into smaller particles. RCA has several advantages over natural aggregate (NA). For instance, because RCA has a lower unit weight than NA, less fuel and energy are needed to transport it than to transport NA [26].

However, the degree of awareness of recycling in the manufacturing or application of recycled aggregates is still generally low in the construction sector in Malaysia [27], despite

the massive volume of construction debris that makes up a substantial component of solid waste in the country [9]. Unsustainable practices, such as the direct disposal of construction waste into landfills or irresponsible and illegal actions that did not properly utilize the waste, are nevertheless common in the construction industry. The primary cause of this is that Malaysia has an abundance of natural aggregate resources available, which are mostly relied upon by the construction industry [28].

The government policy concerning the application of RCA comprises the Malaysian Standard (MS 30), mandating that aggregates should have a water absorption of no more than 2%. Generally, RCA does not meet this requirement by having a water absorption of more than 15%, and it tends to have a worse elongation index than granite, due to the presence of mortar coating in RCA [27]. In fact, the water absorption properties of RCA increase as their size increases. However, when a suitable parent concrete with greater strength is utilized in RCA, the values of the RCA can be comparable to granite [29]. If its water absorption is reduced to 10%, RCA is also suitable for other construction applications in Malaysia, such as structural elements, and minor structural and non-structural elements [27]. Aside from that, according to Aman et al., there is a lack of policy and regulations that are imposed for the usage of RCA in Malaysia. The advantages and disadvantages of using RCA as a green construction material are summarized in **Error! Reference source not found.**.

Table 3. Advantages and disadvantages of utilizing RCA as an eco-friendly construction material.

Advantages	Disadvantages	References
– Utilizing RCA can decrease the volume of waste generated from construction and demolition activities, leading to a reduction in landfill disposal. – The reliance on raw materials is reduced with the use of RCA, thereby preserving natural aggregates such as limestone and gravel. – RCA offers a more economical choice for construction projects as it is produced at a lower cost compared to natural aggregates.	– RCA produced from various sources may exhibit differing qualities, resulting in inconsistencies in strength and durability. – RCA generally has lower compressive strength and higher porosity compared to natural aggregate (NA). – It has a poorer elongation index than NA due to its higher water absorption, which can impact its workability.	[27–33]

5.2. Bamboo.

On the other hand, constructing environmentally friendly buildings with affordable materials has also been challenging in Malaysia, particularly in rural areas [34]. This is because conventional building materials like concrete and steel tend to cost more, due to their specific production and processing required. In addition, the energy-intensive steel manufacturing process contributes to global warming [35]. Hence, timber is being used as a substitute material in the industry since it is easy to manufacture, reusable, and environmentally friendly. However, timber's price is also increasing due to its availability that is getting lower. Moreover, because of its intrinsic defects and grain pattern, timber only has an intermediate strength and is less flexible [34]. This has forced the industry to look into alternative green materials that cost less such as bamboo. The advantages of bamboo include a higher specific gravity than concrete, an exceptional tensile strength-to-weight ratio when compared to steel, and the ability to withstand compressive strength [36]. In contrast to timber, bamboo usually takes only three years to reach the necessary strength to be harvested, whereas timber can take up to ten years to reach the same strength [34]. Consequently, bamboo is an excellent green material that can

be used to substitute other conventional building materials to promote sustainability in the construction industry.

Despite the excellent mechanical properties that bamboo exhibits, its physical qualities and anatomical features have not been thoroughly studied, which has led to a lack of interest in its application, particularly in Malaysia [34]. Only a small amount of research on its mechanical properties has been conducted around the globe, resulting in insufficient design rules for its application in construction [34]. In comparison to traditional building materials like concrete, steel, and wood, the lack of knowledge on the structural behaviour of bamboo has led to its underutilization or neglect in construction in Malaysia [37]. Aside from that, further research is also necessary to enhance the interlocking force between bamboo strips and concrete, as this is a crucial factor in determining the performance of bamboo applications in the construction industry [38].

Nonetheless, this green material has shown its advantages in becoming a promising construction material that is widely usable. In a study conducted by Awalluddin et al. [39], four different bamboo species were tested, including those for moisture content, tensile strength, and compression. Because of the decreased moisture content after five months, all bamboo has shown a rise in compressive strength and demonstrated good performance in tensile strength tests. To encourage the implementation of bamboo into the construction sector in Malaysia, some of the bamboo design standards from the International Organization for Standardization (ISO) can be referred [40]. A few notable standards for bamboo are the ISO 22156-2021 Bamboo structures—Bamboo culms—Structural design [41] and ISO 19624 Bamboo structures—Grading of Bamboo Culms—Basic Principles and Procedures [42]. The advantages and disadvantages of substituting bamboo as a green construction material are summarized in Table 3.

Table 3. Advantages and disadvantages of utilizing bamboo as a green material.

Advantages	Disadvantages	References
– More sustainable option compared to traditional lumber because it can be harvested every three to five years without causing harm to the plant or the environment. It is exceptionally strong and durable, with a tensile strength surpassing that of steel, making it suitable for structures that must withstand strong winds or seismic activity. – Highly flexible and can bend without breaking, making it an ideal material for buildings designed to endure earthquakes or strong winds. – Cost-effective than conventional materials such as steel or concrete. Furthermore, its natural elegance and unique texture add distinctive visual appeal to construction projects.	– Bamboo can suffer from rot and decay if exposed to moisture for extended periods, potentially leading to structural issues or a reduced lifespan as a construction material. – Its flammability limits its use, making it unsuitable for areas prone to wildfires. – Bamboo's quality can be compromised by fungi and insects, as it is susceptible to pest damage. While bamboo can be grown in various regions, its broader application may be restricted due to the difficulty in sourcing professionally farmed or naturally growing bamboo. – Lower load-bearing capacity compared to stronger materials like steel or concrete, which limits its use in heavy-duty construction.	[38, 43]

6. Challenges in the implementation of recycled concrete aggregate and bamboo.

Implementing recycled RCA as a sustainable alternative to conventional concrete in the construction industry presents several challenges. The primary issue is the inferior quality of RCA compared to natural aggregate (NA). RCA exhibits lower workability and compressive

strength, making NA a more attractive option for performance within the industry, which discourages the full utilization of this sustainable material [27]. Additionally, the quality of RCA can fluctuate significantly when sourced from different locations [28]. This variability is primarily due to the presence of mortar in RCA, which contributes to the differences between RCA from various sources and explains the decline in its quality relative to NA [44, 45]. Consequently, RCA tends to have lower density and mechanical strength, coupled with higher water absorption, due to microcracks present in the material [30–33]. These characteristics can adversely affect the interfacial bond between RCA and cement paste when producing new concrete, posing a challenge to the replacement of NA with RCA [28].

Moreover, additional challenges include the absence of a perceived scarcity of NA, as Malaysia has abundant natural aggregate resources, along with a lack of knowledge and experience in utilizing RCA within the industry [11]. The absence of policies and guidelines regarding RCA use further contributes to the low recovery rates of construction waste, with less than half being recycled [46]. Maintaining consistent bamboo quality across Malaysia can also be challenging due to factors such as genetics and growing conditions, which influence the mechanical, physical, and inherent durability of the material [36]. For instance, the strength of bamboo can vary significantly depending on its species and moisture content [40]. Therefore, it is advisable to conduct mechanical testing on specific bamboo plants before using them as building materials, taking into account their source and the factors mentioned above [40]. Standardization and requirements are essential to ensure consistent bamboo usage in the construction industry, given the complexities associated with the variations among different bamboo species and their unique characteristics [38]. Another challenge Malaysia faces is the lack of laws and regulations governing the use of bamboo as a green building material. Such regulations are crucial for building public confidence in the safety and reliability of bamboo structures. The growing interest in bamboo as a sustainable material highlights the need for codification and standardization to ensure that bamboo is a safe and cost-effective option in the construction industry [47].

7. Conclusion

Understanding the role of green materials in Malaysia is crucial for advancing the nation's environmental and economic goals while addressing global sustainability demands. EMPs are essential for steering Malaysia toward sustainability by enforcing regulations and encouraging the use of green materials, particularly in the construction sector, which remains a significant source of waste. Despite the benefits, challenges such as insufficient awareness, a fragmented industry, limited resource access, and high waste production hinder the effective implementation of EMPs. To overcome these challenges, several strategies have been proposed, including adhering to green building standards, adopting modern technologies, collaborating with NGOs and government agencies, and utilizing sustainable materials like recycled concrete aggregate and bamboo. Recycled concrete aggregate, while effective in reducing waste and cost, has lower compressive strength compared to traditional concrete. Bamboo, on the other hand, offers affordability, strength, and visual appeal but faces limitations due to its structural capacity, flammability, and susceptibility to pests and fungi. The slow adoption of green materials in Malaysia is partly due to inadequate regulations, a lack of industry knowledge, and limited enforcement of best practices. To promote wider use of green materials, Malaysia needs to enhance regulations, improve education and awareness, and

implement more robust strategies for integrating sustainable practices into construction and other industries.

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Conflicts of Interest

The authors declare no conflict of interest.

Author Contribution

Michael Lie: Writing, Conceptualization, Data Collection; Nicholas Tam: Writing, Methodology; Gaurav Talukdar: Methodology, Review.

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