Civil and Sustainable Urban Engineering

Review
Volume 4(2), 2024, 95–111
https://doi.org/10.53623/csue.v4i2.503

Environmental Management Practices and Sustainable Green Concrete Use in Malaysia's Construction Industry: Challenges, Benefits, and Future Directions

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SUBMITTED: 29 September 2024; REVISED: 6 November 2024; ACCEPTED: 9 November 2024

ABSTRACT: This review examines the environmental management practices (EMPs) employed within Malaysia's construction sector, with a particular focus on sustainable practices and the adoption of green concrete, including fly ash, rice husk ash, and palm oil fuel ash varieties. The study identifies key challenges, such as low awareness, high costs, weak legal enforcement, and the underdevelopment of green materials in the country. To address these issues, the report proposes solutions such as capacity-building programs, government incentives like tax breaks and grants, regular site inspections, and investment in research and development of green materials. The review also assesses the advantages and limitations of different green concrete types used in Malaysia. The aim of this study is to enhance sustainability efforts and reduce the environmental impact of construction activities through greater awareness, stronger regulatory support, and commitment from all stakeholders. Implementing greener concrete and EMPs is expected to not only mitigate environmental concerns but also yield long-term economic benefits for Malaysia.

KEYWORDS: Green concrete; environmental management practices; sustainable construction; Malaysia

1. Introduction

The construction industry plays a critical role in developing the economy, health, and standard of living in a country, especially in developing nations like Malaysia [1]. The construction industry is vital for creating jobs, boosting economic growth, and advancing infrastructural development through the construction of roads, bridges, tunnels, buildings, and other infrastructure projects. Over the past 20 years, Malaysia's construction industry has grown rapidly, making a substantial economic contribution to the country (Table 1). In 2010, the construction sector accounted for RM 6,464 million in Malaysia's Gross Domestic Product (GDP). By 2024, its contribution had grown significantly to RM 16,143 million, which represents 5.9% of the country's GDP. This increase in GDP reflects the sector's importance in economic development, particularly through urbanization and infrastructure projects [2–3].

However, despite the beneficial economic contributions, serious environmental challenges have been linked to the industry due to a lack of proper waste management practices, the behavior of the construction workers, and the unsustainable packaging of building materials.

As a result, the industry has contributed significantly to environmental degradation, including pollution, waste generation, greenhouse gas (GHG) emissions, and resource depletion [4]. The industry accounts for nearly half of the GHG emissions and consumes 40% of the materials used in the global economy, making it a major contributor to climate change [5].

The construction sector involves a broad range of activities, including the production and trading of construction materials, the building of new infrastructure and structures, as well as the upkeep, renovation, and repair of existing ones [6]. Malaysia's rapid urbanization and growth have resulted in the generation of approximately 8 million tonnes of construction waste, including materials like concrete, cement, steel, plastic, and timber [7]. If not properly managed, this waste can lead to environmental issues such as soil and water contamination. The pollutants released from construction activities may pose significant health and safety risks to the public [8]. For instance, cement dust is a primary contaminant, being highly alkaline and corrosive due to its chromium content. It can infiltrate the soil when mixed with rainwater, and it may cause eye, skin, and respiratory irritation, as well as damage to human tissues and lungs [7, 9].

With growing environmental concerns surrounding the construction industry, it is essential to implement environmental management practices (EMPs) to ensure sustainability. Environmental management systems help organizations reduce the environmental impact of their operations [6]. As Malaysia advances toward its sustainable development goals, developing and applying comprehensive EMPs in the construction sector is necessary to reduce pollution. These practices focus on minimizing resource use, managing construction waste, reducing pollutant emissions, and interacting responsibly with the surrounding environment. The primary goals of EMPs are to reduce pollution, conserve resources, and promote the use of green and sustainable materials and technologies. This approach ensures that Malaysia's construction industry will not further harm the environment but will instead contribute to its protection, all while supporting the country's long-term economic growth for future generations [10, 11].

Table 1. Malaysia's construction industry and its economic, environmental, and sustainability aspects.

Aspect	Key Points	References
Economic Importance	– Contributes significantly to economic growth and job creation – Supports infrastructure projects like roads, bridges, and buildings	[1–3]
Growth Trends and COVID-19 Impact	– Rapid growth over 20 years – GDP decline in 2020 due to COVID-19 – Reached 5.9% of GDP in 2024	[2, 3]
Environmental Challenges	– Linked to pollution, waste generation, and GHG emissions – Major contributor to resource depletion	[4, 5]
Waste and Pollution	– Generates approx. 8 million tonnes of waste annually – Pollution risks, including cement dust contamination and health hazards	[7–9]
EMPs	– EMPs aim to reduce environmental impact – Focuses on pollution reduction, resource conservation, and green materials usage	[6, 10, 11]
Sustainability Goals	– EMPs support Malaysia's sustainable development goals – Ensures long-term economic growth while protecting the environment	[10, 11]

2. Government Agencies and Environmental Regulations in Malaysia

In Malaysia, the government does not take environmental issues lightly. Government authorities such as the Department of Environment (DOE), National Resources and Environment Board Sarawak (NREB), Occupational Health and Safety (OSHA) and others have constructed and implemented a list of policies and regulations to comply with the construction industry [6, 7]. These policies aim to prevent environmental impact while promoting sustainable development. Malaysia's environmental laws are anchored on the Environmental Quality Act (EQA) 1974, which provides the legislation that regulates pollution and environmental impact. Under this statute, Environmental Impact Assessments (EIA) are mandatory for construction projects, especially large-scale projects, prescribed under Section 34A of the EQA1974 [12]. Before construction commences, EIA must be conducted to identify any possible environmental impacts of the proposed project so mitigation strategies can be carried out to prevent environmental degradation. Companies and organisations are also encouraged to get ISO14001 certification to enhance environmental management systems' implementation efficiency and effectiveness. ISO14001 manages the environmental impacts of a business and improves its environmental performance and accountability. Hence, it can improve health and safety, customer satisfaction, and the company's reputation [13]. There are also many other legislations to manage solid waste, water quality, air quality and noise for the construction industry in Malaysia, which are listed in Table 2.

Table 2. Legislation and regulation in Malaysia.

Legislation and Regulation	Management	Details	References
Local Government Act 1976	General waste (industrial, commercial, and domestic)	Governs local authorities' management of waste collection and disposal.	[14]
Environmental Quality (Licensing) Regulations 1977	License	Requires licenses for activities that may impact the environment.	[18]
Environmental Quality (Clean Air) Regulations 1978	Air pollution	Sets limits on emissions of air pollutants from various sources.	[19]
Factories and Machinery (Noise Exposure) Regulations 1989	Noise pollution	Establishes permissible noise levels in industrial environments.	[22]
Environmental Quality (Control of Emission from Diesel Engines) Regulations 1996	Emissions from machinery and vehicles	Controls emissions from diesel engines used in various applications.	[20]
Environmental Quality (Control of Emission from Petrol Engines) Regulations 1996	Emission from vehicles	Regulates emissions from petrol-fueled vehicles to reduce air pollution.	[21]
Environmental Quality (Scheduled Waste) Regulations 2005	Scheduled Waste	Regulates the management, collection, and disposal of scheduled wastes.	[15]
National Water Quality Standards for Malaysia (NWQS)	Water pollution	Establish water quality criteria for different water bodies.	[17]
Environmental Quality (Sewage) Regulations 2009	Sewage	Sets standards for sewage treatment and discharge into the environment.	[16]
National Construction Policy 2030	Construction	Aims to ensure sustainable construction practices and environmental protection.	[23]

In Malaysia, the government takes environmental issues seriously. Agencies like the DOE, the National Resources and Environment Board Sarawak (NREB), and the Occupational

Health and Safety Administration (OSHA), among others, have developed and enforced various policies and regulations specifically for the construction industry [6], [7]. These policies aim to mitigate environmental impacts while promoting sustainable development. Malaysia's environmental regulations are primarily based on the Environmental Quality Act (EQA) of 1974, which provides the legal framework for controlling pollution and managing environmental impacts. Under this law, Environmental Impact Assessments (EIA) are mandatory for large-scale construction projects, as stipulated in Section 34A of the EQA 1974 [12]. EIAs must be completed before construction begins to identify potential environmental impacts, allowing for the implementation of mitigation strategies to prevent environmental degradation.

Companies are also encouraged to obtain ISO14001 certification to enhance the efficiency and effectiveness of their environmental management systems. This certification helps businesses manage their environmental impact and improve their environmental performance and accountability, leading to better health and safety, increased customer satisfaction, and an enhanced company reputation [13]. In addition to these regulations, there are various other laws in place to manage solid waste, water quality, air quality, and noise in the construction industry, as outlined in Table 3. The Construction Industry Development Board (CIDB) Malaysia has also issued guidelines for proper waste management on construction sites. These guidelines promote the waste management hierarchy, prioritizing the 3Rs: 'Reduce,' 'Reuse,' and 'Recycle,' with waste treatment only when these cannot be applied, and disposal as a last resort due to its contribution to landfill waste [24].

Table 3. Waste management guidelines for proper waste management on construction sites

Aspect	Description	Notes
Reduce	Minimizing waste generation at the source by using fewer materials and optimizing processes.	Encourages design strategies to reduce material use.
Reuse	Finding new uses for materials or products that would otherwise be discarded, prolonging their life cycle.	Promote practices like salvaging materials on-site.
Recycle	Process waste materials to create new products, diverting them from landfills and reducing resource consumption.	Supports recycling programs for construction debris.
Waste Treatment	Treating waste to reduce its volume or hazardous nature before disposal, such as incineration or composting.	Used when reduction, reuse, and recycling are not feasible.
Landfill	The final option for waste disposal, where waste is buried. It should be minimized due to its environmental impact.	Emphasizes that landfill use should be the last resort.

The Construction Industry Transformation Programme (CITP) 2016–2020 was launched to integrate new technologies, such as digital construction tools, into the industry, aiming to enhance productivity, efficiency, and sustainability. Building Information Modelling (BIM) was one such technology introduced to provide a digital representation of buildings throughout their lifecycle in the construction process [25]. Additionally, the Ministry of Energy, Green Technology, and Water developed the 'Green Technology Master Plan (GTMP) Malaysia 2017-2030,' a comprehensive framework to incorporate green technologies into Malaysia's growth across four key pillars: energy, environment, economy, and society, under the National Green Technology Policy. The master plan is designed to steer the country toward a resource-efficient, low-carbon, and sustainable economy [26]. Key strategies include the design and operation of green buildings and the use of sustainable materials. For instance, the Green Building Index (GBI) is a voluntary environmental rating system introduced in Malaysia to evaluate the environmental performance of green buildings. Additionally, sustainable construction practices, such as the use of Industrialised Building Systems (IBS), help reduce carbon emissions and waste generation while continuing the implementation of CITP [26].

3. Current Status of EMPs in Malaysia

3.1. Environmental issues in Malaysia.

Malaysia has taken determined steps to set up and put into place EMPs within the construction industry. Using a variety of governmental policies and incentives, the country has established a strong framework that addresses environmental issues in this sector. However, as a developing nation with burgeoning construction activities driven by a swiftly expanding population, Malaysia faces real problems that relate to sustainability and are compounded by the mismanagement of construction waste. Increased enforcement and additional education may reduce the problem, but for now, several traditional practices related to construction waste disposal and final recovery continue to threaten the environment [1, 2].

Only 76% of Malaysia's solid waste is effectively collected, according to research, and a mere 5% is recycled. The remaining 95% is sent to 112 landfills. These landfills are usually full, and they operate under standards that, at best, are a decade old. They fall short of today's standards for environmental protection. The leachate that comes out of these landfills is grossly under-monitored, and the same can be said for the gas emissions that come out of the tops of these landfills. These emissions represent the exact opposite of the country's intended targets for waste minimization and recycling. Indeed, in 2015, prime minister Najib Razak launched a National Waste Minimization Program with targeted goals that are much too low for any kind of ambitious environmental or public health agenda [2, 3].

An action plan has been put in place to counteract these illicit practices, with specific aims to trim down 2020 goals. The plan signifies and establishes SWCorp's authority to approach the problem at a systemic level and appears to court the involvement of the Ministry of Natural Resources and Environment, state-level assemblymen, and other local actors. SWCorp's plan appears to not only pay lip service to the problem but also to embody some of the real involved with the issue [3, 4].

High costs associated with waste management and transportation drive up the illegal dumping of construction waste. Offenders avoid paying for legal disposal by dumping waste in illegal locations [6]. These offenders not only avoid paying for proper disposal but also save money on transportation and direct labor associated with disposal. While the problem has been identified, the solution is difficult due to several issues. First, construction waste management at the site of a project is poor. Second, the legal means to dispose of construction waste are both far away from the construction site in question and usually already at capacity. Finally, the construction industry suffers from a bad attitude toward waste disposal; if making the industry more positive about disposal were possible, then perhaps the industry could be managed in a way that would not result in so much illegal dumping [3, 4].

3.2. Key challenges.

Even though the government has initiated the formulation of comprehensive policies for the construction sector, the current practices of the construction industry frequently do not conform to the guidelines set forth in these policies. The construction industry in Malaysia runs into a number of problems when it comes to following the EMPs prescribed for it. Almost as if the construction workers are in some form of Stockholm Syndrome, they are oblivious to the consequences of construction activities that might lead to something as dire as climate change. Why? Because not only contractors but also employees in the construction sector lack an understanding of the relationship between construction activities and the environment. To make matters worse, they also lack any semblance of an understanding of the importance of the EMP that has been prescribed for them [1, 3]].

Another major challenge is the considerable expense needed to carry out EMPs. Undertaking EMPs necessitates a sizable infusion of cash, and not only for the hiring of thankfully few but prominently placed experts; the means to execute the plans on a what-they-say-goes basis (as opposed to the usual basis of what one can get away with doing or not doing); and making sure that any materials that don't go back into the ground, with substances that could be harmful to human or environmental health—including significant amounts of the waste that construction projects invariably produce—are processed (with life, it is claimed, in part animated by visions of those profits) in a not-harmful-to-either-human-or-environmental-health way [6, 7].

Moreover, the ineffective enforcement of environmental regulations hampers the adoption of EMPs. Insufficient oversight of construction activities results in rampant noncompliance with environmental laws. Despite the existence of thorough policies and regulations, the absence of effective enforcement means that these frameworks are essentially hollow, as the instances of illegal dumping and water pollution linked to construction activities show. Furthermore, we still lack affordable green construction materials. Though they offer long-term environmental benefits, green materials often come with a price tag that is much higher than their traditional counterparts. There's also a shortage of know-how when it comes to working with green building technologies. Long story short: We still have a ways to go before sustainable materials are fully integrated into construction scenarios [3, 6].

3.3. Prospects.

As the world becomes more aware of the harmful environmental effects of human activities—construction very much included—Malaysia's nascent market for EMPs in the construction industry looks to be positioned for some optimistic growth. And that's not just idle speculation. It's anchored in policy. The Malaysian government has just shown a renewed commitment to sustainability in the construction sector through a series of new and updated directives that now provide the industry with very clear mandates for "greening" both its processes and its products. Moreover, Malaysia is incorporating green materials and high-tech solutions—like Building Information Modelling (BIM), the Industrialized Building System (IBS), and the Green Building Index (GBI)—into its construction projects. These are not only making the construction process itself more efficient but are also serving to lessen the environmental impact of the finished product. With more and more governmental support for the incursion of these solutions and a larger degree of buy-in from the construction firms that carry out these projects, the construction industry in Malaysia stands a very good chance of evolving into a greener, more environmentally conscious sector that meshes well with the sustainable development push the country is making [3, 4, 6].

Table 4. Challenges to implement EMPs in the construction industry.

Items	Description	References
EMPs	– Malaysia has implemented various government policies and incentives to establish EMPs. – There is a strong dedication to addressing environmental challenges in the construction sector. – Despite efforts, issues like illegal dumping and pollution continue to escalate. – Limited awareness and training among contractors hinder effective EMP implementation. – Knowledge gaps restrict the adoption of best practices in environmental management.	[1, 6]
Construction Waste Management	– Landfill disposal and illegal dumping are prevalent for managing construction waste. – Only 76% of solid waste is collected, with about 5% recycled, leaving 95% to landfills. – Landfills often operate at full capacity and have limited controls on leachate and emissions. – In 2014, 851 illegal dumping sites were identified, with a significant portion containing construction debris. – Illegal dumping leads to severe environmental consequences like soil degradation and water contamination.	[1–5]
Future Sustainability Prospects	– The government is committed to fostering sustainability through initiatives like the CITP, Green Technology Master Plan, and National Construction Policy. – There is a growing global awareness of environmental impacts, which supports the push for sustainable practices. – Integration of green materials and technologies like BIM and IBS is progressing. – Continued government support is crucial for collaboration with construction businesses. – There is potential for achieving sustainable development goals in the construction sector.	[1, 6]

The construction sector in Malaysia has an optimistic outlook for environmentally sustainable construction methods and materials, which is finding its way into an increasing number of Malaysian construction projects. The most recent of these is the National Construction Policy 2030; other recent policies include the Green Technology Master Plan 2017 and the Construction Industry Transformation Program 2016-2020. These policies are overlapping and progressing in parallel, and all appear to be working with one another to provide a clear roadmap and set of guidelines, not just for the construction sector itself, but also for the construction materials sector, on how to move toward embracing environmentally sustainable construction practices EMP here means environmentally sustainable construction methods and materials. In addition, Malaysia has made significant moves to embed green materials and modern technologies like Building Information Modeling (BIM), Industrialized Building Systems (IBS), and the Green Building Index (GBI) into construction projects. These technologies and tools allow for construction in a more efficient and environmentally friendly manner. With continued support from the government and collaboration from construction companies, Malaysia is poised to create an even greener construction industry that aligns with the country's climate goals [5, 6].

4. EMPs Planning and Proposal

Malaysia faces several challenges that impede the effective implementation of EMPs within the construction sector (Table 5). This section details some proposed EMPs that attempt to solve the problems that block the pathway to sustainable construction. These proposed practices, if implemented, could expedite the transition toward more sustainable construction in Malaysia. A number of initiatives can be taken to raise awareness and understanding of EMPs in the construction sector. The first is to establish comprehensive capacity-building programs to increase not just the overall environmental knowledge of construction personnel—both managers and technical staff—but also the knowledge of specific tools, like EMPs, that are meant to help manage environmental impacts. I don't mean to imply here that construction personnel are particularly ignorant about environmental issues. Rather, the construction sector has a high number of workers at risk of being adversely impacted by not having a good understanding of environmental problems and the specific EMP processes. At the same time, businesses in the construction sector should achieve ISO14001 certification [6, 37, 38].

Incentives for businesses might help solve what is sure to be a serious obstacle to the implementation of EMPs. These plans can take a great deal of time and money to put into place. Young businesses, particularly, struggle to find the funds necessary not only to comply with environmental regulations but also to achieve the kind of sustainable economic growth that the government would like to see. One means that the government has at its disposal to incentivize businesses is the provision of tax breaks. Grants, particularly from schemes like the Green Technology Financing Scheme, might also be useful in this context. Public-private partnerships (PPPs), in which the government subsidizes part of a project's costs, could likewise serve to bring down the direct expenses that a business might incur when adopting an EMP [38, 40].

Table 5. EMPs proposal according to the challenges in Malaysia.

Key Challenges	EMPs Proposal	References
Lack of awareness and knowledge	– Develop robust capacity-building programs – Encourage businesses to adopt ISO140001 – Provide training to workers on EMS implementation	[6, 37]
High cost of implementing EMP	– Government incentives such as tax exemption and grants – Public-private partnerships adoption – Cost-benefit analysis highlighting the long-term cost reduction	[38, 39]
Poor environmental enforcement	– Revise and stricken the environmental regulations, including punishment or fines – Regular inspections of construction sites and project – Develop and set targets for sustainability performance, such as the Green Construction Index (GCI)	[6, 40]
Immature development of green construction materials	– Invest in R&D of green materials – Encourage the collaboration between academic organisations and business – Provide tax exemption on the production of green materials	[6]

To increase the inadequate enforcement of environmental laws and regulations in the construction industry, the Malaysian government should strengthen and bolster the legal framework. This should begin with a review and fortification of the actual environmental regulations, including compliance consequences (penalties or fines) for non-compliant businesses, which might start with the issuance of a few "shovel-ready" projects that set a tone of working within the established rules. Regular inspections by the various authorities should become the norm to ensure compliance with the established construction guidelines and regulations. Furthermore, a corporate culture similar to the one established within the previous paragraph should become the order of the day in the construction sector, and that can start with the developing and setting of sustainability performance targets that accomplish the same ends.

Both governmental and private-sector investment in the research and development of green materials is essential. Collaborations between colleges and universities and the business world should be encouraged and even enhanced to explore the potential of green materials to exert true innovation. This means even more focus should be placed on the development of sustainable, environmentally friendly materials made from waste products. Because this isn't happening much at all yet, the government chewing up some coal by offering tax exemptions would sure grease the wheels for the local production of green materials in ample amounts. And that would certainly foster their use in construction [6, 39].

5. Current Situation of Green Concretes in Malaysia

5.3. Green concretes.

Green concrete is a concrete that incorporates at least one type of waste material as its components, which has good performance and life cycle sustainability that does not cause environmental degradation [41]. It is also known as environmentally friendly and resource-saving concrete as it makes use of waste material and decreases resource exploitation and consumption, which lessens environmental impacts in its production processes [42]. Green concrete is utilised in Malaysia's construction industry as an initiative to promote sustainable building practices that align with the country's Green Technology Master Plan and sustainable development goals [26]. Green concrete has several advantages over conventional concrete, including reduction in greenhouse gas (GHG) emissions and energy consumption [43]. Typically, approximately 50 to 130kg of CO_2 is generated in the production of 1 ton of conventional cement [44]. By incorporating waste materials into the production of green cement, energy consumption and GHG emissions are reduced significantly, which consumes more energy and poses a lesser environmental impact [43]. Furthermore, green concrete has a low environmental footprint as it partially substitutes cement with waste materials from industrial by-products or agricultural waste such as fly ash, blast furnaces and rice husks. With this, the industrial and agricultural wastes are repurposed, lesser waste is disposed of in landfills, the cost required of raw materials for cement production, and the cost of landfill and waste management taxes are also reduced [43]. The usage of green concrete in the construction industry would drive Malaysia toward more sustainable construction practices and resource conversation.

5.4.Current status of green concrete in Malaysia.

The conventional construction concretes used in Malaysia greatly influence environmental issues such as deforestation, higher carbon footprint, and bad waste management. In response, Malaysia has increasing interest in using green concrete to substitute conventional concrete due to its many environmental benefits, aligning with its sustainability goals in the construction goals. In partnership with the CIDB, the Malaysian government initiated the CITP 2016-2020 with an objective on environmental sustainability as one of its four primary strategic objectives, acknowledging the importance of sustainable development. The plan's main objectives are to minimise waste produced by the agriculture and construction industries and to cut carbon emissions [25]. Furthermore, programs like the National Construction Policy 2030 and the Green Technology Master Plan encourage the use of green concrete and other ecologically friendly building materials [23, 26].

Furthermore, the Malaysian Green Building Confederation (MGBC) actively encourages using green materials and implementing sustainable practices in the construction industry by developing the Green Technology Financing Scheme (GTFS). The GTFS primarily aims to offer financial aid for green technology initiatives, especially in the construction industry [6, 38]. Malaysia has witnessed the implementation of several successful green building projects. For example, the Ken Rimba residential development in Shah Alam, constructed by Ken Holdings Berhad, is a noteworthy project that effectively incorporates green materials into its construction. The project has utilised fly ash and other recycled materials for its green concrete and bricks in its construction, while sustainable wood from bamboo and acacia is utilised to build window frames and doors. To further encourage water and energy efficiency, the development included low-flow water fixtures, solar panels for water heating, and rainwater harvesting systems [45, 46]. Another well-known building project is the Permodalan Nasional Berhad (PNB) 118 Tower in Kuala Lumpur; it is the tallest structure in Malaysia and incorporates various green concrete, such as high-strength concrete with a large percentage of recycled materials, to promote sustainable construction and reduce the environmental footprint [6].

As Malaysia is in rapid development, whether in industrial or construction activities, the wastes generated are also increasing. In Malaysia, a large amount of waste comes from the by-products of industrial or agriculture, such as fly ash, rice husk ash, and palm oil fuel ash. However, Malaysia has been innovating by repurposing and reusing waste in the construction industry, particularly in manufacturing green concrete. This strategy of making use of these by-products is very beneficial and advances environmental protection, such as lessening GHG emissions and waste in landfills while supporting sustainable construction development in Malaysia [42, 43, 47].

5.5.Challenges of green concrete in Malaysia.

Despite the numerous advantages of green concrete's sustainability, several obstacles hinder the implementation of green concrete's full integration into the construction industry. One of the main challenges is the cost of using green concrete. Green concrete for green construction buildings usually has a higher upfront cost regarding new technology, new construction approaches and design. Studies show that the green building incentives initiated by the government are not effective enough to cover the high upfront cost for businesses to enter into green building construction [48]. Other than that, there are insufficient professional workers with the knowledge or expertise in the green concrete building. This may be attributed to the reluctant of older generations of professionals to adopt green projects as they view it as troublesome, unnecessary and additional workloads [45]. The lack of expertise in green concrete building knowledge makes incorporating green concrete into the industry harder. Furthermore, the limited availability of green concrete may be an issue due to the procurement of green concrete taking a long period as it is not widely manufactured in Malaysia, which made it hard to outsource [6, 45]. Lastly, the regulatory barriers to adopting green concrete in construction are also a challenge, as Malaysia's construction norms and regulations may not entirely coincide with the requirements for green materials [6]. **Error! Reference source not found.** summarises the main challenges faced by Malaysians in adopting green concrete.

Table 6. Challenges in implementing green concrete in Malaysia.

Challenge	Description	References
High Initial Costs	– Green concrete often has a higher upfront cost due to new technologies and construction methods. – Existing government incentives are insufficient to cover these costs, deterring businesses from transitioning to green building.	[6, 48]
Lack of Expertise	– There is a shortage of skilled professionals knowledgeable about green concrete. – Older generations may resist adopting green practices, viewing them as troublesome and unnecessary. – Limited training opportunities hinder knowledge transfer.	[6, 45]
Limited Availability	– Green concrete is not widely manufactured in Malaysia, leading to procurement delays. – The production process can be time-consuming, making it difficult to source green concrete efficiently.	[6, 45]
Regulatory Barriers	– Existing construction norms and regulations may not align with the requirements for green materials. – Compliance with traditional regulations can complicate the integration of sustainable practices in construction.	[6, 45]
Market Awareness	– There is a general lack of awareness regarding the benefits of green concrete among industry stakeholders. – Misconceptions about the performance and cost-effectiveness of green concrete can limit its acceptance in the market.	[6, 48]

6. Green Concretes

This section discusses some of Malaysia's most widely used green concretes, including fly ash concrete, rice husk ash concrete, and palm oil fuel ash concrete. These green concretes make good use of the by-products from the industries or agriculture wastes commonly found and abundant in Malaysia, recycling and reusing them into useful products again in green concretes. The advantages and disadvantages of green concrete are evaluated and summarised in Table .

6.1.Fly ash concrete.

Concrete made with fly ash is a widely used form of green concrete in the construction industry. Fly ash, an abundant byproduct of burning coal in power plants, serves as a key ingredient in this type of concrete. Tens of millions of tonnes of fly ash are produced each year, and nearly half that amount is used in the construction sector—especially in power plant construction—with the remainder posing potential environmental threats. Fly ash is mostly (around 60%) amorphous silica, a compound with a high potential for reacting with the calcium hydroxide that is released when portland cement hydrates. This means that fly ash can substitute well for some of the (seriously inadequate) amounts of lime that form when portland cement cures. Since the 1930s, when its use began in the United States, fly ash has been extensively employed in the formulation of green concretes [42, 49]. Compared to traditional portland cement, fly ash boasts several advantages. Indeed, it can be fairly asserted that it reduces waste, given that large quantities of ash otherwise remain sitting within landfills. More to the point, fly ash can even be said to be a better binder than regular cement; its smooth, spherical particles lower friction and allow for a greater fluidity of the concrete mix. Meanwhile, it offers high compressive strength. Indeed, it appears that fly ash may offer several advantages over traditional portland cement, and that is even without considering the environmental angle [42, 51]. Fly ash portland cement brings several advantages over ordinary portland cement; however, it poses challenges to use. The first is a lower heat of hydration, which is beneficial in massive structures where thermal cracking is a problem. The second is lower permeability, which is related to the long-term strength of the concrete and its durability. However, this strength may not be fully manifested for several years; thus, fly ash concrete may not have as great "prestige" in the first few years as ordinary portland cement concrete. The reason for this "prestige" is not solely artistic; concrete is a scale model of the universe, and if it is to have useful properties (e.g., toughness, ductility, and resistance to efflorescence, shrinkage, and sulfate attacks), it must look good on the inside [51, 52].

6.2.Rice husk ash concrete.

Rice husk ash (RHA), a byproduct of rice production, is created when the husk is incinerated. In Malaysia, where the annual rice production is 0.52 to 0.59 million tons, 20 to 22% of the husk is incinerated, producing RHA. RHA is incredibly fine, has a large surface area, and is regarded as a nearly perfect material for pozzolanic concrete, mainly due to its high reactivity and composition. It has high silica content (up to 95%), and silica reacts with the lime produced when portland cement sets and hydrates. This reaction forms various compounds that not only bind the other components of concrete together but also enhance its strength. Of course, most of the advantages of RHA are completely negated by the lack of formal structural guidelines for the use of ash in concrete. When compared to traditional Portland cement, RHA provides much better mechanical strength; it also greatly increases the durability of concrete and makes it more resistant to shrinkage. Hwang et al. have conducted pretty thorough research on the matter and found that, when incorporated into concrete, ground rice husk ash can be used to replace up to 20% of the cement and still achieve about 60 MPa in compressive strength at 28 days. Control specimens without RHA achieved only 56 MPa. For anything you might think of as a concrete structure (be it a thin slab or a big hulking retaining wall), compressive strength is absolutely critical. RHA also improves the void structure of concrete pavements, which decreases permeability—a huge deal for any kind of flatwork that might be exposed to rain or ice. Moreover, a high content of RHA can provoke alkali-silica reactions in alkaline surroundings and cause an increase in permeability to chlorides, which could lead to corrosion and other problems. These possible adverse effects can be countered, however, by altering the amount and production methods of RHA. The high LOI of the Banja RHA, on the other hand, raises a red flag about its potential for producing cement that can withstand the high temperatures of situations like a fire [47, 50, 52].

6.3.Palm oil fuel ash concrete.

Palm Oil Fuel Ash (POFA) is a by-product of burning palm oil waste to generate electricity. Malaysia, as a significant palm oil producer, has a burgeoning POFA output: around 60,000 metric tons yearly. Despite being a waste material, POFA has found an application in the production of "greener" concrete as a partial cement replacement. This revalorization of POFA is unexpected, to be sure—after all, concrete is already a massively overproduced material in the modern world, contributing around 10% of annual carbon dioxide emissions. Yet, POFA is certainly better than just using more cement, thanks to its sufficient silt content (51% by mass is less than 45 microns in size) and also its not-uncommon achievement of a pozzolanic reaction.

The greater strength is attributed to fine ash's filling effect and the pozzolanic reaction that rigidifies the bond between the aggregate and the hydrated cement matrix. Even so, using POFA in concrete increases compressive, splitting tensile, and flexural strengths—more so than its control mix—in an effect somehow countering its porosity. In the following work, we explain this better performance. On the downside, too much POFA in the mix can decrease workability because of its absorbent tendency. Thus, POFA must be used judiciously, and with almost anything nowadays, in the right amounts, to get all these benefits and achieve what is rightly seen as a forward-looking, environmentally friendly construction material. Nonetheless, several difficulties manifest, including extended settling periods caused by POFA's superior ability to absorb water and its coarser particle size, which could disrupt the construction timetable [47, 50].

Table 7. Advantages and disadvantages of green concrete.

Item	Advantages	Disadvantages	Reference
FA concrete	• Repurpose by-product from coal burning in power plant • Reduced Water demand and improved Workability • Reduced Heat of Hydration • Higher Strength • Decreased Permeability • Increased Durability • Reduced Sulphate Attack • Reduced Efflorescence • Reduced shrinkage	• Longer setting periods • Slower strength development • Decreased early-age strength, which may delay construction. • Lesser resistance to scaling carbonation caused by deicer salt • Difficult concreting in cold weather	[47, 50, 52]
RHA concrete	• Repurpose paddy wastes • Improved mechanical strength, durability, and shrinkage resistance • Useful for concrete pavement with its enhancement of void structure, • Reduction of permeability • Reduce penetrability of chlorides • Strengthen resistance to magnesium sulphate attacks	• Reduction in flowability • Higher water demand • Poor chloride permeability • Ligh loss on ignition (LOI) leading to low reliability in high-temperature environments	[47, 52]
POFA concrete	• Repurpose by-product from palm oil fuel-burning • Improved concrete strength • Increased compressive, splitting tensile and flexural strength • Reduced releasing heat energy, preventing cracks and shrinkage in concrete. • Greater sulphate resistance • Decreased water permeability	• Long settling time, delaying construction schedule • Higher water engrossment • Reduced workability when excessive volume of POFA in concrete	[44, 47]

7. Conclusion

The construction industry in Malaysia is an important sector of the economy. It provides many jobs, and the pay is decent. But it is a major contributor to environmental challenges, including local illegal dumping and pollution of the water supply. In response, over the past 50 years, the Malaysian government has developed a series of policies, regulations, and guidelines for the use of EMPs in the construction sector. These documents, which include the Environmental Quality Act 1974, appear to be at least partly effective. As of 2020, however, the Malaysian construction sector, by and large, still seems to be struggling to convert to the use of the EMPs. Obstacles, including poor prior knowledge of the practitioners, high costs, movement of staff, commitment across the organization, and a number of other challenges, are impeding the conversion. The solution to these hurdles appears to be some combination of capacity building, government incentives, such as grants and tax breaks, and regular inspections to ensure that the up-to-standard site is truly up to standard. Increased investment in "R&D" on sustainable building materials is another necessity. Green concrete is gaining traction because its environmental advantages—lower greenhouse gas emissions, less energy used, and reduced waste going to landfills—make it a worthy replacement for traditional concrete. But Malaysia has not yet been able to overcome some serious obstacles to ensure that green concrete is used as a replacement. Those obstacles are high initial costs, limited availability, and regulatory and expertise issues. The adoption of green concrete—such as varieties that use fly ash, rice husk ash, or palm oil fuel—will be accelerated in Malaysia by programs like the Green Technology Financing Scheme. The construction industry can become more environmentally friendly if the EMPs that govern it are translated into sustainable practices.

Acknowledgements

The authors thank JNS Engineering Consultant Malaysia and University of Kansas Lawrence USA for facilitating this work.

Author Contribution

John Lim: writing, methodology, data analysis; Gaurav Talukdar: methodology, data analysis.

Conflicts of Interest

The authors declare no conflict of interest.

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