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Utilization of Green Materials and Technology for Sustainable Construction in Malaysia

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ABSTRACT: The aim of this study is to investigate the impact of the construction industry on the environment in Malaysia and propose strategies for mitigating its adverse effects through the adoption of sustainable building techniques. The study recognizes the importance of a healthy ecosystem in promoting health conditions, improving living standards, and ensuring a sustainable future for the nation. However, the recent population expansion has placed increased pressure on Malaysia's building industry and infrastructure, resulting in environmental degradation caused by the construction sector. To address this issue, the study examines the overall framework of ecological management implemented in Malaysia's construction industry. It evaluates key aspects of construction management, including the formulation and implementation of environmental policies, the involvement of stakeholders in decision-making processes, and the effective management of construction waste. Additionally, the study conducts a comprehensive assessment of specific regulations and guidelines pertaining to construction waste, water contamination, and air pollution, all of which are prevalent issues in Malaysia's construction activities. Furthermore, the study highlights the benefits of using green materials in construction to minimize environmental impact and enhance overall quality of life. It explores the implementation of green technologies in Malaysia, considering their advantages and disadvantages within the local context. By doing so, the study aims to provide insights into the challenges faced in the widespread adoption of green technologies, taking into account the perspectives of the government, economy, society, and available resources. Ultimately, the study emphasizes the need for collaboration among all stakeholders to address environmental damage effectively. It stresses the importance of an inclusive approach, ensuring that no one is left behind in the efforts to rectify the situation and prevent further deterioration of the environment. By taking proactive measures and implementing sustainable building techniques, it is hoped that the construction industry in Malaysia can contribute to a greener and more sustainable future for the nation.

KEYWORDS: Construction; policies; management; green material; sustainable; challenges; Malaysia

1. Introduction

A nation's wealth is correlated with its expansion in productivity and economic progress, where all sectors, including fundamental, intermediate, and ancillary, cooperate to maintain financial stability [1]. The construction field has made significant contributions to wealth creation and the enhancement of living standards through government socio-economic policies focused on infrastructural development. Furthermore, it has a compounding effect on other sectors such as manufacturing, wealth management, and engineering facilities [1, 2]. Thus, inadequate and improper construction infrastructure can hinder a country's divisions, impede economic development, reduce living quality, and create income inequality, all of which contribute to the economic collapse of the nation. Effective management of the construction industry leads to improved living conditions nationwide, increased international visitors, a healthy ecosystem, enhanced financial flow, and job opportunities. Gross Domestic Product (GDP) plays a key role in coordinating and regulating the economy across all sectors. Globally, the construction industry generates approximately $2 trillion USD and contributes an average of 6% to the GDP of most nations. Therefore, expansion and innovation in this field are crucial as they significantly contribute to a country's GDP [1]. Given the crucial role played by the construction industry in economic growth, the Malaysian government must prioritize it and take action for Malaysia to qualify as a developed country [3].

In Malaysia, the construction sector has experienced substantial expansion over the past few decades and contributed nearly 6% to the GDP in 2017. This growth has reduced the unemployment rate by creating millions of job opportunities and boosting the nation's economy. However, inappropriate waste management practices in construction projects, employee behavior, and unsustainable packaging of essential supplies have resulted in significant environmental issues [4]. Research indicates that Malaysia's urban growth generates an estimated 8 million tonnes of construction waste per year, posing risks to the environment, ecosystem, and public health. Construction waste refers to unwanted materials or excess resources generated during construction activities [4, 5]. The increasing amount of construction waste has led some construction companies to illegally dispose of waste at sites to reduce expenses [4]. The most suitable and cost-effective solution to address this issue is efficient and environmentally sound management of construction debris to minimize waste and prevent adverse environmental impacts. Construction waste management should be prioritized and emphasized in every project to benefit the environment, the community, and economic growth [5].

Urbanization also results in the extensive consumption of resources and the release of carbon-containing emissions into the atmosphere, leading to contamination and adverse effects on human health. These actions can potentially trigger a range of natural and anthropogenic disasters. The only viable solution to mitigate the consequences of pollution and address current environmental challenges is to transition towards sustainable building practices by incorporating green and durable materials in infrastructure projects [6]. Green materials refer to substances that can be repurposed or recycled, serving as alternatives to the limited availability of non-renewable resources. The use of green materials in construction can have a positive impact on the environment, enhancing building efficiency and indoor environmental

quality. Some common environmentally friendly building materials utilized in Malaysia include durable concrete, lightweight reinforced concrete, and wooden floors [7]. Furthermore, Malaysia is also implementing green technology as it provides a pathway to reconcile the need for economic growth with environmental responsibility. The green technology policy in Malaysia encompasses various programs and regulations aimed at promoting the adoption of ecological methods across all industries, reducing reliance on fossil fuels, which are a primary contributor to climate change. As the urgency to combat climate change intensifies globally, sustainable construction and green technology must collaborate to stimulate the economy, generate employment opportunities, and attract investments [8]. The aim of this study is to investigate the impact of the construction industry on the environment in Malaysia and propose strategies for mitigating its adverse effects through the adoption of sustainable building techniques

2. Current State of Construction Management Practices and Legislative Policies in Malaysia.

Construction must comply with the regulations established by governmental agencies to preserve the ecosystem and safeguard public health. For instance, regulatory bodies such as the Occupational Health and Safety Administration (OSHA), National Resources and Environment Board Sarawak (NREB), Department of Irrigation and Drainage (DID), and Department of Environment (DOE) have devised guidelines and restrictions that construction projects in Malaysia must adhere to. Prior to commencing a construction project, it is mandatory to conduct an Environmental Impact Assessment (EIA) in strict compliance with the environmental regulations and recommendations provided by OSHA, NREB, DID, and DOE. This assessment ensures that the implementation of the construction project does not impose any negative burden on the surrounding environment. The EIA report includes information about anticipated pollution during the project and outlines management strategies to mitigate potential environmental impacts [4, 9]. The subsequent section provides a more comprehensive exploration of the significant issues caused by construction projects in Malaysia.

2.1. Problems resulting from the construction activities with their governmental policies.

2.1.1. Illegal dumping.

In the last ten years, the construction sector has proven to be both a valuable investment and a major contributor to the nation's economy. The development of the building infrastructure is required to tackle the population explosion in order to improve living conditions while boosting the economy [10]. There are currently 46 illegal construction waste disposal sites, just in the Malaysian state of Johor, demonstrating that waste management in Malaysia has to be examined in order to curb the rising production of construction waste. The primary cause of unlawful dumping is the lengthy travel distance between the project area and the disposal facility. Hence, the authorities decided to illegally dump its waste to avoid paying delivery and disposal fees [11, 12]. Illegal dumping has caused several environmental effects, such as land deterioration, leachate-related groundwater and surface water contamination, soil degradation, and natural resource depletion. This persistent scenario poses risks to the biological system and the citizens. The management of construction waste can be evaluated and examined from the angles of law and enforcement. A comprehensive legal structure is needed to provide a guideline for stakeholders involved in the construction business. Enforcement must be

implemented to provide punishment to those that do not adhere to the law to ensure that the system is well functioning [12]. Table 1 lists the commonly involved parties and environmental policies with descriptions in Malaysia in order to ensure proper handling the waste and to prevent the waste from causing environmental degradation.

Table 1. Acts related to construction waste.

Stakeholders	Legislations	Descriptions	Reference
Ministry of Housing and Local Government (MLGH)	Solid Waste and Public Cleansing Management Act 2007 (Act 672)	This Act gives the housing and local authorities power over managing solid waste and public cleaning in order to establish a healthy environment. This Act mandates the adoption of waste management techniques like recycling, reusing, and reducing, and it imposes hefty fines on anyone who violates its rules. However, it only applies to communities and regions that are under local administration.	[12, 13]
Ministry of Works (JKR)	Standard Specifications for Buildings Works (2005 Edition) Clause 46.3	This rule primarily applies to contractors working on projects for the Public Works Department. It has stated that any waste from construction projects must be cleared twice weekly and adequately disposed of at the standard disposal site.	[12]
Ministry of Natural Resources and Environment (NRE)	Environmental Quality Act 1974 (Act 127)	This legislation is focused on eliminating, minimising, and managing pollution. The wastes mentioned in this Act might be solids or liquids, but they are only regarded as wastes when dumped and cause environmental pollution.	[12, 13]
Construction Industry Development Board (CIDB)	Construction Malaysia Act 1994 (Act 520)	This enforcement law gives the officer authority and responsibility to check on construction projects whenever they are underway to make sure that the authorities maintain a spotless construction site at all times. This enforcement statute provides the authorities to deal with construction waste left behind throughout the site clearance process.	[12, 13]

2.1.2. Surface water and groundwater pollution.

Construction waste discharged into the waterways without being treated or processed can degrade water quality, diminish its aesthetic value, and endanger aquatic life. Volatile organic compounds, paintings, lubricants, and cement are the most prevalent substances found on construction sites that are released into the water bodies, affecting water turbidity and reducing water use. Additionally, soil erosion is more likely to occur at construction sites due to the increased exposure of the ground surface to the air and rain. This situation makes the water murky and cloudy, posing threats to the rivers' aquatic creatures [14]. Additionally, construction activities like earthmoving and deforestation can significantly increase the amount of suspended solids in the nearby water bodies. Large-scale construction projects can also have a substantial effect on water contamination as a result of inefficient worker sewage management. Normally, a large number of employees are involved in the project, and the authorities installed no septic systems at the initial phases of the construction, which contributed to the immediate wastewater or sewage disposal into the neighbouring watercourses. Hence, a short-term treatment system must be constructed and estimated based on the project period to meet DOE standards [4, 14]. Malaysia has implemented the Environmental Quality Act 1974 under Section 25; anyone who discharged waste into rivers would be subject to an MYR 100,000 fine, imprisoned for five years, or both, depending on how severe the offense was. The punishment may be considerably more punitive if it involves

hazardous wastes, as these wastes have a tremendous potential to harm the environment when released in small quantities. Since the drainage system plays a significant role in spreading the contaminants, adequate management and upkeep of the system for building site discharges are crucial to prevent water pollution [15].

2.1.3. Air pollution.

Construction sites frequently contain atmospheric dirt particles, coal ash, and microscopic particulates due to the usage of heavy machinery and vehicles during construction. The building materials that the manufacturers are using, such as concrete, mortar, and wood, are likely to release these dust particles and can be spread over a long distance. Besides, gasoline engines and other on-site machinery can discharge fine particulate matter into the atmosphere. Moreover, the developers might get rid of the construction waste through open burning; this action is also considered one of the major sources of decreasing air quality by generating smoke. Severe health risks can pose to the local population, particularly those who face respiratory issues, if a significant amount of smoke gets into the nearby housing neighbourhoods [16]. Open burning is not permitted based on the legislation under Section 29A in Environmental Quality Act 1974. The occupant who engages in open burning is susceptible to a fine of MYR 500,000, incarceration, or both. Opening burning activities are particularly allowed under the Environmental Quality Act (Declared Activities) (Open Burning) Order 2003 if they are conducted with the appropriate reason and under surveillance and monitoring. The approved set fire are plantation lands for pest management, replanting purposes, and crematorium [17].

2.2. Environmental management system (EMS).

EMS is a collection of procedures and protocols that assist a corporation in reducing its ecological consequences and improving operational performance. It is a mechanism to aid the company in defining, managing, and evaluating firm activities related to its outputs and operations that may have temporary or permanent effects on the environment [18]. The environmentally conscious approaches implemented on Malaysian construction sites to reduce the pollution in terms of air and water, as well as solid waste management, are shown in Table 2. The system is designed to generate more ecologically responsible constructions with efficient resources and energy consumption, as well as offer healthier living and working circumstances to boost economic growth and productivity [19]. Designing, carrying out, reviewing, and responding are the primary tasks involved in this mechanism, which enables the EMS framework to be continuously improved to properly tackle the pace of development issue we are currently facing [18]. One of the standards developed for a company to utilise as a manual while establishing an EMS is ISO 14001. The goal of this guideline is to create a universal foundation for all EMS that can support a wide range of applications globally. It tends to unify global environmental management criteria and practices [19]. Using this system, a contracting authority can define specific and clear objectives, assess project performance and decide when to take corrective and preventive responses. It serves as a framework for the authorities to methodically manage its environmental element. It also assists to reduce operational expenses due to the implementation of waste minimisation procedures and decreases the likelihood of receiving fines for failing to comply with environmental regulations [20].

Table 2. Good practice to address issues at the construction site [15, 21].

Statement	Strategies	References
Air Quality		
Trucks that transported construction materials in and out of the project sites	- Trucks are fully covered with impermeable sheets after loading with dusty materials to prevent the particulates from being exposed to the atmosphere and contaminating the air. - Tyres of the trucks are being sprayed with water or cleaned before accessing a public route	[15, 21]
Black smoke being released from the on-site machinery or automobiles	- Inspections are recorded during regular maintenance in order to make sure that air pollution is kept to a minimum. - Machinery can only be fuelled with gasoline that satisfies the vendor's quality requirements.	[21]
Project area	- Fences or retaining walls are built around the project site to control the dust emission and its impact on the neighbourhood.	[21]
Construction waste		
Solid waste	- Set up storage areas for waste separation to make recycling and reprocessing easier. - Wastes that can be used for restoration or landscape development should be separated and sent to the public dumping sites that the regulators have authorised, and others need to be disposed of at public landfill.	[15, 21]
Water Quality		
Septic tank / wastewater	- The short-term toilet system should be constructed with the standards of the Sewerage Service Department. - Desludging work needs to be done regularly to prevent sewage overflow. - All wastewater generated from the construction site must be treated with the standard treatment process.	[15, 21]

2.3. Environmental initiatives through the 3Rs concept.

The 3Rs idea has been identified as the most effective strategy among several that Malaysia has performed to decrease the waste volume in the construction industry. Reuse, recycle and reduce are the three key construction-related variables that have been considered in this approach [22]. Table 3 describes how each variable is implemented at the construction site in reducing the waste produced throughout the construction process.

Table 3. The implementation of 3Rs at construction site.

Variables	Descriptions	References
Reduce	Using minimal original resources and minimising waste are two ways in reduce methods. Reduction is thought to be the most economical and practical way of managing construction waste since it not only lowers the production of garbage but also reduces the expenses associated with waste disposal, recycling, and transportation.	[23, 24]
Reuse	This initiative aims to use the materials as efficiently as possible. The contractor will typically choose reuse as their first course of action because some construction debris can be reused in other projects, and reuse is less expensive than disposal. Materials that cannot be reused and has the capabilities to recycle will be delivered to a recycling facility.	[23, 24]
Recycle	Recycling is using waste resources to produce new goods for other purposes. Recycling is recommended and preferred when reduce and reuse are challenging to achieve. Recycling can be categorised into on-site and off-site. On-site recycling is the process of differentiation and separation of the construction trash for use as raw materials in future construction activities. On the other hand, off-site recycling involves sorting construction waste and transporting it to another site where it is employed as a source of primary components.	[23, 24]

The 3R approach, founded on the idea of completely utilising resources before disposal, has grown in popularity as it has been incorporated into policy and is one of the alternative methods to the waste management hierarchy. This strategy has become increasingly important in reducing waste and has served as a guide for handling construction and demolition debris. Research shows that more than 70% of recyclable materials are in Malaysian landfills [24]. The 3Rs concept has been included in the 8th Malaysia Plan by the Malaysian government,

which gives authorities the duties and responsibilities to ensure that effective waste management policies can be enforced to reduce the sources of consumption, environmental pollution, and waste production [25].

3. Green Materials Utilised in Malaysian Construction Activities

Materials are crucial for the construction of buildings. Their characteristics, such as chemical, physical, and mechanical, along with the right design, are responsible for the building's structural rigidity. Implementing green materials with comparable or superior properties to conventional construction components should be the first step in designing green structures. In the past decades, the criteria for building materials selection have been through operational and budgetary considerations; however, the nation has focused on sustainability as a top priority. The construction industry, which is actively or passively accountable for a sizeable portion of the annual environmental damage, can embrace the obligation to support ecological sustainability by identifying more eco-friendly development techniques. The easiest way for building authorities to incorporate sustainable design principles in construction is to choose eco-friendly sustainable building materials carefully [26]. The example of green materials employed in the Malaysian construction site is described in the following section. Table 4 has summarised each green materials with their usages and benefits.

Table 4. Summary of green materials with their applications.

No	Materials	Purpose	Pros	References
1	Bamboo	Used as earthquake retrofitting technology	- Eco-friendly materials - Equivalent strength as steel - Higher resistance to compression weight	[29]
2	Coal fly ash	Substituted for Portland cement	- Water conservation by producing concrete with same qualities - Reduce ecological footprint	[31]
3	Organic waste	Palm oil fuel ash used as stabilizer	- Enhance the structural integrity and engineering qualities of soil	[35]
		Palm oil clinker and Palm Kernel Shell as aggregate component for asphalt concrete	- Increase the strength of asphalt concrete	[35]
		Rice husk ash as cement substitute	- Reduce the amount of waste being disposed of - Reduce carbon emission in producing cement	[36]
4	Recycled plastics	Plastic as brick aggregates	- Reduce the amount of waste for landfill disposal - Minimize the environmental damage from inappropriate plastic waste disposal - Lower the cost spent of purchasing new building supplies	[42]

3.1. Bamboo.

As people become more aware of environmentally friendly materials, bamboo has gained favour as a possible replacement for synthetic fibers in composite materials used in building. Bamboo has advantages over conventional materials, such as higher specific gravity, a more excellent weight-to-tensile strength ratio than steel, and the ability to withstand compressive strength than concrete. If particular natural forests are reduced, it is a great substitute for wood due to the decreasing availability of lumber and growing concern among consumers of wood manufactured commodities about the environmental impacts. Bamboo's structural, physical, and inherent resilience are changed based on a number of variables such as farming practices and heredity [27]. Guada bamboo and Moso bamboo are the two most popular species used in

construction; they have the equivalent strength-to-weight ratio as steel and about double the compression-to-weight ratio of concrete, indicating their high ability to endure tremendous pressure and weight [28]. This is proven by the presence of the mosque Buluh in Kuala Kangsar, Perak, which was built from bamboo, and the building can house around 500 pilgrims at once [29].

3.2. Coal fly ash.

Currently, the recovery of useful resources and the use of waste as building materials wherever practical are the contemporary international tendencies to protect the ecosystem from the garbage. A waste product called fly ash is produced when coal is burned in electric generating plants, and they are collected from the combustion chamber in the furnace by the syngas using mechanical or electrostatic separation techniques. In Malaysia, there are approximately 6.8 million tons of fly ash are produced each year. Based on studies, the production of fly ash outpaces consumption from the growing communities that are generated by coal power stations [30]. Fly ash has become well-known as cementitious material utilised as a substitute in the production of cement concrete due to its high fineness and low carbon content. Compared to conventional cement concrete, its features enable concrete manufacturing at lower water contents of the same strength and durability, making it more environmentally sustainable [31]. In Malaysia, cement is a fundamental element for making bricks, and the use of fly ash has unquestionably reduced the ecological footprint [32]. Table 5 in appendices highlights the differences between fly ash brick and conventional red clay brick, as well as their pros and cons. The comparison clearly demonstrates that fly ash brick is more durable and sustainable materials that can replace traditional brick in order to preserve the environment.

Table 5. Evaluation of the properties of fly ash brick versus conventional red clay brick [32, 33].

Characteristic	Fly ash brick	Red clay brick
Geometry	Uniform	Uneven
Weight	Lighter	Heavier
Compressive strength	Higher (≈90 kg/cm^2)	Lower (≈35 kg/cm^2)
Porous availability	Lesser	Higher
Thermal tolerance	Lower (≈0.98W/m^2℃)	Higher (≈ 1.30W/m^2℃)
Price	Lower	Higher
Plastering availability	Yes	No

3.3. Organic waste.

Malaysia is one of the greatest palm oil producers, accounting for over 50% of global palm oil production. This suggests that the country generates enormous amounts of waste that pose significant storage and environmental challenges [34]. The commonly available wastes from the palm oil industry are Palm Kernel Shell (PKS), Palm oil clinker (POC), Palm oil Fibre (POF), and Palm oil fuel ash (POFA). POFA can be applied as a stabilizer to substitute chemical additions like lime and Ordinary Portland Cement to increase soft soil's structural integrity and engineering qualities before paving. Using chemicals can release high quantities of carbon dioxide into the environment, increasing the severity of global warming. POC and PKS are highly valuable as aggregate components in concrete due to their potential to increase the strength of asphalt concrete [35]. Besides, rice husk ash is being used as a component of green building materials; it is formed from the raw rice husk throughout the process from under 700℃ to 800℃. It is a suitable choice to replace cement in cement production due to its high silica composition, which produces better cement attributes, including practicability, durability, and steel reinforcement oxidation [36]. There are approximately 2 million metric

tonnes of rice husk are generated annually in Malaysia, which produces an environmental problem because the rice husk is either incinerated or discarded as waste. Therefore, it should be used as an alternative for producing cement to reduce the negative influence on the environment [37].

3.4. Plastics.

The production of solid waste is increasing in the current era of urban and industrial revolution, as is its management in landfills [38]. In Malaysia, plastic waste accounts for around 13% of overall production, due to its numerous uses in the manufacturing, wrapping, medical, and industrial applications, among others [38, 39]. Plastic is comprised of multiple harmful compounds that have the capabilities to cause environmental damage to contemporary society if improperly handled or processed [38]. By recycling these plastics, the ecosystem will be protected, and landfill space will not only be conserved but also energy consumed in the production of new plastics [39]. Plastic has been introduced in production the red bricks to consume less sand and make lighter bricks. It is because cement and sand are the primary raw materials used to produce concrete bricks, with sand has a hefty load, so plastic pellets are substituted as aggregates for sand with a variety of mixing methods [40]. Analysis demonstrates that adding plastics to bricks or blocks has the potential to increase their strength qualities and decrease their heat conductivity, making them exceptional building and construction materials [41]. Additionally, plastic wastes can be utilised in place of aggregate wholly or partially while constructing roadways. They are usually implemented in pavement sub-base and base to increase their load carrying capacity, structural integrity, and tensile stress, thereby enhancing the road performance and lifespan. The usage of recycled plastics for building and construction purposes is a workable approach to being green by maximizing their usage as alternatives for conventional building materials. The main benefits of this technique include a reduction in the volume of garbage dumped in landfills, a decrease in the severity of environmental contamination brought on by the disposal of plastic waste, and a reduction in expenses of construction materials [42].

4. Green Materials Technology in Malaysia

Green Technology (GT) is a progression that aims to improve strategies and resources, from techniques for producing energy to environmentally friendly products. Utilising GT helps to mitigate the detrimental effects of human activity on the ecosystem. GT’s cross-sectoral character offers a way to strike a balance between the demands of economic growth and our duty to protect the surroundings. The sustainability of economic growth is the key objective to be achieved in this continually expanding construction industry [43]. With GT, Malaysia may improve economic expansion while preserving and reducing the energy demand. GT improves Malaysia's competitiveness globally and the nation's ability for innovation [44]. The GTs introduced in Malaysia are described below, along with their benefits and drawbacks. Table 6 in Appendices provides an overview of Malaysian green technologies, with their implementation sites, as well as their pros and cons.

Table 6. Summary of green technologies with their applications.

No	Technology	Type	Implementation location	Pros	Cons	References
1	Solar	Solar water heaters	- Residential area Cheras, Kuala Lumpur - Residential area Semenyih, Selangor - Government buildings of Pusat Tenaga, Selangor	- Reduce the reliant on fossil fuels - Reduce carbon footprints - Reduce electricity bills	- High initial costs - Climate dependent	[47–50]
2	Hydropower	Dam	- Bakun Dam, Sarawak - Murum Dam, Sarawak - Baleh Dam, Sarawak	- Reduce the reliant on fossil fuels - Reduce carbon footprints - Facilitate flood management	- Impact on aquatic ecosystem	[53–55]
3	Biogas	Landfill	- Bukit Tagar Sanitary Landfill, Selangor - Jeram Sanitary Landfill, Selangor - Seelong Sanitary Landfill, Johor	- Reduce the reliant on fossil fuels - Reduce carbon emissions	- High maintenance costs - Safety issues	[57–61]
4	Green roof	Intensive Extensive	- KL Central Park, Kuala Lumpur - Serdang Hospital, Selangor - State Development Corporation, Selangor - Heriot-Watt University, Selangor - Newcastle University Medicine, Johor - Putrajaya City Hall, Putrajaya	- Facilitate the city cooling effect - Reduce the occurrence of heat island mechanism - Increase internal thermal conformity	- High initial costs - High maintenance costs	[63, 65, 66]
5	Rain water harvesting	Belowground tank Aboveground tank	- State Mosque, Penang - Bukit Indah Mosque, Selangor - Building complex, Pahang	- Enhance the soil conservation - Reduce the occurrence of flash floods at urban area - Preserve the aquatic ecosystem	- Water quality is dependent on air contaminants - Regular maintenance required to ensure the water cleanliness - High initial and maintenance cost	[69, 70]

4.1. Solar technology.

Malaysia is one of the countries with the greatest potential for solar energy intake due to its advantageous location close to the equator. A study found that Malaysia absorbs 500 MJ/m^2 of solar energy on average each month and has the potential to generate up to 6500MW of electricity. Therefore, Malaysia has immense opportunities for solar energy production due to its hot and sunny climate with minimal temperature variations [45]. The solar irradiation received by various sites in Malaysia is shown in Table 7. Solar thermal and photovoltaic (PV) technologies make up the two main subfields of solar energy technologies in Malaysia. Solar thermal innovation utilised solar heat for heating applications, while PV technology employs a module made of solar PV components to convert solar radiation into electric power. Solar

thermal includes solar water heaters (SWHs), solar space heaters, and coolers. Despite Malaysia's favourable climate for the expansion of solar energy and the usage of SWHs in several aspects of the economy, many Malaysian households continue to use electric water heaters (EWHs) due to SWHs' high upfront cost and low environmental awareness [46].

According to a study comparing the annual cost of SWHs and EWHs over time, installing SWHs is more cost-effective because utilising EWHs will result in a higher electricity bill due to growing families and potential rises in electricity rates [46]. The annual carbon dioxide (CO_2) avoided due to the use of PV technology is anticipated to rise by 16.75 million tonnes between 2011 and 2050. This translates to MYR 2.1 billion in cost savings because further CO_2 emission control is not necessary to reduce the release of CO_2 from industrial or commercial regions [47]. Therefore, it results in clean and renewable electrical power for the communities. There is no noise pollution generated during operation as the solar energy is transformed directly into electricity by the PV systems [48]. When opposed to using fossil fuels to produce electricity, one of the main drawbacks of using solar energy is that it is heavily reliant on meteorological conditions. This makes solar energy volatile and unpredictable, which significantly limits and complicates power production [49].

Table 7. Solar irradiation absorbed by different locations in Malaysia [46].

Locations	Monthly average value (kWh/ m^2)
Kuching, Sarawak	122.50
Kuala Lumpur, Selangor	130.92
Seremban, Negeri Sembilan	131.00
George Town, Penang	148.75
Kota Kinabalu, Sabah	158.33
Taiping, Perak	147.33

4.2. Hydropower technology.

Hydropower is the most widely used source renewable source of energy, with 1308 GW of generating capacity worldwide as of 2019. Large hydropower plants, typically more than 10 GW, with a reservoir have advantages associated with their multi-functional uses, including energy production, employment opportunities, effective water handling and control, as well as stabilization of the electric network due to its versatile operating condition. In contrast to small hydropower, which is generally constructed for local development, decentralized energy generation, and investment opportunities in distant regions [51]. Malaysia is enriched with the goodness of water supplies with a total of 200 rivers in the country. These waterways have their origins in the mountainous regions, which make up 41% of the total land area. Additionally, West Malaysia and East Malaysia are expected to receive an average yearly rainfall of 5080 mm and 3850, respectively, during the rainy season. This indicates that hydropower has a significant potential for producing electricity [52].

Hydropower is 35% more efficient than conventional fossil fuel power generation due to its various benefits, including being a sustainable, green, low carbon footprint, and affordable energy source [53]. Only a relatively small quantity of greenhouse gases is released into the environment as a result of the usage of hydroelectric energy, with an average of 9g of CO_2 equivalent per kWh (CO_2 eq/kWh) produced annually from the utilization of hydropower to generate electricity. Since no harmful chemical additives are used in this operation, there will be little to no waste produced throughout the hydropower generation, eliminating the possibility of improper disposal of hazardous waste. Furthermore, the development of dams and hydropower generate infrastructure that facilities flood management. Since the water resources are kept by barricades, it is simpler to monitor and maintain their flow rate, which

lowers the risk of flooding. Although hydropower is beneficial for the environment, there are restrictions on its introduction. Despite the comparatively low cost of electricity production, building a hydroelectric plant construction is expensive due to the challenges of underwater installation, which necessitate the use of sophisticated specialized equipment. Additionally, the time needed to construct a hydropower station is almost equivalent to an entire decade, which raises expenses even more. The introduction of a hydropower plant can alter the life cycles of aquatic creatures due to the plant serving as a barrier in the water bodies, limiting mobility and availability of nutrients necessary for survival. The heat generated by the plant may cause the water bodies to become warmer, endangering aquatic life and driving them to migrate [54].

4.3. Biogas technology.

One alternative renewable energy source that could reduce the need for fossil fuel is biogas. Malaysia is heavy reliance on fossil fuels, which account for 88% of the overall energy source, this caused global greenhouse gas emissions have increased significantly [56, 57]. Remarkably, the CO_2 eq emissions from the combustion of fossil fuel reached 54 Gt in 2010 and are projected to achieve 70 Gt in 2050. Biogas is produced by anaerobically digested organic wastes, either they are in the solid or liquid phase. Solid organic wastes include domestic waste, grass clippings, and household organic waste, while liquid wastes include palm oil mill effluent, wastewater sludge, and livestock excrement. Anaerobic digestion employs microbes to break down the organic matter under the condition without the presence of a high oxidative catalyst or oxygen. The primary end product of this process is biogas, which is odourless and colourless gas that is composed of methane (CH_4) (50–70%) and CO_2 (30–50%). The main substances that utilised in Malaysian biogas plants are POME and landfill waste [57].

The potential benefit of biogas generation is the capacity to convert waste into a useful resource and helps reduce waste and waste disposal costs while preserving the aesthetic value of the environment. Even though biogas combustion does result in the production of CO_2, the primary distinction between biogas and fossil fuels is the relatively low carbon content of the former, which allows plants to readily remove it from the atmosphere through photosynthesis [58]. Besides, the biogas-derived CH_4 is often converted to biomethane, suitable for use as transportation fuel, or supplied to the national natural gas infrastructure. The use of biomethane as a gasoline alternative is anticipated to enhance environmental air quality because it has up to ten-fold lower emission factors than liquid fuels, with particulates, reactive organic pollutants, and polycyclic aromatic hydrocarbons have taken into account. Biomethane introduced to the national grid can reduce the reliance of households on solid fuel to consume energy with respect to indoor air quality and human hazards [59]. The drawback of this technology is the biogas still consists of impurities even after going through several refinement steps, which leads to engine metal parts degrading. This expense of maintenance would increase as a result of this engine deterioration and damage. Furthermore, CH_4 released from the plant needs to be handled cautiously because it can ignite when comes into contact with O_2, illustrating that the biogas is unstable and prone to explosions [60].

4.4. Green roof system.

Green roof can be described as top floor garden with aesthetic plantations or greenery areas, or known as a vegetated roofing framework that has been integrated with irrigation to preserve

the green areas [62]. The roofs are constructed using a system of prefabricated layers that are purposefully affixed to roofing elements that support growth media and vegetation. Green roofs can be classified into two types: extensive and intensive systems. Table 8 lists the key variations between these two systems [62, 63]. By simply describing these systems, extensive green roofs are lightweight with thin covering of plantation, whereas intensive green rood has thicker soil structure and capable of supporting small trees and bushes. Evapotranspiration can be produced by the plant communities atop green roofs, and the resulting humidity and air cooling will decrease the heat island phenomenon. The heat island effect will result in higher energy costs for air conditioners and higher air pollution rates. Green roof systems can also increase internal thermal conformity by assimilating and reflecting the solar radiation, so reducing the quantity of radiated heat. Therefore, green roofs are seen to be an efficient way to reduce urban island effect in urban areas without taking up precious area [63].

The main drawback of green roof systems is the construction cost significantly more expensive than conventional roofs due to their unique design. The system involves many more foundation layers and is constructed of pricey, frequently imported components. A specialised gardener is required to ensure that the plantations are developed properly and are kept safe against pests, and weeds, which has resulted in higher maintenance expenses. Otherwise, the introduction of green roofs will be decreased the visual value of the building if the plantations are not adequately care for. Additionally, green roofs are rumoured to have downsides including leaks and building surface mould, due to the frequent errors made during the cover's construction. Thus, systematic planning and expert construction are important to assure that such roofs will function as intended [65].

Table 8. Comparison between intensive and extensive green roof mechanisms

Criteria	Intensive system	Extensive system	References
Thickness of foundation	-Involves deeper foundation with a minimum of 15 cm	-Involves shallow foundation with normally within the range of 2 cm to 15 cm	[63, 64]
Weight	-Heavy weight with an average of saturated weight of 350kg/m^2	-Lightweight with an average of saturated weight of 105kg/m^2	[63, 64]
Expenses	-High implementation cost	-Low implementation cost	[63]
Ease of construction	-Complicated	-Easy	[64]
Public Accessibility	-Accessible	-Inaccessible	[63, 64]

4.5. Rain water harvesting system (RWHS).

The imbalance between freshwater consumption and supply has caused an issue that contributes to water shortages. Exploring and using rainwater appears to be an alternative for reducing the mentioned challenge. Malaysia is favoured for the adoption of RWHS since it is a country with significant yearly precipitation and is strategically located to collect rainwater for cleaning, drinking, or cooking purposes [67]. RWHS is generally the process of gathering and storing the rainwater for usage instead of letting it flow off into the environment, increasing the water availability for users [68]. There are several RHWS types, including which rooftop or man-made belowground and aboveground catchment areas as well as backyard mechanism. The most common system in Malaysia is the backyard system since it is less expensive and simpler to construct than other systems that need pipe network system [67].

The introduction of RWHS introduction offers both environmental and economic benefits. RWHS has reduced the effect of rainwater on the soil system, which has decreased the frequency of soil erosion and flash floods in urban areas. The river ecosystem is conserved as the soil pollutants are prevented from contaminating water sorces and aquatic organisms are

not endangered by the toxins. RWHS has the ability to save money by lowering the amount of water consumed from public utilities because it is particularly beneficial for non-potable water consumption [69]. The main disadvantage of RWHS is that airborne pollutants such as particles, microbes, heavy metals and organic matters have a significant impact on the quality of rainwater harvested. Therefore, tests must be performed to determine its practicability and relevancy before using it for drinking purpose [70]. The initial and maintenance costs of RWHS continue to be a problem because they are not economical and affordable for all communities. Precautions must be taken for storage tanks by closing them tightly to reduce the risk of contamination from individuals, animals, or other toxic pollutants, as well as to prevent algal bloom and mosquito breeding. Regular maintenance should be conducted by cleaning and disinfecting the interior walls of the water storage to keep it free of microbiological contamination, which is time and effort consumption. Storage tank cleanliness is crucial for preserving human health [71].

5. Challenges.

Implementing green construction may face difficulties because it is challenging to strike a balance between sustainability with economics, particularly in emerging nations like Malaysia. The main obstacles to initiating sustainability initiatives for the Malaysian construction industry are high initial costs, inadequate environmental academic achievement for operational and management, immaturity of the use of green building materials, resistance to change, and insufficient environmental law enforcement of the construction company [72]. Table 9 outlines the difficulties encountered in employing green buildings based on different categories, and each factor is covered in more detail in the following section.

Table 9. Barriers to deploying green buildings.

Factor	Challenges	References
Government	- Deficiency of design standards and regulatory requirements	[72, 73]
	- Deficit of incentives	
Financial	- Expensive start-up costs	[72–74]
	- Insufficient credit capabilities to pay for upfront costs	
Resource	- Lack of skills and knowledge	[72, 73]
	- Absence of modern technology	
Communities	- Absence of environmental responsibility and awareness	[72–74]

The primary party involved in enhancing green development is the government. The relationship between government structure and green construction results in institutional structures and regulations has been underlined to hasten the transformation. The primary mechanisms used by the government to encourage the construction of green buildings are financial support and legislative action. However, there are insufficient policies or guidelines that strictly enforced for the construction industry to comply, which has led to a lack of incentive and a disregard for the environmental issues brought on by the construction process [72]. Introducing sustainable building will be difficult for a corporation with limited financial resources because green building materials are more pricey than conventional buildings, with an upfront cost increase of up to 25% [72, 73]. Additionally, this is a prolonged profit payback period and the builders will be more concerned with its profitability than environmental sustainability [73].

Other than that, the upper management has a significant impact on how green initiatives are adopted. It is because a decision made by upper management without environmental

concerns can directly impact the employees' attitudes toward applying green buildings. As the idea of green buildings is still new to Malaysia compared to other countries, it requires using cutting-edge building materials and techniques. Meanwhile, the availability of technologies is limited, making it problematic for the development companies to obtain all the supplies they need to construct green buildings [73]. Furthermore, adopting green technology requires specialised knowledge because they are more complex to operate than conventional methods. The construction industry also needs to adhere additional policies and standards to ensure that the company properly understands the implementation of green practises, lengthening building process as since more procedures are required. Therefore, the parties and investors are undermining their confidence in implementing green technology due to the complexity of green technologies and the scarcity of experienced individuals. Some businesses reluctant to offer training for their employees to enhance their knowledge and competences due to their concern that employees may leave for a firm offering a greater compensation, wasting their effort and expense [74].

4. Conclusions

The environmental problems in Malaysia have drawn particular attention because the country is constantly improving its living conditions and facilities to accommodate its expanding population growth. Therefore, environmental protection strategies should be applied in all types of businesses, specifically the construction industry, as it has become a popular area for researchers and societies to evaluate and examine. It is because the introduction of construction projects can have a significant negative influence on the environment by producing solid waste, releasing harmful toxins into the adjacent waterways, and emitting greenhouse gases into the atmosphere. This study has outlined the construction waste handling and governmental legislation, demonstrating that Malaysia has a comprehensive and detailed environmental sustainability mechanism that construction companies must adhere to. Bamboo, coal fly ash, organic waste, and plastics have also been used as building materials in Malaysia to reduce waste, energy consumption, and enhance health conditions. Furthermore, green material technologies, include solar, water, biogas, green roof system and rainwater harvesting mechanism are promoted to reduce and control the carbon and methane emissions, reducing their negative effects on the climate system. Although practicing green approaches are beneficial for the environment and human health, stakeholders confront different aspects of problems that make it challenging to adopt green management in construction sector. The key to addressing the issues is increasing the environmental consciousness and enlisting the participation of all the relevant parties in performing the green practices.

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Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Alaloul, W.S.; Musarat, M.A.; Rabbani, M.B.A.; Iqbal, Q.; Maqsoom, A.; Farooq, W. (2021). Construction sector contribution to economic stability: Malaysian GDP distribution. *Sustainability, 13*, 5012. https://doi.org/10.3390/su13095012.

[2] Khaertdinova, A.; Maliashova, A.; Gadelshina, S. (2021). Economic development of the construction industry as a basis for sustainable development of the country. *E3S Web of Conferences, 274*, 10021. https://doi.org/10.1051/e3sconf/202127410021.

[3] Khan, R.A.; Liew, M.S.; Ghazali, Z.B. (2014). Malaysian construction sector and Malaysia vision 2020: Developed nation status. *Procedia-Social and Behavioral Sciences, 109*, 507–513. https://doi.org/10.1016/j.sbspro.2013.12.498.

[4] Chang, T.W.; Kumar, D. (2021). Overview of Environmental Management Practice for Construction in Malaysia. *Civil and Sustainable Urban Engineering, 1*, 15–25. http://dx.doi.org/10.53623/csue.v1i1.33.

[5] Hasmori, M.F.; Zin, A.F.M.; Nagapan, S.; Deraman, R.; Abas, N.; Yunus, R.; Klufallah, M. (2020). The on-site waste minimization practices for construction waste. *IOP Conference Series: Materials science and engineering, 713*, 012038. http://doi.org/10.1088/1757-899X/713/1/012038.

[6] Patel, P.; Patel, A. (2021). Use of sustainable green materials in construction of green buildings for sustainable development. *IOP Conference Series: Earth and Environmental Science, 785*, 012009. http://doi.org/10.1088/1755-1315/785/1/012009.

[7] Kuppusamy, S.; Chew, H.Y.; Mari, T.S.; Chai, C.S.. (2019). Implementation of green building materials in construction industry in Johor Bahru, Malaysia. *IOP Conference Series: Earth and Environmental Science, 268*, 012006. http://doi.org/10.1088/1755-1315/268/1/012006.

[8] Zaboon, A.A.; Salih, R.J. (2021). The Experience of Green Technology in Malaysia and its Role in Enhancing Sustainable Development. *Review of International Geographical Education Online, 11*, 2631–2643. http://doi.org/10.48047/rigeo.11.08.246.

[9] Paul, B. (2021). Multi-Dimensional Effectiveness of Environmental Impact Assessment (EIA) in Malaysia: The Perspectives of Practicing Environmental Consultants. Doctoral dissertation, Sunway University, Malaysia.

[10] Nagapan, S.; Rahman, I. A.; Asmi, A. (2012). Factors contributing to physical and non-physical waste generation in construction industry. *International Journal of Advances in Applied Sciences, 1*, 1–10. http://doi.org/10.11591/ijaas.v1.i1.pp1-10.

[11] Nagapan, S.; Rahman, I.A.; Asmi, A.; Adnan, N.F. (2013). Study of site's construction waste in Batu Pahat, Johor. *Procedia Engineering, 53*, 99–103. https://doi.org/10.1016/j.proeng.2013.02.015.

[12] Nagapan, S.; Rahman, I.A.; Asmi, A. (2012). Construction waste management: Malaysian perspective. International Conference on Civil and Environmental Engineering Sustainability (IConCEES), Malaysia, 2, 299–309.

[13] Wahi, N.; Joseph, C.; Tawie, R.; Ikau, R. (2016). Critical review on construction waste control practices: legislative and waste management perspective. *Procedia-Social and Behavioral Sciences, 224*, 276–283. https://doi.org/10.1016/j.sbspro.2016.05.460.

[14] Rahman, N.N.N.A.; Esa, N. (2014). Managing construction development risks to the environment. In Sustainable living with environmental risks; Kaneko, N., Yoshiura, S., Kobayashi, M., Eds.; Springer: Tokyo, Japan, pp. 193–202. https://doi.org/10.1007/978-4-431-54804-1_16.

[15] Yahaya, I. (2020). The Implementation of Environmental Practices by Malaysian Contractors. *International Journal of Integrated Engineering, 12*, 310–318. https://doi.org/10.30880/ijie.2020.12.04.030.

[16] Tao, G.; Feng, J.; Feng, H.; Feng, H.; Zhang, K. (2022). Reducing Construction Dust Pollution by Planning Construction Site Layout. *Buildings, 12*, 531. https://doi.org/10.3390/buildings12050531.

[17] Kamaruddin, H.; Khalid, R.M.; Supaat, D.I.; Shukor, S.A.; Hashim, N. (2016). Deforestation and haze in Malaysia: Status of corporate responsibility and law governance. In Be-Ci 2016: 3rd International Conference On Business And Economics. https://doi.org/10.15405/epsbs.2016.11.02.34.

[18] Din, S.A.M. (2011). The implementation of Environmental Management System (EMS) ISO 14001 among construction companies in Malaysia. *Journal of Architecture, Planning and Construction Management, 1,* 89–108.

[19] Omran, A.; Yahya, S.H.S. (2020). Environmental management system (EMS) within construction site: a case study in kelantan state, Malaysia. *IOP Conference Series: Materials Science and Engineering, 847*, 012039. https://doi.org/10.1088/1757-899X/847/1/012039.

[20] Farouq, M.M.; Lawan, U.F.; Garba, N.; Anwar, F.H.; Baba, Z.B.; Labbo, M.S.; Aliyu, D.S. (2017). Implementation of Environmental Management System in Construction Industry: A Review. *IOSR Journal of Mechanical and Civil Engineering, 14,* 33–38. http://doi.org/10.9790/1684-1405043338.

[21] Yusoff, S.; Nordin, R.; Yusoff, H. (2015). Environmental Management Systems (EMS) ISO 14001 implementation in construction industry: A Malaysian case study. *Issues in Social And Environmental Accounting, 9,* 18–31. http://doi.org/10.22164/isea.v9i1.97.

[22] Aadal, H.; Rad, K.G.; Fard, A.B.; Sabet, P.G.P.; Harirchian, E. (2013). Implementing 3R concept in construction waste management at construction site. *Journal of Applied Environmental and Biological Sciences*, *3*, 160–166. https://doi.org/10.3390/su131910660.

[23] Oyenuga, A.A.; Bhamidimarri, R. (2015). Sustainable approach to managing construction and demolition waste: An opportunity or a new challenge. *International Journal of Innovative Research in Science, Engineering and Technology, 4*, 10368–10378. http://doi.org/10.15680/IJIRSET.2015.0411007.

[24] Ng, L.S.; Tan, L.W.; Seow, T.W. (2017). Current practices of construction waste reduction through 3R practice among contractors in malaysia: Case study in penang. *IOP Conference Series: Materials Science and Engineering, 271*, 012039. http://doi.org/10.1088/1757-899X/271/1/012039.

[25] Nazry, K. (2021). A Review Of The Sustainable Development Goals Policy Framework For Malaysian Local Governments. *Malaysian Journal of Sustainable Environment, 8*, 157–177. https://doi.org/10.24191/myse.v8i2.13245.

[26] Sharma, N.K. (2020). Sustainable building material for green building construction, conservation and refurbishing. *International Journal of Advanced Science and Technology, 29*, 5343–5350.

[27] Osman, S.; Ahmad, M.; Zakaria, M.N.; Zakaria, A.M.; Ibrahim, Z.; Abu, F.; Bahari, S.A.; Jaafar, W.W. (2022). Bamboo as future bio-industrial material: Physical behaviour and bending strength of Malaysia's Beting bamboo (*Gigantochloa levis*). *IOP Conference Series: Earth and Environmental Science, 951*, 012001. http://doi.org/10.1088/1755-1315/951/1/012001.

[28] Mofidi, A.; Abila, J.; Ng, J.T.M. (2020). Novel advanced composite bamboo structural members with bio-based and synthetic matrices for sustainable construction. *Sustainability, 12*, 2485. http://doi.org/10.3390/su12062485.

[29] Noh, H.M.; Sukri, N.H.A.; Kasim, N.; Zainal, R.; Musa, S.M.S.. (2021). Utilisation of Bamboo as Reinforcement Material in Concrete. *Research in Management of Technology and Business, 2*, 905–920. https://doi.org/10.30880/rmtb.2021.02.01.068.

[30] Ghazali, N.; Muthusamy, K.; Ahmad, S.W. (2019). Utilization of fly ash in construction. *IOP Conference Series: Materials Science and Engineering, 601*, 012023. http://doi.org/10.1088/1757-899X/601/1/012023.

[31] Zeggar, M.L.; Azline, N.; Safiee, N.A. (2019). Fly ash as supplementry material in concrete: A review. *IOP Conference Series: Earth and Environmental Science, 357*, 012025. http://doi.org/10.1088/1755-1315/357/1/012025.

[32] Thakur, A.; Tiwary, A.K. (2021). A Comparative Study on Conventional Clay Bricks and Autoclaved Aerated Concrete Blocks. *IOP Conference Series: Earth and Environmental Science, 889*, 012061. http://doi.org/10.1088/1755-1315/889/1/012061.

[33] Sharma, A.K.; Kumar, S.; Mishra, N. (2019). Environmental Impact of Fly Ash Brick in Comparison with Traditional Brick. In Smart Technologies for Energy, Environment and Sustainable Development. Lecture Notes on Multidisciplinary Industrial Engineering; Kolhe, M., Labhasetwar, P., Suryawanshi, H., Eds.; Springer, Singapore, pp. 195–201. http://doi.org/10.1007/978-981-13-6148-7_21.

[34] Abdullah, N.; Sulaiman, F. (2013). The oil palm wastes in Malaysia. *Biomass now-sustainable Growth and Use, 1*, 75–93. http://doi.org/10.5772/55302.

[35] Yaro, N.S.A.; Napiah, M.; Sutanto, M.H.; Hainin, M.R.; Usman, A.; Rafindadi, A.D.; Abdulrahman, S.; Saeed, S.M. (2021). Utilization of palm oil mill residue as sustainable pavement materials: A review. *International Journal of Integrated Engineering, 13*, 66–78. http://dx.doi.org/10.30880/ijie.2021.13.03.008.

[36] Zaid, O.; Ahmad, J.; Siddique, M.S.; Aslam, F. (2021). Effect of incorporation of rice husk ash instead of cement on the performance of steel fibers reinforced concrete. *Frontiers in Materials, 8*, 665625. https://doi.org/10.3389/fmats.2021.665625.

[37] Ozturk, M.; Saba, N.; Altay, V.; Iqbal, R.; Hakeem, K.R.; Jawaid, M.; Ibrahim, F.H. (2017). Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia. *Renewable and Sustainable Energy Reviews, 79*, 1285–1302. https://doi.org/10.1016/j.rser.2017.05.111.

[38] Kamaruddin, M.A.; Abdullah, M.M.A.; Zawawi, M.H.; Zainol, M.R.R.A. (2017). Potential use of plastic waste as construction materials: recent progress and future prospect. *IOP Conference Series: Materials Science and Engineering, 267*, 012011. https://doi.org.10.1088/1757-899X/267/1/012011.

[39] Nyika, J.; Dinka, M. (2022). Recycling plastic waste materials for building and construction Materials: A minireview. *Materials Today: Proceedings, 62*, 3257–3262. http://doi.org/10.1016/j.matpr.2022.04.226.

[40] Noh, H.M.; Bakar, N.F.N.A.; Kasim, N.; Zainal, R.; Musa, S.M.S. (2021). The Acceptance of Utilizing Low-density Polyethylene (LDPE) Plastic in Concrete Brick Among Construction Stakeholders. *Research in Management of Technology and Business, 2*, 865–876. https://doi.org/10.30880/rmtb.2021.02.01.065.

[41] Ogundairo, T.O.; Adegoke, D.D.; Akinwumi, I.I.; Olofinnade, O.M. (2019). Sustainable use of recycled waste glass as an alternative material for building construction-a review. *IOP Conference Series: Materials Science and Engineering, 640*, 012073, https://doi.org/10.1088/1757-899X/640/1/012073.

[42] Lamba, P.; Kaur, D.; Raj, S.; Sorout, J. (2021). Recycling/reuse of plastic waste as construction material for sustainable development: a review. *Environmental Science and Pollution Research, 29*, 86156–86179. https://doi.org/10.1007/s11356-021-16980-y.

[43] Mahat, N.A.A.; Alwee, S.N.A.S.; Adnan, H.; Hassan, A.A. (2019). Propelling green building technologies adoption in Malaysia construction industry. *IOP Conference Series: Earth and Environmental Science, 233*, 022032. https://doi.org/10.1088/1755-1315/233/2/022032.

[44] Puvanasvaran, A.P.; Yop Zain, M.F.; Al-Hayali, Z.A.; Mukapit, M. (2012). Sustainability of Green Technology in Malaysia Industry. International Conference on Design and Concurrent Engineering. Universiti Teknikal Melaka.

[45] Abdullah, W.S.W.; Osman, M.; Ab Kadir, M.Z.A.; Verayiah, R. (2019). The potential and status of renewable energy development in Malaysia. *Energies, 12*, 2437. https://doi.org/10.3390/en12122437.

[46] Mekhilef, S.; Safari, A.; Mustaffa, W.E.S.; Saidur, R.; Omar, R.; Younis, M.A.A. (2012). Solar energy in Malaysia: Current state and prospects. *Renewable and Sustainable Energy Reviews*, *16*, 386–396. https://doi.org/10.1016/j.rser.2011.08.003.

[47] Almaktar, M.; Abdul Rahman, H.; Hassan, M.Y.; Wan Omar, W.Z. (2015). Photovoltaic technology in Malaysia: past, present, and future plan. *International Journal of Sustainable Energy*, *34*, 128–140. https://doi.org/10.1080/14786451.2013.852198.

[48] Silveira, J.L.; Tuna, C.E.; de Queiroz Lamas, W. (2013). The need of subsidy for the implementation of photovoltaic solar energy as supporting of decentralized electrical power generation in Brazil. *Renewable and Sustainable Energy Reviews, 20,* 133–141. https://doi.org/10.1016/j.rser.2012.11.054.

[49] Maradin, D. (2021). Advantages and disadvantages of renewable energy sources utilization. *International Journal of Energy Economics and Policy*, *11*, 176–183. https://doi.org/10.32479/ijeep.11027.

[50] Kamaruzzaman, S.N.; Abdul-Rahman, H.; Wang, C.; Karim, S.B.; Lee, T.Y. (2012). Solar technology and building implementation in Malaysia: A national paradigm shift. *Maejo International Journal of Science and Technology, 6,* 196. https://doi.org/10.11591/ijpeds.v12.il.pp474-488.

[51] Quaranta, E. (2021). Innovative Projects and Technology Implementation in the Hydropower Sector. In Technological Innovations and Advances of Hydropower Engineering; Shang, Y. Ed.; IntechOpen: London, UK, pp. 75–90.

[52] Yah, N.F.; Oumer, A.N.; Idris, M.S. (2017). Small scale hydro-power as a source of renewable energy in Malaysia: A review. *Renewable and Sustainable Energy Reviews, 72,* 228–239. http://doi.org/10.1016/j.rser.2017.01.068.

[53] Hossain, M.; Huda, A.S.N.; Mekhilef, S.; Seyedmahmoudian, M.; Horan, B.; Stojcevski, A.; Ahmed, M. (2018). A state-of-the-art review of hydropower in Malaysia as renewable energy: Current status and future prospects. *Energy Strategy Reviews, 22,* 426–437. https://doi.org/10.1016/j.esr.2018.11.001.

[54] Walczak, N. (2018). Operational Evaluation of a Small Hydropower Plant in the Context of Sustainable Development. *Water*, *10*, 1114. https://doi.org/10.3390/w10091114.

[55] Tang, K.H.D. (2020). Hydroelectric dams and power demand in Malaysia: A planning perspective. *Journal of Cleaner Production, 252*, 119795. https://doi.org/10.1016/j.jclepro.2019.119795.

[56] Rashidi, N.A.; Chai, Y.H.; Yusup, S. (2022). Biomass Energy in Malaysia: Current Scenario, Policies, and Implementation Challenges. *Bioenergy Research, 15,* 1371–1386. https://doi.org/10.1007/s12155-022-10392-7.

[57] Lim, Y.F.; Chan, Y.J.; Abakr, Y.A.; Sethu, V.; Selvarajoo, A.; Singh, A.; Lee, J.; Gareth, M. (2021). Review of biowastes to energy in Malaysia: Current technology, scalability and socioeconomic analysis. *Cleaner Engineering and Technology, 4,* 100257. https://doi.org/10.1016/j.clet.2021.100257.

[58] Zieliński, M.; Kazimierowicz, J.; Dębowski, M. (2023). Advantages and Limitations of Anaerobic Wastewater Treatment—Technological Basics, Development Directions, and Technological Innovations. *Energies*, *16*, 83. https://doi.org/10.3390/en16010083.

[59] Paolini, V.; Petracchini, F.; Segreto, M.; Tomassetti, L.; Naja, N.; Cecinato, A. (2018). Environmental impact of biogas: A short review of current knowledge. *Journal of Environmental Science and Health, Part A, 53*, 899–906. https://doi.org/10.1080/10934529.2018.1459076.

[60] Damyanova, S.; Beschkov, V. (2020). Biogas as a source of energy and chemicals. Biorefinery Concepts, Energy and Products. In Biorefinery Concepts, Energy and Products; Venko, B. Ed.; IntechOpen: London, UK. https://doi.org/10.5772/intechopen.90558.

[61] Yong, Z.J.; Bashir, M.J.; Ng, C.A.; Sethupathi, S.; Lim, J.W.; Show, P.L. (2019). Sustainable waste-to-energy development in Malaysia: Appraisal of environmental, financial, and public issues

related with energy recovery from municipal solid waste. *Processes, 7,* 676. https://doi.org/10.3390/pr7100676.

[62] Mahdzir, M.; Talib, R.; Mohamed, N.N.A.N.; Qing, S.H.; Khuzzan, S.M.S.; Yahya, N.F.A.N. (2020). The Application Of Green Roof In Malaysian Construction Industry: Issues And Challenges. International Journal of Technology Management and Information System, 2(3), 9–23.

[63] Chow, M.F.; Bakar, M.A. (2016). A review on the development and challenges of green roof systems in Malaysia. *International Journal of Architectural and Environmental Engineering, 10*, 16–20. https://doi.org/10.5281/zenodo.1338620.

[64] Azis, S.S.A.; Razali, M.N.M.; Maimun, N.H.A.; Yusoff, N.S.M.; Rahman, M.S.A.; Zulkifli, N.A.A. (2021). An Analysis On The Efficiency Of Green Roof In Managing Urban Stormwater Runoff. *Planning Malaysia, 19*, 111–122. https://doi.org/10.21837/pm.v19i17.991.

[65] Drozd, W. (2019). Problems and benefits of using green roofs in Poland. *IOP Conference Series: Earth and Environmental Science, 214*, 012076. http://doi.org/10.1088/1755-1315/214/1/012076.

[66] Shaharudin, S.; Khalil, N.; Saleh, A.A. (2019). Review of significant maintenance criteria for tropical green roofs in Malaysia. *International Journal of Technology, 10*, 69–80. http://doi.org/10.14716/ijtech.v10i1.1696.

[67] Hafizi Md Lani, N.; Yusop, Z.; Syafiuddin, A. (2018). A review of rainwater harvesting in Malaysia: Prospects and challenges. *Water, 10*, 506. http://doi.org/10.3390/w10040506.

[68] Juliana, I.C.; Syahril Badri Kusuma, M.; Cahyono, M.; Kardhana, H.; Martokusumo, W. (2017). Rainwater harvesting system implementation for domestic water use: the environment and financial benefits. In ICoSI 2014. Springer: Singapore, pp. 411–421. http://doi.org/10.1007/978-981-287-661-4_41.

[69] Rahman, A.; Keane, J.; Imteaz, M.A. (2012). Rainwater harvesting in Greater Sydney: Water savings, reliability and economic benefits. *Resources, Conservation and Recycling, 61*, 16–21. https://doi.org/10.1016/j.resconrec.2011.12.002.

[70] Rahman, S.; Khan, M.T.R.; Akib, S.; Din, N.B.C.; Biswas, S.K.; Shirazi, S.M. (2014). Sustainability of rainwater harvesting system in terms of water quality. *The Scientific World Journal, 2014*, 721357. https://doi.org/10.1155/2014/721357.

[71] Afrose, T.; Anthony, L.; Fernandez, K.; Latt, S. (2018). Global access to clean water: the role of rain water harvesting. *Annals of Reviews and Research, 2*, 555585. http://dx.doi.org/10.19080/ARR.2018.02.555585.

[72] Ong, Y.S.; Yusof, N.A.; Osmadi, A. (2021). Challenges of green office implementation: A case study in Penang, Malaysia. *International Journal of Sustainable Construction Engineering and Technology, 12*, 153–163. https://doi.org/10.30880/ijscet.2021.12.01.015.

[73] Yee, H.C.; Ismail, R.; Jing, K.T. (2020). The Barriers of Implementing Green Building in Penang Construction Industry. *Progress in Energy and Environment, 12*, 1–10.

[74] Ayarkwa, J.; Opoku, D.G.J.; Antwi-Afari, P.; Li, R.Y.M. (2022). Sustainable building processes' challenges and strategies: The relative important index approach. *Cleaner Engineering and Technology, 7*, 100455. https://doi.org/10.1016/j.clet.2022.100455.