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# Green Material Technologies in the Malaysian Construction Industry: Current Trends and Future Prospects

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**ABSTRACT:** Rapid urbanization and industrialization coupled with growing population causes rapid development of the construction industry. The construction activities carried out and improper construction waste management can result in significant environmental impact if not mitigated such as air and dust pollution, surface water pollution and noise pollution. Government policies and initiatives for sustainable construction has been formulated and implemented in Malaysia to promote green construction. The adoption of industrialised building system (IBS) is encouraged to achieve construction waste minimization and reduction starting from the design and planning stage of construction. The implementation of 3Rs strategies is also significant to reduce the construction waste generated and minimize the environmental pollution caused by landfill disposal of construction waste. Agricultural waste can be incorporated in the manufacturing of concrete as substitute for cement or aggregate hence can decrease the greenhouse gases emission associated with cement manufacturing. Several green materials technologies including solar photovoltaic system, cooling roof system and rainwater harvesting system are implemented in Malaysia.

**KEYWORDS:** Sustainable construction; environmental management practice; green materials; agricultural waste; green technology

## 1. Introduction

The rapid urbanization and industrial development, combined with increased population growth, propelled the development of the construction industry in developing countries, as there was increasing demand for the development of housing and infrastructure projects to meet living standards. The contribution of the construction industry to the Gross Domestic Product (GDP) of Malaysia accounted for 15.1% in 2015, and the industry provided increased employment opportunities, with around 1.4 million workers among the total workforce employed in the construction sector in Malaysia [1].

However, the construction industry was one of the major contributors to environmental pollution and greenhouse gas emissions. With the rapid development of the construction industry, huge amounts of construction and demolition waste were generated every year, estimated to be around 8 million tonnes annually [2]. This raised waste management issues, as most of the construction waste was disposed of in landfills, which had limited capacity and insufficient land for expansion. The construction activities carried out and improper management of construction waste caused environmental issues, including air and dust pollution, deterioration of surface water quality, and noise pollution. Therefore, the implementation of environmental management practices was significant in minimizing and reducing the environmental impact caused by construction activities [2, 3].

Greenhouse gas emissions from the building sector alone in Malaysia accounted for around 20% of total emissions, and the construction industry contributed 20% of total carbon dioxide emissions. Greenhouse gas emissions associated with construction were caused by the manufacturing of construction materials, as well as the equipment, machinery, and vehicles used, which consumed fuel, along with the disposal of construction waste [3]. Therefore, the utilization of sustainable and green construction materials in construction projects gained much attention for reducing carbon and energy footprints.

Numerous studies investigated the incorporation of agricultural waste into the manufacturing of construction materials like concrete to substitute cement or aggregates, aiming to reduce GHG emissions. Green building was another approach toward sustainable construction, where the concept of green building promoted the efficient use of energy, water, and materials [3–6]. This study provided an overview of the government policy on environmental management practices in Malaysia's construction industry, as well as the planning and implementation of those practices. The green construction materials and green material technologies available in Malaysia were also summarized in this study.

## 2. Current Status of Construction Industry and Government Policy in Malaysia

It was estimated by the Minister of Urban Wellbeing, Housing and Local Government Malaysia that around 26,000 tonnes of construction and demolition waste (CDW) were produced daily in Malaysia. Malaysia generated the most CDW among Southeast Asian countries in 2014, with approximately 9.49 million tonnes of CDW. The authorities involved in the management of CDW in Malaysia were the Ministry of Works, the Ministry of Natural Resources and Environment, and the Construction Industry Development Board (CIDB) Malaysia. The legal policy associated with CDW management was the Solid Waste and Public Cleansing Management Act [Act 672] (2007), where construction solid waste was defined as “any solid waste generated from any construction or demolition activity, including improvement, preparatory, repair or alteration works” [7].

Most of the solid waste, including construction and demolition waste, was disposed of in landfills, accounting for 95% to 97%, while the remaining waste was incinerated or recycled. The recycling rate of CDW remained low in Malaysia, at around 15% [1, 8]. However, due to rapid urbanization and industrialization, coupled with population growth, the increased generation of construction waste exacerbated illegal dumping issues in Malaysia, where Solid Waste Corporation Malaysia (SWCorp) discovered 851 illegal dumping sites. The cost of construction waste disposal at landfills and the distance between construction sites and landfills contributed to the increase in illegal dumping in Malaysia [9].

The Environmental Quality Act (EQA) 1974 was the main environmental legislation for environmental protection in Malaysia. Before the commencement of any large-scale construction project, the submission of an Environmental Impact Assessment (EIA) report to the Department of Environment (DOE) Malaysia or the Natural Resources and Environment Board was required for construction projects classified under prescribed activities. The submitted EIA report included the identification and evaluation of key environmental impacts of the project, proposals for mitigation measures, and an Environmental Management Plan (EMP). The compliance of construction activities with the EQA 1974 was significant in ensuring pollution control and minimizing environmental impacts from construction projects.

The Green Building Index (GBI) Malaysia was established by the Association of Consulting Engineers Malaysia (ACEM) and Pertubuhan Akitek Malaysia (PAM), and was introduced on 21st May 2009. GBI was adopted to rate buildings in terms of sustainability and efficiency based on various green aspects, including energy, materials, and water. The design and construction of green buildings in Malaysia were promoted through the implementation of this rating tool, thereby minimizing the environmental impact of buildings. The design of green buildings focused mainly on energy and water savings and the use of recycled materials. There were four classifications for green building ratings based on points awarded: platinum, gold, silver, and certified. The rating criteria included energy efficiency, indoor environmental quality, sustainable site planning and management, materials and resources, water efficiency, and innovation [10].

Tax and financial incentives were introduced by the Government of Malaysia, such as the Green Investment Tax Allowance (GITA) and Green Income Tax Exemptions (GITE), to promote the development of green technology by attracting investment in green technologies, including renewable energy technologies. GITA focused on renewable energy, energy efficiency, green buildings, waste management activities, and green data centers, while green technology services related to renewable energy, energy efficiency, green buildings, green townships, electric vehicles, and certification were allowed income tax exemptions under GITE. The Green Technology Financing Scheme (GTFS) was also launched by the Malaysian government to facilitate the utilization, production, and supply of green technology in Malaysia [11].

The National Green Technology Policy was introduced in 2009 by the Government of Malaysia to facilitate the application and development of green technologies in various sectors, including energy supply and utilization, buildings, water and waste management, and transportation. The green technologies used were expected to achieve minimal greenhouse gas emissions and environmental degradation, conservation of energy and natural resources, increased use of renewable resources, and the promotion of a healthy environment. There were five strategic thrusts of the green technology policy: strengthening institutional frameworks, providing a conducive environment for green technology development, intensifying green technology research and innovation, and promoting public awareness [12]. The government policies on environmental management practices in Malaysia is summarized in Table 1.

**Table 1.** Government policies on environmental management practices in Malaysia.

| Policy/Initiative | Description | Key Aspects | Reference |
|---|---|---|---|
| Environmental Quality Act (EQA) 1974 | The EQA 1974 is Malaysia's principal legislation for environmental protection. It mandates that large-scale construction projects submit an Environmental Impact Assessment (EIA) to the Department of Environment (DOE) or the Natural Resources and Environment Board before starting. The EIA must detail potential environmental impacts, propose mitigation measures, and include an Environmental Management Plan (EMP). Compliance ensures pollution control and reduces ecological disruption during project execution. | - Mandatory EIA submission for certain projects<br>- Evaluation of environmental risks and mitigation<br>- Environmental Management Plan (EMP)<br>- Legal compliance to minimize construction-related environmental harm | [13] |
| Green Building Index (GBI) | Launched in 2009 by ACEM and PAM, GBI is a rating system to assess building sustainability in Malaysia. It promotes the use of energy-efficient systems, water-saving technologies, and sustainable or recycled materials. Buildings are rated Platinum, Gold, Silver, or Certified based on points earned across criteria such as energy efficiency, indoor environmental quality, site planning, material usage, water efficiency, and innovation. The system supports Malaysia's commitment to greener urban development. | - Rates buildings on environmental performance<br>- Encourages energy, water, and resource efficiency<br>- Promotes use of sustainable and recycled materials<br>- Rating tiers: Platinum, Gold, Silver, Certified | [10] |
| Green Investment Tax Allowance (GITA) & Green Income Tax Exemption (GITE) | These financial incentives were introduced by the Malaysian government to stimulate investment in green technology. GITA offers tax allowances for companies investing in renewable energy, energy efficiency, green buildings, and waste management. GITE provides income tax exemptions for companies offering green technology services. These incentives are aimed at lowering the entry barrier for green investments and accelerating Malaysia's transition to a green economy. | - Encourages private sector investment in green tech<br>- GITA: tax relief for green tech assets<br>- GITE: income tax exemption for green tech services<br>- Focus areas include renewable energy, EVs, green buildings, waste management | [11] |
| Green Technology Financing Scheme (GTFS) | GTFS is a government-backed financing initiative designed to support the deployment and commercialization of green technologies in Malaysia. It offers soft loans and financial support to eligible companies, making it easier to adopt or produce environmentally friendly technologies. This scheme supports various sectors such as energy, manufacturing, and construction, contributing to the country's sustainable development goals. | - Financial support for green technology ventures<br>- Aims to reduce barriers to green tech adoption<br>- Covers supply and usage of green technologies<br>- Supports sustainable industrial development | [11] |
| National Green Technology Policy (2009) | Introduced in 2009, this policy sets a national framework to foster the development and implementation of green technologies across multiple sectors, including energy, water, building, waste management, and transport. The policy is guided by five strategic thrusts: strengthening institutions, creating a supportive environment, advancing R&D, promoting education and awareness, and encouraging market-driven adoption. | - Nationwide strategy for green technology adoption<br>- Sectoral focus: energy, water, buildings, transport<br>- Aims for GHG reduction, resource conservation<br>- Five strategic thrusts: governance, environment, R&D, awareness, market growth | [12] |

## 4. Environmental Management Practices for Construction

### *4.1. Environmental control measures at construction sites.*

The environmental management practices implemented at the construction site covered several aspects, including environmental protection and construction waste management, such as reuse and recycling (Table 2). Proper management of construction waste generated on site was significant in preventing the discharge or leaching of pollutants into surface water bodies, which could cause pollution [5]. To control dust pollution at the construction site, unpaved roads were sprayed, and trucks transporting construction materials such as sand were covered to minimize dust emissions [5, 6]. Noise barriers were installed around the construction site as part of the noise control measures, and construction activities were conducted within working hours [5]. These actions ensured that noise exposure from construction activities adhered to the Guideline for Environmental Noise Limits and Control by DOE Malaysia, causing minimal disturbance to the nearby community. A proper erosion and sediment control plan was prepared before the commencement of the construction project, based on the Guideline for Erosion and Sediment Control in Malaysia. The implementation of erosion and sediment control practices at the construction site was necessary to reduce the entry of soil particles into surface water. This was achieved by installing erosion and sediment control facilities: earth banks and diversion channels diverted surface runoff away from water bodies, while sediment traps and silt fences were used to control and trap sediments [5, 6].

### *4.2. Construction waste management.*

Construction waste management is a critical component of sustainable construction practices, especially in response to growing environmental concerns and regulatory pressures. Among the major issues identified were illegal dumping, excessive generation of construction waste, and the resultant adverse environmental effects such as land degradation, water contamination, and increased greenhouse gas emissions. Construction waste was generated throughout the project lifecycle, from the design and planning stage, through procurement and actual construction, to eventual demolition. Each of these phases offered opportunities for intervention and waste reduction. To address these challenges effectively, a comprehensive and proactive waste management strategy was adopted [12, 14]. This included applying the principles of the circular economy, which emphasized a closed-loop system of reducing, reusing, and recycling materials. Reducing waste began with efficient design, precise quantity estimation, and the use of prefabricated materials. Reuse involved salvaging and repurposing materials such as timber, bricks, and steel either on-site or for other projects. Recycling diverted waste from landfills, turning materials like concrete, asphalt, and aggregates into usable construction inputs. Implementing waste minimization measures not only helped conserve natural resources and reduce environmental degradation but also offered economic benefits by lowering material and disposal costs. Therefore, strategic construction waste management was essential for promoting long-term sustainability in the built environment [14, 15].

### *4.3. Industrialised building system.*

During the design and planning stage, the construction method applied in the construction project, for example, industrialized building system (IBS) can achieve minimization of the construction waste generated. Construction Industry Development Board (CIDB) Malaysia has introduced Construction industry transformation plan (CITP) 2016-2020 to promote sustainable construction with initiatives on the full implementation of the industrialised building system (IBS). The IBS system adopts modular approach where the construction components and elements are prefabricated and precast off site and then transported to the construction site to be assembled and erected. Conventional timber formwork is substituted with steel formwork that is prefabricated under the cast in-situ system while the structural components are cast off-site or on the construction site for prefabricated system, and the composite construction system is the combination of different construction systems. Previous study stated that the adoption of IBS system has the lowest construction waste generation rate compared to the conventional construction and mixed system method [14, 15]. One of the main advantages for implementation of IBS in Malaysia is enhanced construction productivity as the simultaneous production of the construction components disintegrated from the main construction process at different locations can occur, without any disturbance from unfavourable conditions. Moreover, the manufacturing of the construction components in the factories equipped with machinery with high accuracy can ensure that the manufactured components not only adhere to the required design specifications but are consistent in terms of high performance and quality. Apart from that, construction waste reduction can be achieved under IBS with elimination of formwork activities and the use of temporary structures. The IBS implemented system can lead to minimization of the life cycle costs in terms of labour and construction waste as well as construction time [14–16].

*4.4. 3R strategy (reduce, reuse and recycle).*

Construction and demolition waste management should adhere to the waste management hierarchy with reduction as the most preferable option to disposal as the least preferable option as shown in Figure 1. The 3Rs strategy, known as reduce, reuse and recycle as part of the waste management hierarchy is implemented to manage the construction waste generated. Reduce can achieve minimization of construction waste generation, consequently saving the cost of transportation and cost of landfill disposal for construction waste generated. Reuse involves reusing construction materials in the same or different construction processes on site. For the recycling of construction waste, the construction waste can be sorted and segregated for on-site recycling or off-site recycling where the sorted construction waste can be recycled as raw material for another construction process or other companies respectively [2, 14].

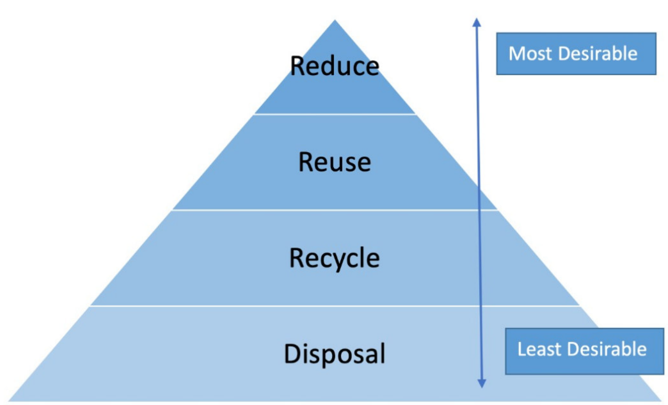


**Figure 1.** Waste management hierarchy.

**Table 2.** Some environmental management practices for construction.

| Category | Description | Reference |
|---|---|---|
| Environmental Control Measures at Construction Site | Implementation of comprehensive environmental controls is crucial at construction sites. Measures include proper waste management to prevent pollution from leaching into surface water, dust control via spraying unpaved roads and covering material transport trucks, and noise control using barriers and restricting activities to working hours. Adherence to the *Guideline for Environmental Noise Limits and Control* (DOE Malaysia) is essential. Additionally, a detailed Erosion and Sediment Control Plan (ESCP) should be developed before work begins, guided by the *Guideline for Erosion and Sediment Control in Malaysia*. Key practices include constructing earth banks and diversion channels to manage runoff and installing silt fences and sediment traps to capture soil particles. | [5, 6] |
| Construction Waste Management | Construction waste management should address issues such as illegal dumping and excessive waste generation across all stages of a project—from design to demolition. A lifecycle approach involving waste minimization should be applied using circular economy principles such as reducing, reusing, and recycling. This approach not only decreases environmental impacts but also improves resource efficiency and reduces overall project costs. | [14] |
| Industrialised Building System (IBS) | IBS is a modular construction approach where components are prefabricated off-site and assembled on-site, significantly reducing waste. CIDB Malaysia's Construction Industry Transformation Programme (CITP) 2016–2020 promoted IBS for sustainable development. Compared to conventional methods, IBS shows lower waste generation, improved productivity, consistent quality, and cost-effectiveness. It eliminates formwork-related waste and temporary structures. The system also benefits from factory-controlled conditions for higher precision and performance of building components. | [15, 16] |
| 3R Strategy (Reduce, Reuse, Recycle) | The 3R hierarchy is critical for sustainable construction waste management. "Reduce" focuses on minimizing waste generation and related costs. "Reuse" involves repurposing materials like timber for hoarding or formwork. "Recycle" converts materials such as metal, concrete, asphalt, and timber waste into raw materials for future use. Ferrous and non-ferrous metals are especially valuable due to their recyclability. Asphalt waste is reused using cold-in-place recycling (CIPR), while brick and concrete waste can be crushed into fill or recycled aggregate. This approach conserves natural resources, reduces landfill use, and minimizes environmental pollution. | [2, 8, 17, 18] |

The timber used for formwork was reused several times and repurposed as timber hoarding. Timber waste produced from the demolition of old buildings was sold to be recycled, where the recycled timber of specific sizes was used as timber beams and timber flooring. Apart from that, ferrous and non-ferrous metal waste generated during construction, such as steel and copper, was also recycled, retaining high monetary value without degradation of the metals. Brick waste, when crushed, produced filling materials, and CIPR was adopted as the recycling method for asphalt waste [17]. The large amount of construction waste generated from construction activities generally constituted a high proportion of concrete and aggregate, and this waste was recycled into recycled aggregates to substitute natural aggregates in concrete manufacturing [18]. The reuse and recycling of construction waste led to reduced consumption of natural resources and environmental pollution, while also addressing the issue of limited landfill capacity by reducing the amount of waste disposed of in landfills [8].

## 5. Green Materials for Construction

Concrete is commonly used as a building material in the construction industry. Rapid urbanization and development in Southeast Asian developing countries, including Malaysia, resulted in increased utilization and production of concrete, which consequently generated a growing amount of CDW waste. Cement manufacturing was one of the major sources of greenhouse gas emissions in the construction sector, largely due to carbon dioxide emitted from the calcination of limestone, as well as fossil fuel combustion [19]. Approximately 1 ton of carbon dioxide was emitted with the consumption of 1.5 tons of raw materials and 4 kJ of energy during the production of 1 ton of Ordinary Portland Cement (OPC) [20]. The design and application of green concrete were encouraged to reduce greenhouse gas emissions and limit the depletion of fossil fuels and mineral resources such as calcium during cement manufacturing. Green concrete incorporating agricultural waste focused on the use of such waste as supplementary cementitious material or aggregate substitution. This practice reduced the volume of waste sent to landfills and minimized environmental impacts by recycling agricultural by-products. Other benefits included improved concrete properties and reduced production costs [19, 21].

Examples of agricultural waste used as supplementary cementing materials included palm oil fuel ash (POFA), rice husk ash (RHA), and sugarcane bagasse ash (SCBA). As one of the world's largest palm oil producers, Malaysia generated approximately 53 million tons of palm oil waste annually. By-products from palm oil extraction such as empty fruit bunches, oil palm shells, and fibers, were utilized as fuel in boilers at palm oil mills, producing POFA as a by-product [22]. The high silica ($SiO_2$) content in POFA made it suitable as a supplementary cementitious material through pozzolanic reactions. After cement hydration, the calcium hydroxide produced reacted with the silica in POFA to form calcium silicate hydrate gel [23]. The incorporation of POFA in concrete improved both tensile and compressive strength. A study by Bamaga et al. showed that sulfate and chloride resistance increased with 20% cement replacement by POFA [24]. Rice husk ash, another pozzolanic agricultural waste, was also used to replace cement in concrete manufacturing. It was generated from the combustion of rice husk to produce electricity in biomass plants. The annual generation of rice husk in Malaysia was estimated at 2.14 million tonnes. The high amorphous silica content (over 90%) in RHA contributed to its pozzolanic activity, enabling it to form calcium silicate hydrate gel. Kishore et al. found that replacing 10% of cement with RHA yielded optimal concrete strength [25]. Sugarcane bagasse ash also held significant potential as a supplementary cementitious material. Sugarcane bagasse waste, generated from crushing sugarcane during juice extraction, served as input for combined heat and power plants, with SCBA as the combustion by-product [22]. The feasibility of using SCBA to replace cement was supported by its composition, which included silicon dioxide, aluminium oxide, ferric oxide, and calcium oxide. Mangi et al. (2017) reported that a 5% replacement of cement by SCBA achieved maximum compressive strength [26].

Other agricultural waste and by-products were also utilized as aggregate substitutes. Oil palm shell (OPS), a by-product of palm oil extraction, was generated at over 4 million tonnes annually in Malaysia. OPS offered desirable properties such as lightweight, shock absorbance, and wear resistance [21]. Shafigh et al. demonstrated that using old OPS without fiber in high-strength lightweight concrete resulted in increased compressive strength and workability, with good water absorption characteristics. They recommended a moist curing period exceeding 7 days to improve compressive strength [27]. Sobuz et al. found that concrete with 15% OPS replacement, cured for 28 days, met the compressive and splitting tensile strength requirements for lightweight concrete [28]. OPS-based lightweight concrete was implemented at Universiti Malaysia Sabah (UMS) in structures such as a 59 $m^2$ floor area house and a footbridge with a 2-meter span. Coconut shell was also explored as a potential aggregate substitute in lightweight concrete. Malaysia's annual coconut shell production was estimated at around 4 million tonnes. Itam et al. investigated the use of coconut shell as a coarse aggregate substitute and revealed that 50% substitution could meet the compressive strength requirements for lightweight concrete [29]. Azunna et al. reported that replacing 30% of fine aggregate with coconut shell enabled the concrete to qualify as structural concrete based on compressive strength results [30].

## 6. Green Material Technology

### *6.1. Solar photovoltaic system.*

The potential for implementing solar photovoltaic (PV) systems on residential houses, commercial, and industrial buildings in Malaysia is high, given the country's tropical equatorial climate. Malaysia experiences favorable solar conditions, with a monthly average solar radiation ranging from 400 to 600 MJ/m² and a daily average ranging from 4000 to 5000 W/m² [31]. The increasing adoption of solar PV systems in Malaysian buildings can be attributed to several factors: the declining cost of solar panels, which has made the technology more accessible; the consequent reduction in electricity costs; and the growing demand for energy driven by rapid urbanization, industrial development, and population growth. Common green material technology implemented in Malaysia is shown in Table 3.

**Table 3.** Common green material technology implemented in Malaysia.

| Technology | Main Description | Advantages / Disadvantages | References |
|---|---|---|---|
| Solar Photovoltaic System | Utilizes Malaysia's high solar radiation to generate renewable electricity. Grid-connected solar PV systems convert solar radiation into DC and then AC electricity. Can be integrated into buildings as Building Integrated Photovoltaic (BIPV) systems. Projects like MBIPV and SURIA 1000 promote implementation. GEO building in Selangor is a notable case study. | Advantages: Reduces GHG emissions, low maintenance. Disadvantages: High initial cost, large area needed, weather dependent. | [31–35] |
| Cool Roof System | Reflective roof technology reduces solar heat gain and lowers indoor temperature and cooling energy demand. Uses light-colored or reflective materials to maximize solar reflectance and thermal emittance. Can reduce roof surface temperature and improve thermal comfort indoors. | Advantages: Reduces cooling load and energy demand. Disadvantages: Reduced heating efficiency in cooler seasons, performance affected by dirt and glare risk near airports. | [36–39] |
| Rainwater Harvesting System | Collects rainwater from roofs using gutters and downpipes into storage tanks for non-potable use. Widely implemented in Malaysia due to high rainfall. Helps address rural water scarcity and reduces dependence on treated water. Aboveground tanks preferred due to low cost and easier maintenance. | Advantages: Alleviates water scarcity, energy-efficient, cost-effective. Disadvantages: Manual first flush cleaning, potential contamination, limited to non-potable use unless treated. | [40, 41] |

Figure 2 showed the diagram of a typical solar PV system connected to the grid. The application of the solar photovoltaic system connected to the grid system aims to generate electricity using renewable solar energy to reduce consumption of fossil fuels. The mechanism behind the renewable electricity generation is the conversion of solar radiation to electricity through the photovoltaic materials inside the array of solar cells, and the direct current generated is converted into alternating current through the inverter to be sent to the national grid system, where the grid system allows export and import of energy to and from the grid if the energy of solar PV system is excessive or insufficient [32]. The solar photovoltaic system can be adopted at the building as building integrated photovoltaic where the photovoltaic modules are installed at the top of building or used as building materials for replacement of facades, roofs and windows [33].

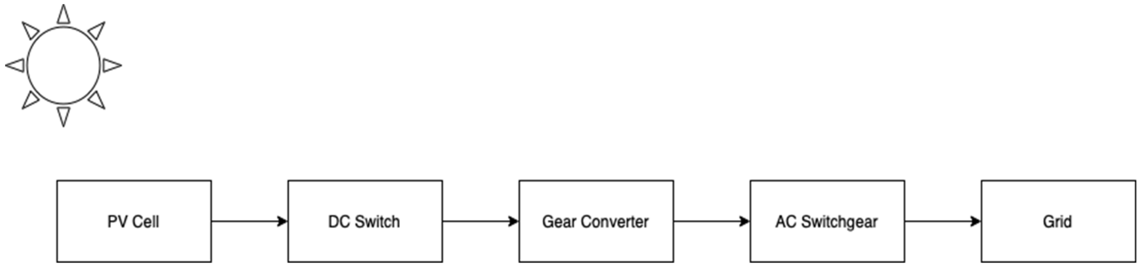


**Figure 2.** Solar photovoltaic system.

The Malaysian BIPV project, launched from 2005 to 2010, aimed to reduce the long-term costs of BIPV systems, thereby decreasing greenhouse gas emissions. The SURIA 1000 project, a key component of the MBIPV initiative, focused on the installation of BIPV systems in residential houses. Starting with the 9th Malaysia Plan, the Malaysian government allocated funds for the implementation and application of solar technology, particularly in Sarawak and Sabah [31]. One of the case studies of solar PV systems in Malaysia is the Green Energy Office (GEO) building. Located in Selangor, the GEO building at the Malaysia Energy Centre was completed in 2007, and a BIPV system was integrated into its design. The BIPV system in this building consists of polycrystalline BIPV panels with a capacity of 47.28 kWp, monocrystalline BIPV panels with capacities of 27 kWp and 11.64 kWp, and amorphous silicon BIPV panels with a capacity of 6.08 kWp [32]. The main advantages of using solar photovoltaic systems for electricity generation include a reduction in greenhouse gas emissions and a lower carbon footprint using renewable solar energy. The PV system is also reliable with low operation and maintenance costs. However, the main disadvantage of solar photovoltaic technology is its high initial capital and investment cost, and the installation of solar PV systems typically requires large areas of land. The efficiency and performance of the solar PV system in generating electricity depend largely on climatic factors related to geographical location [34, 35].

### *6.2. Cool roof system.*

The roof is a significant contributor to heat gain in a building, especially on sunny days, as it transfers trapped heat to the entire structure. Approximately 70% of the building's heat gain originates from the roofing system. The design of a cool roof system aims to reduce solar heat gain by increasing sunlight reflectance and decreasing heat absorption compared to standard roofs. The cooling performance of reflective roofs is influenced by the physical characteristics of the roofing materials, which are demonstrated through solar reflectance and thermal emittance [36. Solar reflectance refers to the reflection of solar energy, while thermal emittance refers to the radiation of solar or heat energy, as shown in Figure 3. Reflective roofs can maximize both thermal emittance and solar reflectance, leading to a decrease in indoor room temperature and, consequently, a reduction in energy consumption due to air-conditioning use. Yew et al. investigated various cool roof systems and found that the application of thermal reflective coating (TRC) reduced the roof surface temperature by 7°C compared to ordinary coatings [37]. The color of the roof surface also affects the cooling performance, with lighter-colored roofs reflecting more solar radiation than darker-colored ones [36]. Farhan et al. revealed that white roof tiles have the highest solar reflectance value, which results in a reduction of heat conduction transfer to the indoor environment through the roof tiles [38].

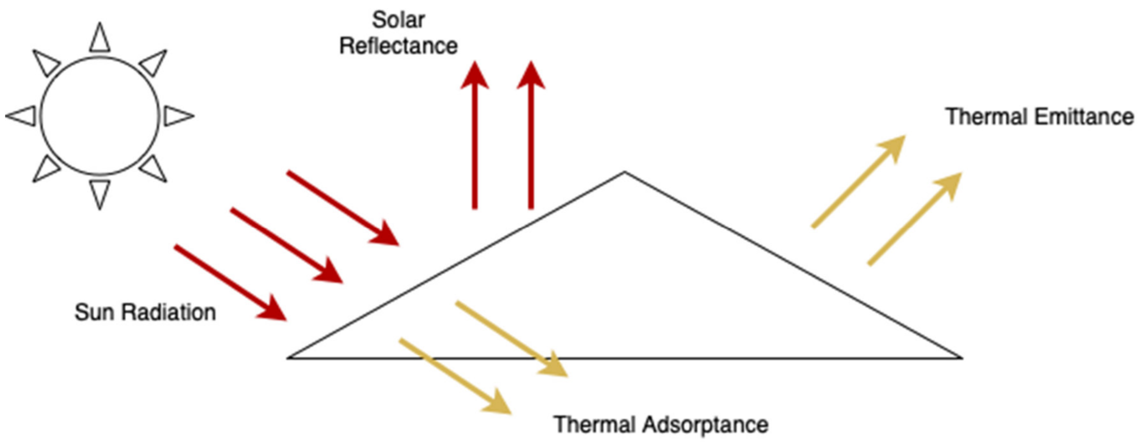


**Figure 3.** Cooling roof mechanism.

The application of cool roofs offers numerous advantages, including a reduction in cooling loads and energy consumption associated with air-conditioning systems. In addition, heat gain can be reduced using cool roofs, which also improve indoor thermal comfort. The operating temperature of the roof's decreases, allowing for a longer operating duration under cool roof applications [36, 39]. Despite the reduction in cooling loads and energy demand, the use of cool roofs can increase heating loads and energy demand in colder climates [39]. However, the weathering of the roof surface, along with the accumulation of dirt, can lead to a decrease in solar reflectance, thereby affecting the efficiency and performance of cool and reflective roofs. Another issue with reflective roofs is the potential for glare, making them unsuitable for use near airports [36].

*6.3. Rainwater harvesting system.*

Rainwater harvesting systems have been implemented in several states in Malaysia, including Kuala Lumpur, Penang, Pahang, Perak, Langkawi, Sarawak, Terengganu, Kelantan, and Kedah, under the Department of Irrigation and Drainage Malaysia. The tropical climate of Malaysia, with an estimated annual rainfall of around 2,400 mm, makes it feasible to adopt a rainwater harvesting system. It is estimated that domestic water consumption in Malaysia can reach up to 228 liters per capita per day, increasing the need for the widespread implementation of rainwater harvesting systems across the country. The main types of rainwater harvesting systems adopted in Malaysia are backyard systems, underground systems, and frontage systems [40]. The key components of a rainwater harvesting system include the roof catchment surface, conveyance system, and storage system. The rainwater runoff from roof surfaces is collected, and the ideal roof catchment surfaces should have characteristics such as imperviousness and smoothness to ensure higher rainwater collection efficiency and good water quality, such as the zinc roofs found on rural houses in Malaysia. The conveyance system consists of gutters and downpipes, typically made of plastic, that transport the collected rainwater from the roof catchment surface to the storage tank. The storage system refers to the rainwater storage tank, which can be made of plastic or concrete, and can either be aboveground or underground. Aboveground storage tanks are preferred over underground tanks due to their lower cost, easier maintenance, and cleaning. Additionally, leaks in aboveground tanks are easier to detect, and rainwater extraction does not require pumping [41].

One advantage of the rainwater harvesting system is that it helps address water scarcity issues in rural areas, providing an alternative water supply and reducing reliance on surface water resources such as rivers and lakes. The system also requires less pumping to supply and distribute water to households, thereby promoting higher energy efficiency. Typically, rainwater is used as a non-potable water supply, with the collected rainwater being used directly without treatment. However, rainwater intended for potable use must undergo basic treatment, as some roof rainwater quality parameters, such as lead, turbidity, total coliform, and fecal coliform, may fail to meet the World Health Organization (WHO) standard limits. Another disadvantage of existing rainwater harvesting systems is the need for manual emptying of the first flush collector. Contamination of rainwater can occur if the first flush collector is not emptied, as it may contain leached and deposited materials from the roof [40].

## 7. Conclusions

Progress towards practicing sustainable construction in Malaysia has been made to minimize the environmental impact caused by the construction. The formulation and implementation of several government policies and initiatives such as EQA 1974, green building index, green tax incentives and National Green Technology Policy can further promote green and sustainable construction practices and the successful implementation of these policies requires cooperation from all stakeholders including government agencies, contractors and the public as well to achieve sustainable construction. For environmental management practices, especially construction waste management, adopting circular approach with emphasis on the reuse and recycling of construction waste can achieve construction waste minimization and reduction hence reducing the environmental pollution caused by construction waste. Recycling of construction waste should be mandatory under the enforcement of new laws and regulations in the future to address the low recycling rate in Malaysia. The utilization of green construction materials incorporating the agricultural waste has been studied and applied in Malaysia. The agricultural waste including palm oil fuel ash, rice husk ash, sugarcane bagasse ash, oil palm shell and coconut shell can be used as substitute for cement or aggregate in the manufacturing of concrete to reduce greenhouse gas emissions. The green material technology used in Malaysia include solar photovoltaic system, cool roof system and rainwater harvesting system which can be the components of the green building, which can achieve renewable resources utilization, energy consumption reduction and water conservation. The utilization of green construction materials and green materials technology in the construction industry will require a certain level of technical expertise and high investment cost, added with the low awareness of the contractor or other stakeholders hence impeding their use by the contractors.

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### Author Contribution

Audrey Primus, Muhammad Syafruddin, Abbas Zulkifly, Surya Dewi Puspitasari, and Cut Yusnar contributed to the conceptualization, manuscript drafting, writing and revisions, as well as data analysis. Jovale Vincent Tongco, Amit Kumar Maharja, Rabin Maharjan, and Jayapadma Mudalige Miyuru Uthpala Jayapadma were responsible for the methodology and interpretation of results. Yuangga Rizky Illahi and Muhamad Diki Permana were involved in research design, data collection, result interpretation, and manuscript writing and revision.

### Competing Interest

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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