Tropical Environment, Biology, and Technology

Review
Volume 2(1), 2024, 44–56
https://doi.org/10.53623/tebt.v2i1.441

Advancements in Green Materials for Concrete in South East Asia: A Mini Review

Rachel Liong[1]*, Surya Dewi Puspitasari[2], Faisal Saud Binhudayb[3], Salem Hesham[4]

[1]GL Water Environmental Technology, Seksyen 25, 40400 Shah Alam, Selangor, Malaysia
[2]Department of Civil and Environmental Engineering, the Norwegian University of Science and Technology, Trondheim, Norway
[3]Department of Chemistry, College of Science, King Saud University, P.O. Box 22452, Riyadh 11495, Saudi Arabia
[4]Faculty of Engineering, Ain Shams University, 1 Elsarayat St., Abbaseya, 11517 Cairo, Egypt

*Correspondence: rmliong@outlook.com

SUBMITTED: 24 April 2024; REVISED: 29 May 2024; ACCEPTED: 1 June 2024

ABSTRACT: The rapid growth in the global population necessitated an increase in construction activities to provide shelter for humans, consequently driving the construction industry's significant contribution to the GDP of ASEAN countries. This study specifically examined the utilization of green materials for concrete in Singapore, Malaysia, Indonesia, Thailand, and Vietnam. Construction, being a material-intensive sector, consumed vast amounts of natural resources and generated substantial waste and harmful emissions, posing significant environmental challenges. In response, sustainable development initiatives were prioritized across ASEAN nations to address these issues. Governments and relevant authorities implemented various strategies to promote sustainable practices in construction, including providing financial support to both public and private sectors. Among these practices, the adoption of green materials for concrete stood out as a promising approach for sustainable development in the construction sector. By incorporating recycled aggregates, supplementary cementitious materials (SCMs), and other environmentally friendly alternatives, these countries aimed to reduce resource consumption, minimize waste generation, and mitigate environmental impact. Embracing sustainable construction practices not only promoted environmental stewardship but also contributed to long-term economic viability and social well-being in the ASEAN region.

KEYWORDS: Sustainable development; concrete; ASEAN; green material; construction

1. Introduction

The world population reached 7.8 billion in 2020, as accurately predicted by the 2019 Revision of World Population Prospects. This statistic showed that the human population experienced a massive leap compared to the population in 1800, which was 1 billion. The massive growth of the human population began in the 1970s, when the population growth rate reached 2.1%, three times more than during the entire previous human history [1]. This huge increase was mainly due to the rise in birth rates and the decline in mortality rates, caused by modern medical achievements and the availability of more reliable water, food, and shelter supplies [2].

To accommodate this large population, the number of houses and buildings needed to increase, leading to a new era in the construction industry, resulting in a significant rise in the construction sector. Global Data's lead Economist for the Construction Industry predicted that construction in the Association of South-East Asian Nations (ASEAN) region would expand by over 6% per annum on average starting from 2018. He also said that the South-East Asia region would reach an annual economic growth rate of 5% by 2022, which would be the fastest economic growth among all global regions if they continued to develop at this current speed. This was mainly due to the large investments in new infrastructure and the expansion of buildings across residential and non-residential areas. This meant that the construction industry not only served as a shelter purpose but also acted as a catalyst to stimulate the economy of the country, especially in ASEAN. On the 31st of December, leaders from the Association of South-East Asian Nations (ASEAN) planned to establish an economic community, the ASEAN Economic Community (AEC), to attract investors from different countries to support their construction projects (ASEAN Secretariat, 2012; ADB, 2015). Starting from 2008, they produced an ASEAN Economic Community Blueprint to help countries facing economic and technical difficulties [3].

Cambodia was one of the targeted countries, where its GDP per capita was very low at $1,008 in 2013 compared to its neighbors Thailand at $5,779 and Laos at $1,646 [4]. Countries like Thailand, India, Japan, China, and the USA lent a hand by providing financial and human support to Cambodia, which led to better development in the construction of infrastructure [5]. By 2013, they had invested approximately 2,773 million USD in 1,642 construction projects of around 1,300 construction companies, including 121 large, 163 medium, and 1,043 small ones, resulting in strong construction sector growth in Cambodia. Additionally, these companies sought help from the AEC to recruit a large number of foreign workers, designers, and constructors from different ASEAN countries to meet the requirements of local construction industries, thus reducing the cost of construction. With the help of the AEC, Cambodia achieved 7.2% economic growth in 2013 by increasing investment in construction industries, which contributed almost 7% of the total GDP of the country each year [6].

Due to the importance of construction as a main income source for ASEAN regions, a huge number of construction sites could be seen around us. However, this might not have been a good sign for the environment. This was because the catastrophes created by most of the construction projects generated a huge amount of construction waste as well as greenhouse gas (GHG) emissions. Let's take one of the developing ASEAN regions, Malaysia, as an example. In 2011, Batu Pahat, Johor, one of the states of Malaysia, generated over 50% of wood waste during a construction project [7]. Researchers also found that wood wastes were mainly disposed of during construction activities in Malaysia due to it being one of the main components in conventional construction, used as structural support in buildings. In addition, construction projects in Malaysia also contributed a large amount of greenhouse gas. Data from the International Energy Agency stated that Malaysian construction industries released nearly 32% of carbon dioxide emissions in 2011, with a small amount coming from cement production processes [8].

So, governments and authorities from different ASEAN regions started to implement strategies to reduce construction waste and greenhouse gas emissions from construction sites. Sustainable development played an important role in this sector, leading the concrete industry to consider practical interpretations of sustainability and other mitigation actions during construction activities [9]. For sustainable development practices in the concrete industry, the focus was usually on short and long-term environmental impacts of structures, construction, and materials, with particular emphasis on the high amount of greenhouse gas emissions, overuse of natural resources such as sand, water, and aggregates, and waste generation during construction projects [10]. The application of green materials in concrete was one of the most common practices of sustainable development during construction projects. Consequently, many governments from different countries started to include research and development of green concrete in their construction industries. For example, the Hong Kong Building Environment Assessment Method (HK-BEAM) in Hong Kong, Building Research Establishment Environmental Performance Assessment Method (BREEAM) in the United Kingdom, and Green Building Challenge in the United States [11]. This review mainly focused on the overview of the utilization of green materials for concrete in ASEAN, as well as the approaches to sustainable development in green materials for concrete. In addition, it also included research objectives, principles of green building materials, development of green materials for concrete in ASEAN regions, challenges of using green materials, and lastly, discussions and personal thoughts.

2. Sustainable Development Strategies in the Concrete Industry

Construction of buildings may have been one of the most material-consuming activities, consuming around 40% of natural resources such as gravel, sand, timber, and raw stone, 12% of portable water, and using virtually 70% of electricity. Besides that, this activity also contributed 30% of greenhouse gas emissions and around 55% of waste in landfills during its operation [12]. From an environmental impact perspective, the construction industry had significant effects on the entire environment and even the economy [13]. Thus, the principle of sustainable development, especially the utilization of green energy for concrete, was necessary and should have been implemented in all countries.

Most developed countries started to take action at national and multinational levels to ensure that sustainable development was correctly implemented in all phases of the concrete life cycle. For example, the United Kingdom established the Concrete Industry Sustainable Construction Strategy to deliver a range of sustainability objectives to construction companies and publish an annual report on the sustainability performance of the related industries and companies [14]. In the United States, they established the Concrete Joint Sustainability Initiative to guide and support the actions of industry stakeholders when executing sustainable development in the North American concrete industry [15]. It also helped to ensure that the concrete industry improved in sustainability. Furthermore, the Nordic Concrete Federation, a collaboration organization of Norway, Finland, Denmark, Iceland, and Sweden, helped construction companies solve environmental challenges in different ways: Norway developed an online database of important documents for the concrete industry, while Denmark built a research center to develop green concrete for the construction industry [16].

However, the efforts mentioned above were commonly seen in developed countries in the northern part of the world and were rarely seen in Asian countries, especially in Southeast Asian Nations. This might have been due to the maturity of the technology for implementing green construction in their concrete industry. Although developing countries in Asia did not seem to be putting effort into practicing sustainable development in the construction industry, the demand for and production of concrete-making materials in developed countries still led them to grow in the construction sector [10]. To ensure the growth of the concrete industry while minimizing the negative environmental impact, the Asian Concrete Federation (ACF) conducted a meeting with representatives from various Asian countries, including Vietnam, Taiwan, Indonesia, South Korea, Japan, India, and Mongolia, to discuss issues about sustainability practices in construction and set targets in the 2010 ACF Taipei Declaration on Sustainability.

There were six steps that the ACF should have followed to achieve sustainability in this declaration. First and foremost, the ACF should acknowledge the importance of the Asian concrete society's role in achieving global sustainable development due to the huge increase in concrete consumption throughout the world. Next, the ACF should realize the requirements for sustainable development by decreasing the use of natural resources and carbon footprint in the life cycle of a concrete structure during the construction stage. Moreover, the ACF should encourage the concrete industry to make changes to cater to the well-being of human society by providing serviceable, safe, and environmentally friendly structures. Furthermore, the ACF should promote the concrete industry to employ the best technologies and make technical innovations in the future for sustainable development. In addition, the ACF should provide education about the importance of concrete structures in sustainable development to the concrete industry and the public to ensure that they had knowledge about it. Last but not least, the ACF should collaborate with other international associations on sustainable developments in the concrete society to share thoughts and ideas between them, thus improving the efficiency of the progress [17]. As mentioned above, most of the participants of the ACF were from Southeast Asian Nations, which meant that ASEAN nations started their effort in the sustainable development of green materials for construction activities. However, each of these ASEAN regions may have differed during the actual implementation of sustainable strategies. Therefore, the main objective of this review is to identify the degree of compliance and utilization of green building materials and concrete by different ASEAN regions.

3. Development of green material for concrete in ASEAN regions

3.1. Singapore.

The current status of green materials for concrete in Singapore is shown in Figure 1. Due to the limited land size of this country, Singapore lacked natural resources for construction. As the construction sector was one of the key drivers of its economy, this made Singapore heavily reliant on the import of construction materials such as aggregates, cement, blast furnace slag, concrete, etc. [18]. Because of this, the materials used in construction became very precious, causing strong cost competition. To solve this problem, the implementation of sustainable development practices in the construction sector became a necessity in Singapore. In January 2005, Singapore's government started to promote green construction through a program named the Building and Construction Authority's Green Mark Scheme. The main purpose of this program was to encourage Singapore's construction industry to adopt more environmentally friendly building practices. It also helped to promote sustainability in the construction sector, raising environmental awareness among builders, designers, and developers during project planning, design, and construction stages [19].

Furthermore, Singapore's government agencies joined forces with the Building and Construction Authority (BCA) and industry associations to produce a Sustainable Construction Masterplan. This plan was implemented to promote sustainable development practices in the construction industry, ensuring a high-quality, safe, sustainable, and friendly built environment. The Sustainable Construction Masterplan focused on increasing the reusability of materials and reducing natural resource consumption by choosing the right products and materials for construction and buildings. The chosen products were required to be almost the same or similar to the original products, either chemically or physically. This indicated that Singapore was generally putting effort into two main criteria of green construction: using sustainable materials in the construction sector and implementing research and development to increase the efficiency of building design, thereby optimizing the use of natural materials [20].

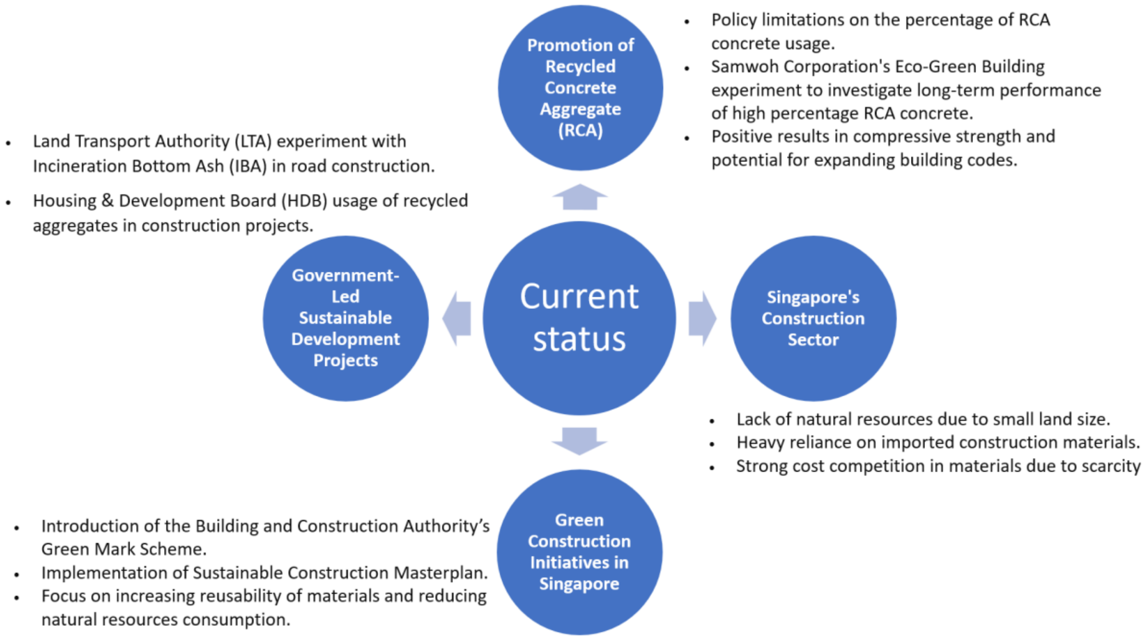

Figure 1. Current status of green material for concrete in Singapore.

Furthermore, Singapore's government took the lead in applying sustainable development construction, also known as green building, in public sector projects. The first example is the Land Transport Authority (LTA), which conducted an experimental test on the use of Incineration Bottom Ash (IBA) as an alternative material in road construction. The use of Incineration Bottom Ash (IBA) in road construction was an excellent move as it helped replace natural minerals such as gravel, sand, and crushed rock [21]. The second example is the Housing & Development Board (HDB), one of the top public housing developers, which performed sustainability measures by reducing the use of original materials in construction and replacing them with recycled materials. HDB used recycled aggregates in non-structural elements in their construction projects and also conducted sequential demolition for the demolition of old buildings [22].

Discussing recycled aggregates, one of the most common recycled materials used in almost all construction activities is recycled concrete aggregate, also known as RCA. To spread the use of this special material in the construction industry, Singapore's government and authorities were responsible for convincing construction investors by proving the long-term performance of RCA concrete in structural elements, especially for buildings. Currently, Singapore policy only allowed developers to use RCA concrete at a low percentage, around 15%, for building construction, meaning that RCA concrete might not be effectively sustainable for widespread use during construction. To address this, Samwoh Corporation, a leading concrete aggregate recycler in Singapore, constructed Samwoh's Eco-Green Building as a full-scale study to investigate the long-term performance of high-percentage RCA concrete when applied in building construction [20].

The construction process of Samwoh's Eco-Green Building was divided into two different stages: stage 1 involved laboratory investigation of the long-term performance of RCA concrete, and stage 2 involved structural health observation of the three-story Samwoh's Eco-Green Building. In stage 1 of the experiment, different percentages, from 0% to 100%, of RCA concrete were tested by using it in the construction of Samwoh's Eco-Green Building. The final results showed that the compressive strength for low and medium concentrations remained consistent, whereas there was some increase in strength when the percentage of RCA concrete increased [23]. The success of the RCA concrete results could be used to expand building codes to permit the implementation of RCA concrete in the construction industry. This experiment served as an important showcase of applied research and development in concrete technology for the future construction sector [20].

3.2. Thailand.

Due to its large land size and huge population, most of the construction work in Thailand had low labor costs. Therefore, price served as the most important aspect for construction materials such as concrete, leading to high cost competition, which limited the adoption or testing of new technologies. Another reason was that most concrete technologies depended on cement companies, which required a huge amount of investment in research and development, although foreign countries had provided a small amount of financial support. Additionally, Thailand did not implement education to promote sustainable development practices in the construction sector, making it difficult to convince customers of the importance of the environment [24].

However, there was a special case where sustainable concrete, fly ash concrete, was introduced in Thailand to reduce the environmental impact of concrete materials. This special incident happened because of the properties of fly ash, which is a by-product released from the coal-burning process. Instead of disposing of fly ash in landfills, they used it to make sustainable concrete for the construction industry to reduce the cost of making concrete. Starting in 2005, almost all fly ash produced in Thailand was used to replace cement as a green material for concrete to reduce costs and environmental impact. About 95% of the total fly ash produced came from the Mae Moh generating plant of the Electricity Generating Authority of Thailand, located in the north of Thailand [25].

According to research, the use of fly ash as a green material for concrete played an important role in reducing energy consumption for clinker production, which in turn reduced greenhouse gas emissions. It was estimated that about 1 ton of greenhouse gases was reduced for each ton of clinker produced with this implementation [26]. Additionally, the replacement of traditional concrete with fly ash concrete as a building material had numerous benefits. These included improving the long-term strength of buildings, enhancing resistance against chloride-induced steel corrosion, reducing the risk of alkali-aggregate reaction, minimizing building temperature, increasing durability, improving ease of pumping, minimizing shrinkage, and improving workability in construction [27].

However, fly ash concrete was not perfect in all properties and still contained some shortcomings when implemented as a green concrete material. Fly ash concrete had lower freezing resistance, initial strength, thawing resistance, and carbonation compared to traditional concrete. Therefore, the application of fly ash concrete in the construction industry should be evaluated by professionals to ensure its safety and to effectively reduce the environmental impact of the construction sector. The challenges and limitations of the development of green materials for concrete in Thailand are shown in Figure 2.

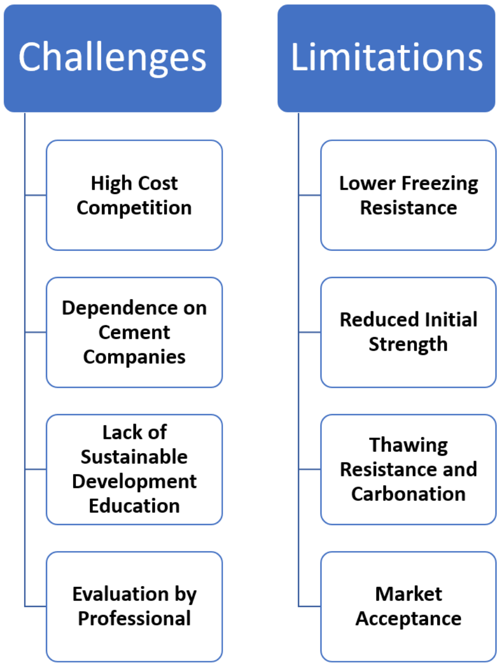

Figure 2. Challenge and limitation of development of green material for concrete in Thailand.

3.3. Malaysia.

According to the world map, Malaysia is located at the equator line which means that this country has tropical rainy climate and is suitable for palm oil and paddy field plantation. The large amount of palm oil and rice production had being a serious environment problem which is agricultural waste generation [28]. It had documented that most of these by-product such as palm oil fuel ash and rice husk ash had not go through proper disposal which can be seen in pond or lake [29]. As issues on sustainable construction gains more province, researches from Malaysia put huge effort in researching on utilization of using agricultural waste products such as palm oil fuel ash and rice husk ash in concrete for construction of buildings. By applying this sustainable method, damage done to environment can be reduce significantly at the same time the material needed in concrete can also be minimised. Studies in Malaysia had shown that utilizing palm oil fuel ash in concrete has benefit in strength. This proved by an experiment on the replacement of palm oil fuel ash in concrete for 10%, 20% and 30%. The result indicated that 20% replacement of palm oil fuel ash in concrete has the maximum compressive strength and improvement in modulus of elasticity. The main reason of the huge strength improve in this special concrete is due to the filling effect of the fine ash and also the pozzolanic reaction which makes the bond between aggregate and hydrated cement matrix stronger [30]. Additionally, the densification of the internal structure of concrete also can bring huge improvement to the performance of this concrete. This is due to the pozzolanic chemical reaction where silica reacted with calcium hydroxide generates by cement hydration. This show that Malaysia has expertise and professionals in the chemistry field which makes the green concrete works well in the construction sector thus securing a sustainable environment. The challenge and limitation of development of green material for concrete in Malaysia is shown in Figure 3.

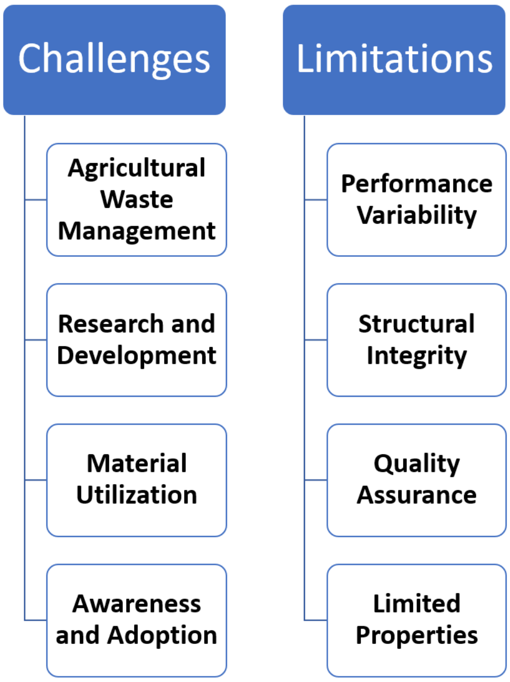

Figure 3. Challenge and limitation of development of green material for concrete in Malaysia.

3.4. Indonesia.

The utilization of green materials for concrete in Indonesia presents a crucial avenue for sustainable development in the construction sector (Figure 4). Indonesia, with its burgeoning population and rapid urbanization, faces significant environmental challenges stemming from construction activities. Concrete production, a cornerstone of the construction industry, contributes to substantial resource consumption, energy usage, and greenhouse gas emissions. To mitigate these environmental impacts, the adoption of green materials in concrete production is imperative [31]. Green materials, such as recycled aggregates, fly ash, slag, and silica fume, offer environmentally-friendly alternatives to traditional concrete components. Incorporating these materials not only reduces the reliance on natural resources but also decreases energy consumption and carbon emissions associated with concrete production. One notable initiative in Indonesia's journey towards sustainable concrete is the promotion of recycled aggregates. These aggregates, sourced from crushed concrete waste, offer a sustainable solution to address the country's mounting construction waste problem. By diverting construction waste from landfills and reusing it as aggregate material, Indonesia can significantly reduce its environmental footprint while conserving natural resources. Furthermore, the utilization of supplementary cementitious materials (SCMs) like fly ash and slag holds promise in enhancing the sustainability of concrete production. These by-products of industrial processes not only reduce the carbon footprint of concrete but also enhance its durability and strength. By incorporating SCMs into concrete mixtures, Indonesia can achieve both environmental and performance benefits, thereby fostering sustainable construction practices [32].

Moreover, Indonesia can leverage its rich biodiversity to explore innovative green materials for concrete production. Bamboo fibers, for instance, have emerged as a sustainable alternative to conventional reinforcement materials like steel. Bamboo, abundant in Indonesia's tropical forests, offers high tensile strength and durability, making it an ideal reinforcement material for concrete structures. Integrating bamboo fibers into concrete mixtures not only enhances structural performance but also promotes sustainable forestry practices and supports local economies. Despite these promising initiatives, challenges remain in the widespread adoption of green materials for concrete in Indonesia. Limited awareness and technical expertise among industry stakeholders hinder the transition towards sustainable construction practices. Additionally, regulatory frameworks and market incentives are necessary to incentivize the adoption of green materials and promote sustainable concrete production on a larger scale [33].

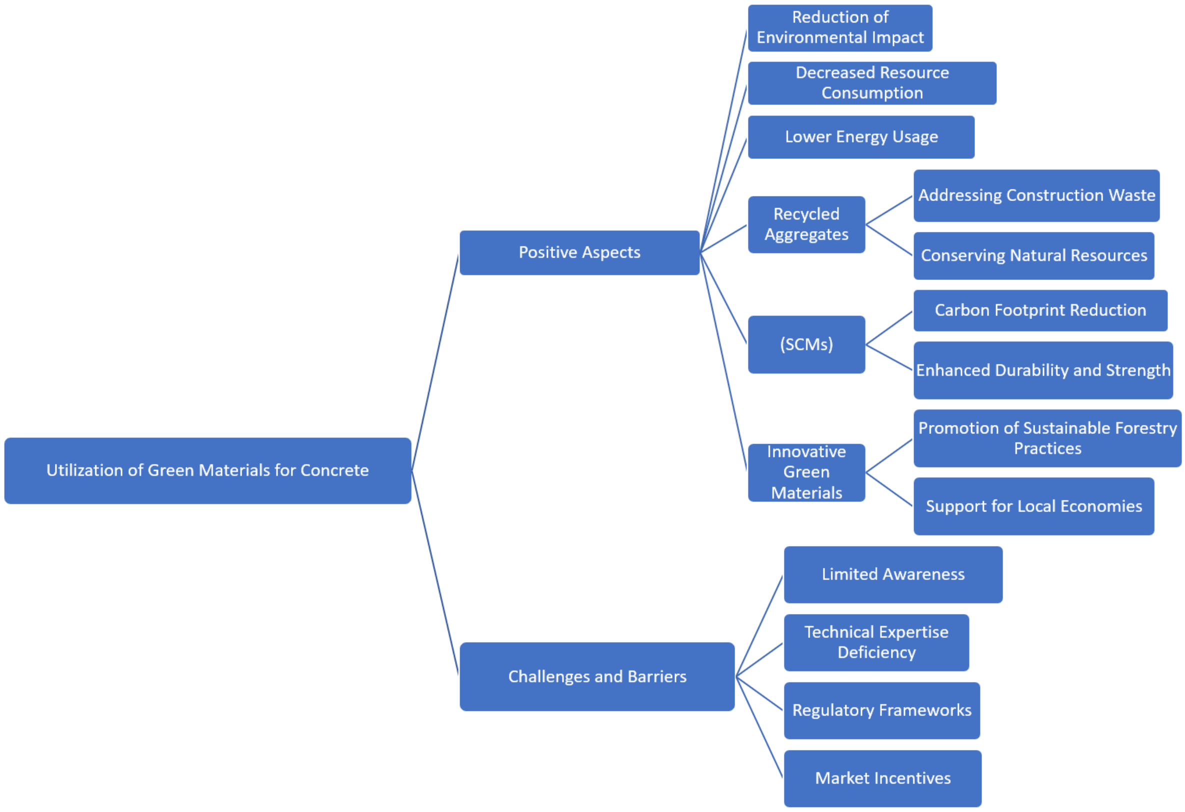

Figure 4. The utilization of green materials for concrete in Indonesia.

3.5. Vietnam.

The utilization of green materials in concrete production holds significant potential for promoting sustainability in Vietnam's construction industry. As the country undergoes rapid urbanization and industrialization, the demand for concrete continues to escalate, resulting in substantial environmental impacts. However, by incorporating green materials into concrete production, Vietnam can mitigate these impacts while fostering sustainable development. One of the primary challenges facing Vietnam's construction industry is the depletion of natural resources and the generation of construction waste. Traditional concrete production relies heavily on natural aggregates, such as sand and gravel, which are finite resources. Moreover, the disposal of construction waste poses environmental hazards and contributes to land degradation. To address these challenges, Vietnam can embrace green materials like recycled aggregates, which are derived from crushed concrete waste. By recycling construction and demolition waste into aggregate materials, Vietnam can reduce the strain on natural resources while minimizing the environmental footprint of concrete production [34].

Furthermore, the utilization of supplementary cementitious materials (SCMs) offers another avenue for enhancing the sustainability of concrete in Vietnam. SCMs, such as fly ash, slag, and silica fume, are by-products of industrial processes that can be incorporated into concrete mixtures. These materials not only reduce the carbon footprint of concrete production but also enhance its performance characteristics, such as durability and strength. By integrating SCMs into concrete production, Vietnam can achieve both environmental and economic benefits, thus promoting sustainable construction practices. In addition to recycled aggregates and SCMs, Vietnam can explore innovative green materials for concrete production. Bamboo fibers, for instance, have emerged as a sustainable alternative to conventional reinforcement materials like steel. Vietnam's abundant bamboo resources make it well-suited for exploring the use of bamboo fibers in concrete. Bamboo offers high tensile strength and durability, making it an ideal reinforcement material for concrete structures. By incorporating bamboo fibers into concrete mixtures, Vietnam can reduce its reliance on steel reinforcement while promoting sustainable forestry practices and supporting local economies. Despite the promising potential of green materials in concrete production, challenges remain in their widespread adoption in Vietnam. Limited awareness and technical expertise among industry stakeholders hinder the transition towards sustainable construction practices. Additionally, regulatory frameworks and market incentives are necessary to incentivize the adoption of green materials and promote sustainable concrete production on a larger scale [35, 36]. The challenges and limitations of incorporating green materials in concrete production in Vietnam is shown in Figure 5.

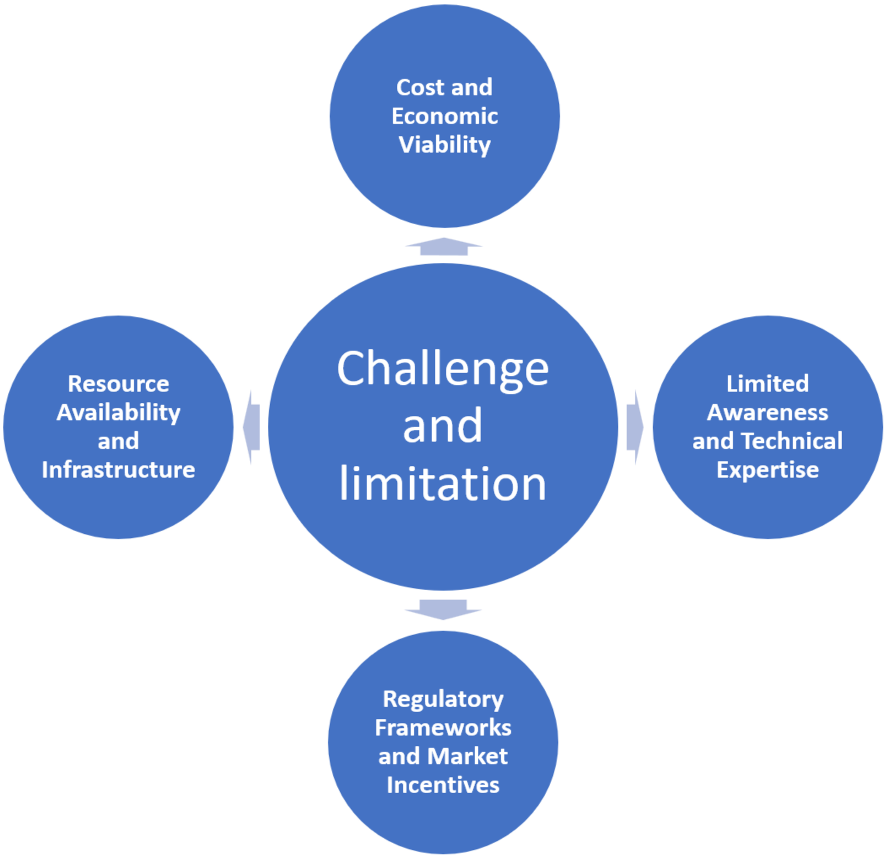

Figure 5. The challenges and limitations of incorporating green materials in concrete production in Vietnam.

Conclusion

The global population's exponential growth, hitting 7.8 billion in 2020, has fueled construction activities worldwide, notably in ASEAN regions experiencing rapid economic development. This surge in construction, driven by medical and resource advancements, brings environmental challenges like resource depletion and greenhouse gas emissions. Recognizing the urgency for sustainability, ASEAN governments and stakeholders are implementing strategies to reduce environmental impact. Initiatives like the ASEAN Economic Community and ACF Taipei Declaration on Sustainability show a commitment to sustainable construction practices. Singapore, Thailand, Malaysia, Indonesia, and Vietnam are actively pursuing sustainable development, employing measures like green building certifications and recycled materials. Singapore's Green Mark Scheme and Thailand's fly ash concrete exemplify these efforts. Malaysia uses palm oil fuel ash and rice husk ash, while Indonesia and Vietnam explore recycled aggregates and SCMs. However, challenges like limited awareness and technical expertise hinder widespread adoption of green materials. Overcoming these obstacles necessitates collaborative efforts to educate, incentivize, and regulate sustainable practices in the construction sector.

Acknowledgments

The authors thank Water Environmental Technology, Norwegian University of Science and Technology Norway, King Saud University Saudi Arabia, and Ain Shams University Egypt for facilitating this work.

Competing Interest

All authors have no competing interest.

References

[1] Population. (accessed on 3 March 2024) Available online: https://www.un.org/en/global-issues/population.

[2] Ejeta, A.G.; Bekele, G. (2017). Threats to Biodiversity And The Role of Conservation Biology for Future Sustainability: A Review. *International Journal of Research -GRANTHAALAYAH*, *5*(3), 238–242. https://doi.org/10.29121/granthaalayah.v5.i3.2017.1773.

[3] Construction in ASEAN region to grow by over 6% annually over next five years. The Weekly. (accessed on 3 March 2024) Available online: https://www.bdcnetwork.com/construction-asean-region-grow-over-6-annually-over-next-five-years#:~:text=X-,Construction%20in%20ASEAN%20region%20to%20grow%20by%20over%206%25%20annually,in%20the%20next%20five%20years.

[4] GDP per capita (current US$). (accessed on 3 March 2024) Available online: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD.

[5] Sato, J.; Shiga, H.; Kobayashi, T.; Kondoh, H. (2011). "Emerging Donors" from a Recipient Perspective: An Institutional Analysis of Foreign Aid in Cambodia. *World Development*, *39*, 2091–2104. https://doi.org/10.1016/j.worlddev.2011.04.014.

[6] Min, V.; Leungbootnak, N.; Srinavin, K.; Aksorn, P.; Deewong, W. (2016). Cambodian Construction Industry's Issues in the ASEAN Economic Community. *Journal of Construction Engineering and Project Management*, *6*(1), 1–10. https://doi.org/10.6106/JCEPM.2016.6.1.001.

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

[8] CO_2 emissions from fuel combustion highlights 2012 Edition. (accessed on 3 March 2024) Available online: https://www.pbl.nl/en/publications/co2-emissions-from-fuel-combustion-2012-edition.

[9] Horvath, A.; Matthews, H.S. (2004). Advancing sustainable development of infrastructure systems. *Journal of Infrastructure Systems*, *10*, 77–78. http://doi.org/10.1061/(ASCE)1076-0342(2004)10:3(77).

[10] Sakai, K.; Noguchi, T. (2012). The Sustainable Use of Concrete, 1st Ed. CRC Press: London, UK.

[11] Zhang, X.; Wu, Y.; Shen, L. (2015). Embedding "green" in project-based organizations: The way ahead in the construction industry?. *Journal of Cleaner Production*, *107*, 420–427. https://doi.org/10.1016/j.jclepro.2014.10.024.

[12] Pulselli, R.M.; Simoncini, E.; Pulselli, F.M.; Bastianoni, S. (2007). Energy analysis of building manufacturing, maintenance and use: building indices to evaluate housing sustainability. *Energy and Buildings*, *39*, 620–628. https://doi.org/10.1016/j.enbuild.2006.10.004.

[13] Yu, C. (2008). Environmentally sustainable acoustics in urban residential areas. PhD dissertation, University of Sheffield, UK.

[14] Vagtholm, R.; Matteo, A.; Vand, B.; Tupenaite, L. (2013). Evolution and Current State of Building Materials, Construction Methods, and Building Regulations in the U.K.: Implications for Sustainable Building Practices. *Buildings*, *13*, 1480. https://doi.org/10.3390/buildings13061480.

[15] Industry-wide concrete collaboration unveils initiatives to put sustainable messages into action (accessed on 3 March 2024) Available online: https://www.concrete.org/news/newsdetail.aspx?f=51686311.

[16] Glavind, M.; Mehus, J.; Gudmundsson, G.; Fidjestol, P. (2006). Concrete – the sustainable construction material. *ACI Concrete International*, *28*(5), 41–44.

[17] Henry, M.; Kato, Y. (2014). Understanding the regional context of sustainable concrete in Asia: Case studies in Mongolia and Singapore. *Resources, Conservation and Recycling*, *82*, 86–93, https://doi.org/10.1016/j.resconrec.2013.10.012.

[18] Hwang, B.-G.; Shan, M.; Phua, H.; Chi, S. (2017). An Exploratory Analysis of Risks in Green Residential Building Construction Projects: The Case of Singapore. *Sustainability*, *9*, 1116. https://doi.org/10.3390/su9071116.

[19] Siva, V.; Hoppe, T.; Jain, M. (2017). Green Buildings in Singapore; Analyzing a Frontrunner's Sectoral Innovation System. *Sustainability*, *9*, 919. https://doi.org/10.3390/su9060919.

[20] Chew, K.C. (2010). Singapore's strategies towards sustainable construction. *The IES Journal Part A: Civil & Structural Engineering*, *3*, 196–202. https://doi.org/10.1080/19373260.2010.491641.

[21] Lift Upgrading Programme is introduced. (accessed on 3 March 2024) Available online: https://www.nlb.gov.sg/main/article-detail?cmsuuid=7144a2bf-3ff8-4d1f-a7b1-824493296b5a#:~:text=The%20Lift%20Upgrading%20Programme%20(LUP,to%20stop%20at%20every%20floor.

[22] Zhang, D.; He, Y. (2022). The Roles and Synergies of Actors in the Green Building Transition: Lessons from Singapore. *Sustainability*, *14*, 13264. https://doi.org/10.3390/su142013264.

[23] Skocek, J.; Ouzia, A.; Vargas Serrano, E.; Pato, N. (2024). Recycled Sand and Aggregates for Structural Concrete: Toward the Industrial Production of High-Quality Recycled Materials with Low Water Absorption. *Sustainability*, *16*, 814. https://doi.org/10.3390/su16020814.

[24] Sribanasarn, W.; Techarungruengsakul, R.; Khotdee, M.; Thuangchon, S.; Ngamsert, R.; Phumiphan, A.; Sivanpheng, O.; Kangrang, A. (2024). The Sustainable Development Goals for Education and Research in the Ranking of Green Universities of Mahasarakham University. *Sustainability*, *16*, 3618. https://doi.org/10.3390/su16093618.

[25] Development of Fly Ash Usage in Thailand. (accessed on 3 March 2024) Available online: https://ssms.jp/img/files/2019/03/SMS05-003_Tangtermsirikul.pdf.

[26] Jwaida, Z.; Dulaimi, A.; Mashaan, N.; Othuman Mydin, M.A. (2023). Geopolymers: The Green Alternative to Traditional Materials for Engineering Applications. *Infrastructures*, *8*, 98. https://doi.org/10.3390/infrastructures8060098.

[27] Khunthongkeaw, J. & Tangtermsirikul, S. (2004). Model for Simulating Carbonation of Fly Ash Concrete. The 1st International Conference of Asian Concrete Federation, Chiang Mai, Thailand, 907–917.
[28] Awal, A.S.M.A. & Shehu, I.A. (2013). Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash. *Journal of Fuel, 105,* 728–731. https://doi.org/10.1016/j.fuel.2012.10.020.
[29] Amran, M.; Lee, Y.H.; Fediuk, R.; Murali, G.; Mosaberpanah, M.A.; Ozbakkaloglu, T.; Yong Lee, Y.; Vatin, N.; Klyuev, S.; Karelia, M. (2021). Palm Oil Fuel Ash-Based Eco-Friendly Concrete Composite: A Critical Review of the Long-Term Properties. *Materials*, *14*, 7074. https://doi.org/10.3390/ma14227074.
[30] Alsubari, B., Sha, P., & Zamin, M. (2016). Utilization of high-volume treated palm oil fuel ash to produce sustainable self-compacting concrete. *Journal of Cleaner Production*, *137*, 982–996. https://doi.org/10.1016/j.jclepro.2016.07.133.
[31] Teo, H.C.; Lechner, A.M.; Sagala, S.; Campos-Arceiz, A. (2020). Environmental Impacts of Planned Capitals and Lessons for Indonesia's New Capital. *Land*, *9*, 438. https://doi.org/10.3390/land9110438.
[32] Liu, Y.; Su, Y.; Xu, G.; Chen, Y.; You, G. (2022). Research Progress on Controlled Low-Strength Materials: Metallurgical Waste Slag as Cementitious Materials. *Materials*, *15*, 727. https://doi.org/10.3390/ma15030727.
[33] Muhtar, M. (2024). The use of a bamboo reinforced concrete foundation for a simple environmentally friendly house in Indonesia. *Advances in Bamboo Science*, *6*, 100056. https://doi.org/10.1016/j.bamboo.2024.100056.
[34] Le, T.S.; Zegowitz, A.; Le, C.C.; Künzel, H.; Schwede, D.; Luu, T.H.; Le, T.T.; Nguyen, T.T. (2023). The Development of Energy-Efficient and Sustainable Buildings: A Case Study in Vietnam. *Sustainability*, *15*, 15921. https://doi.org/10.3390/su152215921.
[35] Bui, Q.-B.; Grillet, A.-C.; Tran, H.-D. A (2017). Bamboo Treatment Procedure: Effects on the Durability and Mechanical Performance. *Sustainability*, *9*, 1444. https://doi.org/10.3390/su9091444.
[36] Martijanti, M.; Sutarno, S.; Juwono, A.L. (2021). Polymer Composite Fabrication Reinforced with Bamboo Fiber for Particle Board Product Raw Material Application. *Polymers*, *13*, 4377. https://doi.org/10.3390/polym13244377.