Evaluation Of Innovative Techniques for Sustainable Construction Practices in The Philippines: A Comparative Study of Coal and Municipal Waste Beneficiation Methods

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Abstract— Over the years, the term sustainability has made significant importance towards global development. It is a key aspect to ensuring the achievement of progress without compromising the resources for future generations. It has been a common notion that sustainability only deals with the environmental threat of doing things but as the United Nations puts it, it also includes the social and economic aspects. The construction industry is known to be one of the industry sources of global carbon emission and worldwide energy uses. A transformative shift to sustainable construction has been adapted globally to combat these adversities. Sustainable construction is defined as the usage of sustainable methods such as utilizing recyclable and renewable materials in construction projects that lowers energy usage and harmful waste production. This paper aims to discuss a comparative analysis of the coal and municipal waste beneficiation techniques used for sustainable construction practices in the Philippines and the effect of using these upcycled and alternative materials in terms of embodied energy and carbon emission to the construction of a typical Philippine 49 square meter residential unit. The results showed that there is a significant reduction in carbon emission and embodied energy using sustainable materials as opposed to conventional ones. Using concrete with 30% fly ash replacement versus Average CEM I Portland Cement, 94% Clinker alone can reduce the embodied energy and carbon emission to 98% and 94%, respectively.

Index Terms— **Sustainable Construction Practices in the Philippines, Coal, and Municipal Waste Beneficiation, Sustainable Materials.**

1. Introduction

Sustainability has gained substantial importance over the years and has been at the forefront of a country's economic, social, and environmental development. The term has evolved through the years, but the most quoted and most understandable definition was presented by the Brundtland World Commission report in 1987 wherein it defined sustainability as "the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (Kotob, F., 2011). Meanwhile, the United States Environmental Protection Agency defined sustainability using the United Nations three dimensions to sustainable development which are balancing a growing economy, protection of the environment, and social responsibility (Damico, A. et. Al., 2022). The term is a simple yet complex and encompassing topic whose primary aim is to address the ongoing effects of climate change brought about by activities affecting the production and consumption of natural resources, population growth, the destruction of the environment, and pollution, among many others. One of the human activities attributed for causing harmful effect to the environment is the construction industry (Lima, L. et.al., 2021). By nature, the construction sector consumes a lot of natural resources, and more pressure is placed on construction companies to minimize their environmental impact because of growing worries about climate change and the limited nature of these resources.

The concept of construction sustainability is about the application of sustainable development in the construction industry (Sourani, A, 2008). Although the word sustainability has been commonly linked to the environment, it also deals with the social aspect of life as it plays an important role in improving people's lives (Hwang et al., 2017). The overall contribution of construction in the global greenhouse gas (GHG) emission accounted for 39% (Crawford, R., 2021). The sustainable construction aims to reduce the industry's impact on the environment by utilizing renewable energy systems, utilizing alternative construction materials which are greener

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and more earth friendly, and minimizing the embodied energy in building materials. Therefore, this study attempts to analyse and compare different municipal and coal waste beneficiation techniques to produce sustainable products relevant to the construction practices in the Philippines. It also attempts to provide a comparative analysis of using sustainable building materials as opposed to the standard construction resources in terms of embodied energy and embodied carbon dioxide.

2. Understanding Environmental Impact of Construction and Sustainability

Sustainable construction is a practice of building structures by using sustainable method than the typical that is, using less energy, water, and materials while at the same time producing less waste (Plan Radar, 2022). It is one of the significant movements and a key aspect towards sustainability. Some of the sustainable construction techniques include the use of sustainable building resources such as recycled and upcycled materials, the use of green construction methods and technology, and the implementation of sustainable construction practices such as green roofs, solar panels, among others. The socio-economic and environmental benefits of practicing sustainable construction in green buildings include reduced energy consumption, decreased use of natural resources, cost-effectiveness, annual water savings, lower greenhouse gas emissions, better air quality index, among others (Reddy, S., 2016).

Despite the benefits that come with a strong construction industry performance, it poses substantial adverse effects on the environment such as the generation of dust and gas emissions contributing to air pollution, noise pollution, waste generation, and excessive water consumption (Drager, P. and Letmathe, P., 2022). The industry has been accounted for exhausting natural resources. According to the World Watch Institute, the industry uses 25% of the world's virgin timber each year and consumes 40% of its raw stone, gravel, and sand usage (Archdesk, 2021). Furthermore, according to research conducted by Bimhow, the construction sector accounted to 23% of air pollution, 50% of the climatic change, 40% of drinking water pollution, and 50% of landfill wastes. (Woodhart, 2022). This is on top of research made by the U.S. Green Building Council (USGBC) wherein their study yielded that the construction industry accounts for 40% of worldwide energy usage. It is projected that emissions from commercial buildings will grow by 1.8% in 2030 (GoContractor, 2017). Meanwhile, the combination of residential and commercial buildings made up over 33% of energy use and energy related GHG emissions globally (Zhong, X., et. Al, 2021).

In terms of building-related emissions, reduction of the energy needed for in-use buildings and reduction of the production of materials and energy in construction are two of the mitigation methods, with the primary focus of legal frameworks and policies on the former. However, a study in 2018 yielded that the production of building materials alone contributed to 11% of global energy- and process-related GHG emissions due to the consumption of more than 50% global concrete and brick, 40% steel, and substantial numbers of metallic and non-metallic materials (Zhong, X., et. Al, 2021).

Table.1. summarizes the embodied energy and carbon dioxide emissions of some of the building materials.

Building Materials	Embodied Energy	Embodied Carbon Dioxide	Embodied Carbon Dioxide Equivalent
	EE-MJ/KG	EC-kgCO_2/kg	EC-kgCO_2e/kg
Aggregate (Gravel or Crushed Rock)	0.08	0.0048	0.0052
Average CEM I Portland Cement, 94% Clinker	5.50	0.93	0.95
Concrete with 30% Cement Replacement - Fly Ash	0.47	0.057	0.061
Steel Bar & Rod	20.10	1.37	1.46
Bar & Rod - Average Recycled Content	8.80	0.420	0.450
Mortar & CHB (1:3 cement:sand mix)	1.33	0.208	0.221
Bricks (Fly ash)	0.58	0.09	0.10
1.2mX1.2 Sigle Glazed Aluminum Framed Unit	5,470.00	279.00	-
1.2mX1.2 Sigle Glazed Timber Framed Unit	286.00	14.600	-
Steel Bar (Channel)	20.10	1.37	1.46
Timber	10.00	0.30	0.31
Mortar & CHB (1:3 cement:sand mix)	1.33	0.208	0.221
Plaster Board (Gypsum)	6.75	0.380	0.390
Solvent Borne Paint	70.00	2.420	2.910
Water Borne Paint	59.00	2.120	2.540
Steel Bar & Rod	20.10	1.37	1.46
General Insulation	45.00	1.86	-
Insulation Rockwool	16.80	1.86	1.12
Aluminum Rolled	155.00	8.26	9.18
Mineral Fibre Tile (roofing)	155.00	8.26	9.18
Stone (Marble Tiles)	3.33	0.192	0.210
Terrazzo Tiles	1.40	0.12	-

3. Philippine Construction Industry and Waste Beneficiation

The Philippine construction industry is poised to be one of the fastest growing sectors over the next decade (Business World Online, 2023). This growth is propelled by infrastructure projects and more residential and business offices. The country's construction sector has seen a gradual shift into sustainability and has gained rapid push for use of alternative green building materials. Moreover, the country's active participation in sustainable construction to address environmental issues has led for developers to using green building certifications such as LEED (Leadership in Energy and Environmental Design), WELL, EDGE (Excellence in Design for Greater Efficiencies), and BERDE (Building for Ecologically Responsive Design Excellence). As the demand for green buildings keeps growing, various strategies are employed to make them more sustainable which include the use of renewable energy sources, water and energy efficiency, passive cooling designs, and the use of environmentally conscious materials. Developers and builders are now committed to adopting sustainable materials obtained through recycling and upcycling because they understand how important it is to lessen the environmental impact of construction methods. Some of these materials which are gaining tractions are sourced and beneficiated from municipal and coal wastes and are transformed into eco-construction materials such as cement, concrete, bricks, and insulations.

4. Methodology

The information and data needed to attain and accomplish the objectives of this study were gathered using quantitative research method wherein related literatures were comprehensively compiled and analyzed. Quantitative research is used to generate data that is objective and detail oriented. It is a descriptive research design that allows facts to be described by establishing a relationship between variables. In this case, the embodied energy and carbon emissions are the variable components. Microsoft Excel was used as the instrument to compare the numerical difference between conventional and sustainable building materials.

5. Related Literature

A. Aboitiz Power Takes Lead in Fly Ash-to-Bricks Project

Aboitiz Power Corp. has taken in partners for its Fly Ash Brick Project, a community-based initiative that will produce high-value construction products made from fly ash, a by-product of its coal power plant. Aside from being more durable and insulated, fly ash bricks also cost less than hollow blocks per square meter. The average construction cost using the traditional hollow blocks is around P1,300 per square meter while fly ash bricks cost only around P900.

Fly ash is one of the naturally occurring products from the coal combustion process and is a material that is nearly the same as volcanic ash. Its most common use of fly ash is as a replacement for Portland cement used in producing concrete. Concrete made with fly ash is stronger and more durable than traditional concrete. Fly ash concrete is easier to pour, has lower permeability, and resists alkali-silica reactions, which results in a longer service life.

B. Philippine Cement Manufacturers Engage in Green Initiatives

Lafarge Philippines for some time has been marketing their "Fly ash cement" with considerable success. This general-purpose cement, marketed under the type 1P or the blended category, uses less clinker content than the traditional Portland cement while allowing the company to recycle its coal by-product produced in the burning process of coal.

"Adding cementitious materials such as fly ash and slag in the cement mix reduces the need for clinker. It is during the clinker manufacturing process that the most carbon dioxide is emitted as we burn coal to reach the high process temperatures required to produce clinker. Within our manufacturing process, Lafarge is aggressively pursuing the reduction in carbon footprint in two keyways: by minimizing the production of clinker by developing and selling blended cements with more environmentally friendly cement additives," said Pestano (VP for Corporate Communications). Lafarge's fly ash cement is the only product of its kind sold as a general-purpose cement, same with Portland cement, with competing companies having their own blended cement but is marketed as a masonry type of cement, used mostly for finishing jobs in construction works.

C. Why Terrazzo Tiles are Sustainable?

Terrazzo is sustainable simply because of its production and installation process. Terrazzo tiles are produced using significantly less energy and generate less carbon footprint than other tiling solutions. Approximately 70% to 80% of a terrazzo tile consists of recycled and reclaimed materials. Installation is straightforward. No chemical or heat treatment is needed.

The terrazzo cement tiles are eco-friendly because they are handmade and never have to be fired in a kiln, which means that the energy used in our manufacturing process is significantly low. Unlike ceramic and porcelain, the fundamental production processes for terrazzo cement tiles are almost entirely sustainable and straightforward. The primary substance of terrazzo tile is mainly marble and some natural stone chips and granules. They are produced by hand-mixing with cement and using a hydraulic press. The whole stone chips and granules come from wasted materials. Approximately 60 to 80% of terrazzo tile is made of wasted or recycled materials. The reclaimed marble slabs and tiles from old buildings grind to get chips and granules for terrazzo tiles. Terrazzo cement tiles have high thermal mass, acting as excellent insulators. They help increase energy efficiency and average 40% more efficient than ceramic and porcelain tiles.

D. Ambuklao and Binga Hydropower Plant Project

The Ambuklao and Binga Hydropower Plant project in the Philippines. The project involved the refurbishment of the two 40-year-old plants that had become compromised by siltation and volcanic activity. Construction encompassed a network of tunnels and shafts and the building of new intake and outlet structures. The plants were equipped with new electrical and mechanical equipment, as well as new generators. The project used fly ash in all the new structures. The project was completed successfully on the 1st of June 2011.

E. San Roque Dam Project

The San Roque Dam, operated under San Roque Multipurpose Project (SRMP) is a 200-meter-tall, 1.2-kilometre-long embankment dam on the Agno River. It is the largest dam in the Philippines and the sixteenth largest in the world. It spans the municipalities of San Manuel and San Nicolas, Pangasinan and is nearly 200 km north of Metro Manila. This project used huge quantity of Pozzolanic Fly Ash.

6. Study Area

The Philippines is considered one of the fastest growing nations in terms of economy with an annual growth of 12.1% in 2022, and an expected expansion of the construction industry to 7% in real terms in 2023 (Yahoo Finance, 2023). According to a survey conducted in 2022, more than half of households in the Philippines lived in houses with a floor area ranging from 10 to 49 square meters (Statista, 2022). During the second quarter of 2023, residential buildings were reported to have the highest number of constructions at 66.9% from which 90.8% were single-type houses (Philippine Statistics Authority, 2023). Table 2 describes the estimated bill of quantity for a conventional 49-square-meter residential house in the Philippines while Table 3 lists the estimated bill of quantity using sustainable materials.

Table.2. Estimate of the materials required for a 49 sqm residential house in the Philippines using conventional materials.

Conventional Materials				
Estimate of the Materials required for the 49 square meter residential house				
S.no.	Parts of the structure	Material	Unit	Quantity
1	Foundation	Aggregate (Gravel or Crushed Rock)	KG	59.65
2		Average CEM I Portland Cement, 94% Clinker	KG	46,718.50
3	Exterior	Steel Bar & Rod	KG	997.52
4		Mortar & CHB (1:3 cement:sand mix)	KG	12,882.00
5		1.2mX1.2 Sigle Glazed Aluminum Framed Unit (window)	KG	2,112.00
6	Interior	Steel Bar (Channel)	KG	2,165.63
7		Mortar & CHB (1:3 cement:sand mix)	KG	792.78
8		Solvent Borne Paint	KG	132.00
9	Framing / Insulation /Roofing	Steel Bar & Rod	KG	24,871.84
10		General Insulation	KG	813.30
11		Aluminum Rolled	KG	355.81
12	Flooring	Stone (Marble Tiles)	KG	1,121.25

7. Results And Discussion

From the data of the common building materials used in a typical 49 square meter residential house in the Philippines, the analysis of the amount of embodied energies and carbon emissions between conventional construction materials and upcycled and other alternative sustainable materials from municipal and coal wastes was obtained. It is therefore estimated that for an average residential household in the Philippines with a floor area of 49 square meters, the total embodies energies and carbon emissions were approximately 12,496,010 and 583,037, respectively using conventional building materials (see Table 4). This was computed based on the bill of quantity of materials required for the construction about the embodied energies and carbon emissions of the building materials.

Table.3. Estimate of the materials required for a 49 sqm residential house in the Philippines using sustainable materials.

Sustainable Materials				
Estimate of the Materials required for the 49 square meter residential house				
S.no.	rts of the structu	Material	Unit	Quantity
1	Foundation	Aggregate (Gravel or Crushed Rock)	KG	59.65
2		Concrete with 30% Cement Replacement - Fly Ash	KG	46,718.50
3	Exterior	Bar & Rod - Average Recycled Content	KG	997.52
4		Bricks (Fly ash)	KG	30,916.48
5		1.2mX1.2 Sigle Glazed Timber Framed Unit (window)	KG	1,867.70
6	Interior	Timber	KG	424.26
7		Plaster Board (Gypsum)	KG	14,479.00
8		Water Borne Paint	KG	132.00
9	Framing / Insulation /Roofing	Timber	KG	4,091.86
10		Insulation Rockwool	KG	406.65
11		Mineral Fibre Tile (roofing)	KG	25.86
12	Flooring	Terrazzo Tiles	KG	1,121.25

Table.4. Embodied energy and carbon dioxide emissions of a 49 sqm residential house in the Philippines using conventional materials.

Conventional Materials				
Estimate of the Materials required for the 49 square meter residential house				
S.no.	Parts of the structure	Material	Embodied Energy (EE-MJ/KG)	Embodied CO2 (EC-kgCO2/kg)
1	Foundation	Aggregate (Gravel or Crushed Rock)	4.95	0.29
2		Average CEM I Portland Cement, 94% Clinker	256,951.75	43,448.21
3	Exterior	Steel Bar & Rod	20,050.23	1,366.61
4		Mortar & CHB (1:3 cement:sand mix)	17,133.06	6,430.63
5		1.2mX1.2 Sigle Glazed Aluminum Framed Unit (window)	11,552,640.00	521,088.30
6	Interior	Steel Bar (Channel)	43,529.06	581.24
7		Mortar & CHB (1:3 cement:sand mix)	1,054.40	3,011.63
8		Solvent Borne Paint	9,240.00	319.44
9	Framing / Insulation /Roofing	Steel Bar & Rod	499,923.98	5,605.85
10		General Insulation	36,598.50	756.37
11		Aluminum Rolled	55,150.55	213.60
12	Flooring	Stone (Marble Tiles)	3,733.76	215.28
		TOTAL	12496010.25	583037.436

A separate calculation was done using the combination of beneficiated sustainable construction materials and other alternatives used in the Philippines which yielded total embodied energies and carbon emissions which were approximately 996,205 and 48,374, respectively as shown in Table 5. The study shows that by using concrete with 30% fly ash replacement versus the average CEM I Portland Cement, 94% clinker alone can reduce the embodied energy and carbon emission to 98% and 94%, respectively since these represent the key materials used for the foundation of the construction. Furthermore, the use of brick made from fly ash can also significantly reduce embodied energy by 56% and carbon emission by 82% when compared with using conventional concrete hollow blocks and mortar sets. Therefore, as discussed in part two of this study entitled Understanding the Environmental Impact of Construction and Sustainability, material selection has a significant effect on the embodied energy and embodied CO2 of a building.

Table.5. Embodied energy and carbon dioxide emissions of a 49 sqm residential house in the Philippines using sustainable materials.

Sustainable Materials				
Estimate of the Materials required for the 49 square meter residential house				
S.no.	Parts of the structure	Material	Embodied Energy (EE-MJ/KG)	Embodied CO2 (EC-kgCO2/kg)
1	Foundation	Aggregate (Gravel or Crushed Rock)	4.95095	0.29
2		Concrete with 30% Cement Replacement - Fly Ash	21957.695	2,662.95
3	Exterior	Bar & Rod - Average Recycled Content	8778.2112	418.96
4		Bricks (Fly ash)	7535.119788	1,178.42
5		1.2mX1.2 Sigle Glazed Timber Framed Unit (window)	604032	30,835.20
6	Interior	Timber	21656.25	649.69
7		Plaster Board (Gypsum)	5351.265	301.26
8		Water Borne Paint	7788	279.84
9	Framing / Insulation /Roofing	Timber	248718.4	7,461.55
10		Insulation Rockwool	13663.44	1,512.74
11		Mineral Fibre Tile (roofing)	55150.55	2,938.99
12	Flooring	Terrazzo Tiles	1569.75	134.55
		TOTAL	996205.6319	48374.44015

8. Conclusion

The emergence of sustainable construction has raised awareness about the environmental, social, and economic aspects of sustainable development. As one of the industries that emit considerable amounts of greenhouse gases and worldwide use of energies, it is called upon to cut on these statistics by employing sustainable construction practices. Several strategies can be employed to reduce and mitigate the release of embodied carbon emissions and one of them is using recycled or upcycled materials reclaimed from municipal and coal wastes to reduce emissions coming from producing and manufacturing virgin materials. Conscious efforts and going green by selecting sustainable building materials can considerably bring down carbon emissions which can make structures such as residential houses and buildings more sustainable with lesser carbon footprints. The comparative analysis of using conventional versus the combination of sustainable upcycled and alternative materials from wastes yielded that for a 49 square meter residential house in the Philippines, we can reduce approximately 92% for both the embodied energies and carbon emissions, respectively. To reduce the high energy consumption and lessen the carbon emission of the construction industry in the Philippines, developers and owners of buildings and houses are encouraged to use as many sustainable, alternative materials as possible during construction. Beneficiation technologies of waste-to-building materials should be promoted amongst the community and a government push for the use of these materials must have legal frameworks rather than just mere encouragements.

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