A Non-Disruptive Ecological Innovation on Concrete Block Manufacturing: A Product Viability Study for the Philippine Construction Industry

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Abstract

The construction industry plays a significant role in the national economy. In the Philippines, there are very limited research studies involving the use of waste materials as an additional component in producing CHB. Other Asian nations such as Hongkong and Taiwan have been efficiently using waste materials as a component of their CHB. The current study has shown that a mixture of CHB consisting of 3% rubber waste, in terms of its overall volume, yields the best results, both in terms of its specification and its costs. These results were also backed up by other tests in which it had shown in the one-way ANOVA testing that there is a significant difference in results for each different mixture. This means that the waste materials added to the mixtures had a significant effect on the end product. The cost-benefit and value analyses yielded the positive ecological benefits and advantage of innovatively using waste materials as input to CHB manufacture, a breakthrough in the Philippine construction industry.

Keywords
Construction industry, concrete hollow block (CHB), one-way ANOVA, cost-benefit analysis, waste materials

1. Introduction

The construction industry plays a significant role in the national economy. Its activities and construction projects are vital to the national socio-economic development goals of providing citizens with shelter, infrastructure, and employment (Anaman & Osei-Amponsah, 2007). According to Economy Watch (2010), the "construction industry is a booming industry and will remain so with the continuation of the development process, especially in the developing countries." Globally, "the construction industry is expected to reach an estimated $10.5 trillion by 2023, having been forecast to grow at a Compound Annual Growth Rate (CAGR) of 4.2% from 2018 to 2023." Due to the increasing urbanization and booming population, there is an increased need for housing starts and rising infrastructure, thus making them the two key players of the market growth. (PR Newswire, 2018).

Globally, one of the most widely used materials is cement, coming only second after water (Crow, 2008). It allows the construction process itself to be accelerated, and work expenses at the construction site to be reduced. A primary component of concrete is cement and the production of it contributes heavily to greenhouse gas emissions. The use of cement has become an environmental issue, along with several others like heavy use of energy, fuels and/or electricity, and transportation. As a result of its use, the construction industry ranks high among the leading environmental challenges globally (Ayalew et al., 2016). Since the cement is a primary component of the Concrete Hollow Block (CHB) manufacturing process, it cannot be removed nor replaced with an ecologically safer material. However, in an ecological view, it may be worthwhile to look into the reduction of cement usage ratio by mixing material composite alternatives from renewable or non-renewable sources, as well as from waste recycling processes (Douglas and Lawson, 2002; Kennedy et al., 2007). Also, the inclusion of waste materials as either additional components for concrete block production or possible sustainable and eco-friendly concrete block treatments can potentially reduce the overall emission waste in the construction ecosystem.

According to new research from Bimhow (2018), the construction sector contributes to 23% of air pollution, 50% of the climatic change, 40% of drinking water pollution, and 50% of landfill wastes. The global cement industry alone contributes approximately 5% of global carbon dioxide emissions. Being one of the top contributors of carbon emission (Carbon dioxide is a gaseous product of burning fossil fuels like gas and diesel), the construction industry needs to respond to the call of environmental issues. Property consulting firm Pronove Tai (2019) stated the cement shortage in the country has caused a 30% delay in building completion for the first quarter of 2019.

In the Philippines, there are very limited research studies involving the use of waste materials as an additional component in producing CHB. Other Asian nations such as Hongkong and Taiwan have been efficiently using waste materials as a component for their CHB. This knowledge means that the proposal is feasible in the Philippines. However, different factors must also be considered, as the aforementioned countries are in a different socio-economic and political state in comparison to the state of the Philippines. Thus, this study aims to determine whether these practices from other countries are applicable in the Philippine construction industry setting.

According to some estimates from ABS-CBN (2018), the construction industry contributes to around 30 percent (30%) of solid wastes that eventually end up in landfills. In addition, some of these solid wastes may be used as an alternative component for CHB. Hence, this study will provide an insight into the ways to possibly reduce the cement usage ratio in concrete hollow block manufacturing in the Philippines, which would result in lesser demands for cement.

The main objectives of this study are as follows: (1) To assess the viability of eco-friendly concrete hollow block (eco-CHB) manufacture and usage in the Philippine setting; (2) To determine the significant factors that affect the compressive strength and impact resistance of the proposed mixtures of waste components in the Philippines' standard practice on CHB usage and; (3) To identify the most suitable alternative CHB treatment that will contribute to the attainment of the commercial goals of the construction industry in the Philippines.

Individuals within the construction industry may refer to this study, as well as other academic researchers. The results of the study will show significant data in terms of material usage, and specific traits of the components used. This study may also be analyzed by construction firm researchers who searching for products to compare and contrast to other firms. The research will enable them to determine the profitability of new trends and the ability of their firm to reproduce and generate profit from manufacturing the said products. This study will especially benefit firms that are adhering to product sustainability within their company.

The scope of the study will cover research studies and experiments performed by previous researchers from different countries. This would make this study limited in terms of technology and resources. There is also a specific need for some research papers that require different equipment to process the proposed materials into their preferred state. The researchers were only able to perform these tasks with the use of available resources but will aim to have similar required results.

2. Methodology

2.1 Standard Specifications of CHB According to DPWH

After gathering data from the proposed materials, the specifications shall be in compliance with some regulated laws in the Philippines, as enforced by the Department of Public Works and Highways (DPWH). Specifically, the amendment of DPWH standard specification for item 1046 – Masonry Works, states that a concrete hollow block should have the standard specifications as depicted in Table 2.1.1, while Figure 2.1.1 displays the parts of a CHB unit.

Table 2.1.1 Thickness, face shells, and webs

Nominal Width (W) of Units, mm	Minimum Face Shell Thickness (t_{fs}), mm	Minimum Web Thickness (t_w)	
		Webs, mm	Equivalent Web Thickness, mm/linear m
76.2 and 102	19	19	136
152	25	25	188
203	32	25	188
254 and greater	32	29	209

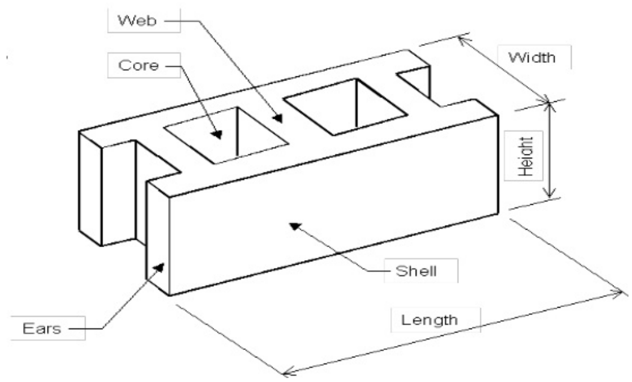

Figure 2.1.1 Parts of a Masonry Unit by Azaleah and Premrose

Having presented the standard physical dimensions as per DPWH, a CHB unit shall also comply with the standard physical load capacities. Results of the comprehensive strength and load tests are to be evaluated with the following standard criteria shown in Table 2.1.2.

Table 2.1.2 Weight Classifications of CHB units according to DPWH

Weight Classification	Oven-Dry Density of Concrete, kg/m^3
Lightweight	Less than 1680
Medium Weight	1680 to less than 2000
Normal Weight	2000 or more

Table 2.1.3 represents the weight classifications for concrete hollow block units. The Concrete block unit is classified into three (3) types, which are lightweight, medium weight, and normal weight. Lightweight and medium weight concrete block units are used for special applications and specifications that do not need strong foundations. An example of which is the external leaves of cavity walls. The normal weight is the traditional multipurpose building block in which it is an ideal background for accepting renders and plasters.

Table 2.1.3 Strength, Absorption, and Density Classification Requirements

Density Classification	Oven-Dry Density of Concrete, kg/m^3	Maximum Water Absorption, kg/m^3		Minimum Net Area Compressive Strength, MPa (Psi)	
	Average of 3 Units	Average of 3 Units	Individual Units	Average of 3 Units	Individual Units
Lightweight	Less than 1680	288	320	13.1 (1900)	11.7 (1700)
Medium Weight	1680 to less than 2000	240	272	13.1 (1900)	11.7 (1700)
Normal Weight	2000 or more	208	240	13.1 (1900)	11.7 (1700)

Table 2.1.4 exhibits the standard compressive strength for load-bearing hollow blocks, and per unit is 3.45 mpa or 500 psi since they are designed for buildings that require high strength walls because of their high-rise structure. The study

falls on the Non-Load bearing or commercial type of hollow blocks that only requires a 200-250 psi capacity. This is cheaper compared to load-bearing blocks and is commonly used for housing and low-rise buildings.

2.2 Costing

One of the researchers is involved in a CHB manufacturing business. With the insights of the said member, the group was able to gather in-depth costing and pricing aspects of CHB manufacturing in the Philippines. Table 2.2.1 represents the standard prices of raw materials and the amount needed for production as of 2019.

Table 2.2.1 Summary of costing and pricing aspects of CHB Manufacturing

Concrete Hollow blocks Size	**120 pcs (1 bag cement)**	**100 pcs (1 bag cement)**	**90 pcs (1 bag cement)**
Cement Price/ Unit	1.83	2.2	2.44
Sand Price/ Unit	0.76	0.91	1.09
UNIT PRICE	***2.59***	***3.11***	***3.53***

2.3 One-Way ANOVA Test

In Statistics Solutions (2013), ANOVA is defined as a statistical technique that assesses potential differences in a scale-level dependent variable by a nominal-level variable having 2 or more categories. A one-way ANOVA has just one independent variable. In this study, the eco-CHB will be evaluated by determining the differences of results in contrast to a commercial standard CHB. The end products of CHB will be assessed by the added components (Rubber, Plastic, Glass), and these components will have different categories in terms of the percentage ratio mixed in a standard CHB mix.

2.4 Tukey's Test

The Tukey HSD ("honestly significant difference" or "honestly significant difference") test is a statistical tool used to determine if the relationship between two sets of data is statistically significant. If the ANOVA test shows the overall results, determining if the data is significant, the Tukey's provides a deeper explanation of where exactly the differences lie. After finding the significant result, Tukey's test compares all possible pairs of means. The test compares the differences between the means of values rather than comparing pairs of values. The value of the Tukey Test is given by taking the absolute value of the difference between pairs of means and dividing it by the standard error of the mean (SE) as determined by a one-way ANOVA test. The SE is in turn the square root of (variance divided by sample size).

2.5 Cost-Benefit Analysis

Once the costs associated with the manufacturing system have been identified and their standard values have been valued in monetary terms, the usual financial and economic performance indicators of the proposed product are computed. One of the factors to be considered is the economic net present value (ENPV), expressed in monetary terms, which can be defined by comparing the values for the standard product with respect to its benefits, and the same values for the proposed product. Another value to be considered is the economic internal rate of return (EIRR) where it will show the projected time needed for the proposed product be able to gain back the additional investments, if needed. Also, the benefit-cost (B/C) ratio, or the ratio between the benefits and costs. The performance of the proposed products can be associated whether the results of the analysis will show positive return. This can be determined specifically if the ENPV is higher than zero – the higher the ENPV the larger the social benefits achieved, net of costs and negative externalities, the EIRR is higher than the adopted rate, and lastly, the B/C has a value higher than one.

2.6 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is especially suitable for complex decisions, which involve the comparison of decision elements that are difficult to quantify. It is based on the assumption that when faced with a complex decision the natural human reaction is to cluster the decision elements according to their common characteristics. The CHB industry is driven by three major factors, and are ranked accordingly, these factors are costs, CHB strength and specifications, and external factors such as availability of resources, inflation rate, and other environmental conditions.

One of the main challenges that organizations face today resides in their ability to choose the most correct and consistent alternatives in such a way that strategic alignment is maintained. Given any specific situation, making the right decisions is probably one of the most difficult challenges for science and technology (Triantaphyllou, 2002). The use of AHP will enable the study to analyze data in a way where it involves building a hierarchy of decision elements and then making comparisons between each possible pair in each cluster. This will provide a basis of differentiation amongst the different products, inclusive of the standard product along with its traits. This way, it will be determined whether the new products will be able to outweigh the standards in terms of their overall performance index. Thus, this will result in a decision regarding which is the suitable product to be used to reach the goal of the study.

3. Results and Discussion

3.1 Evaluation of Eco-CHB in comparison to Standard CHB

Compressive Strength Test

The results of the compressive strength test as shown in table 3.1.1 shows that all blocks were significantly stronger than a standard block in terms of their PSI capabilities. Having a higher value for PSI means that the block can resist much stronger compression, which can signify that the block can manage to carry a higher amount of load.

Table 3.1.1 Summary of results of compressive strength test for Eco-CHB and Standard CHB

Product #		Glass			Rubber			Plastic		
	Standard	1%	2%	3%	1%	2%	3%	1%	2%	3%
1	210	270	250	250	280	300	310	280	310	280
2	220	270	250	230	280	300	340	270	300	280
3	200	270	250	240	280	320	320	260	290	270
4	210	270	240	250	260	310	310	290	300	270
5	210	280	250	230	270	310	330	280	310	290
6	230	280	250	250	270	320	330	270	300	280
7	220	280	230	240	290	300	320	260	300	280
8	240	280	240	240	290	300	320	280	320	280
9	210	270	230	230	290	290	320	280	320	270
10	220	290	260	250	280	310	330	260	310	270
Mean	217	276	245	241	279	306	323	273	306	277
Std. Dev	11.60	6.99	9.72	8.76	9.94	9.66	9.49	10.59	9.66	6.75

The different types of materials used (glass, rubber, and plastic) have their own best possible options. This gives the flexibility to choose among which material is available at a specific given time. Although, among the three materials, compressive strength results show that the eco-CHB consisting of rubber is the strongest; followed by plastic, and glass is the weakest among them. However, it also shows that all three are stronger than the standard CHB, which means that in terms of compressive strength, all three materials are viable.

Among the different percentages of mixtures, the strongest mixture consisted of 3% rubber, followed by 2%, which can mean that as the number of rubber increases within the mixture, the compressive strength can go higher up to a certain point. Plastic, being the second strongest among all the materials, shows that the mixture with 2% of the material was the strongest among the other percentages. This can mean that there is a specific amount of peak percentage for plastic mixtures, whereas adding more plastic from that peak point will make the block weaker. This can also be true among the other waste material mixtures. Lastly, the weakest among three waste materials, but is still viable due to it being stronger than the standard is the eco-CHB consisting of glass wastes. Among the percentages of the mixture used, 1% glass was the highest, and the eco-CHB became weaker when the amount of glass within the mixture is increased. This may be the result of the brittle characteristics of glass. Although, having a few amounts of glass among the mixture still increases the compressive strength of a block significantly.

Impact Resistance
Through drop weight testing performed to the blocks, the group should be able to determine how much impact the eco-CHB can absorb in comparison to a standard CHB. These are the results on when the initial crack occurred on each of the tested eco-CHB:

Figure 3.1.1 represents the interval results of impact resistance for the initial crack. After the initial crack, the group had to continue testing and find out when the eco-CHB will completely break. The numbers inside table 3.1.2 indicate the number of drops the block resist before showing cracks.

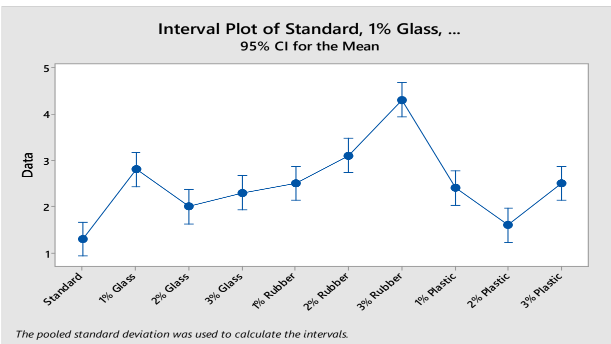

Figure 3.1.1 Interval results for impact resistance (initial crack)

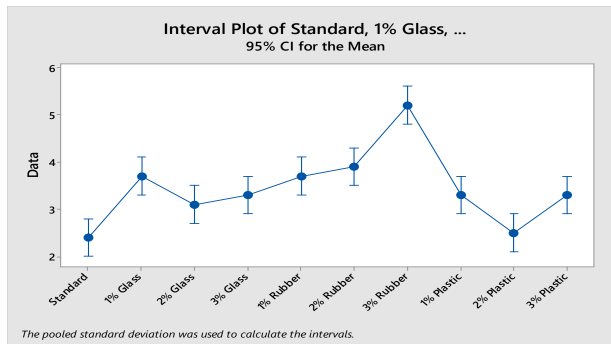

Figure 3.1.2 Interval results for impact resistance (ultimate crack)

Table 3.1.2 Number of drops until ultimate crack occurred

Product #	Standard	Glass			Rubber			Plastic		
		1%	2%	3%	1%	2%	3%	1%	2%	3%
1	1	3	2	2	3	3	4	2	1	3
2	1	3	3	2	2	2	4	3	2	2
3	2	2	2	3	3	3	5	2	2	3
4	1	3	2	2	3	4	3	3	2	3
5	1	4	1	2	2	3	4	2	1	2
6	2	3	2	3	2	2	5	2	2	2
7	1	3	2	2	3	4	4	2	1	2
8	1	2	3	2	3	3	5	3	2	3
9	2	3	1	2	2	4	4	3	1	2
10	1	2	2	3	2	3	5	2	2	3
Mean	1.3	2.8	2	2.3	2.5	3.1	4.3	2.4	1.6	2.5
Std. Dev	0.48	0.63	0.67	0.48	0.53	0.74	0.67	0.52	0.52	0.53

On the other hand, figure 3.1.2 shows that the eco-CHB can resist more impact in comparison to a standard CHB. This was even proven by comparing the impact of energy absorbed by each block. Tables 3.1.3, 3.1.4, 3.1.5 represents the result of the impact of energy and its ability to resist.

Table 3.1.3 Impact energy upon initial crack

Impact Energy	g =	9.81	m/s^2	m =	0.8	kg	h =	36 in =	0.9144	m
in joules	Standard	Glass			Rubber			Plastic		
		1%	2%	3%	1%	2%	3%	1%	2%	3%
$E_{p,dwi} = N_1 mgh$	9.329	20.093	14.352	16.505	17.941	22.246	30.858	17.223	11.482	17.941

Table 3.1.4 Impact energy upon ultimate crack

Impact Energy	g =	9.81	m/s^2	m =	0.8	kg	h =	36 in =	0.9144	m
in joules	Standard	Glass			Rubber			Plastic		
		1%	2%	3%	1%	2%	3%	1%	2%	3%
$E_{p,dwu} = N_2 mgh$	17.223	26.552	22.246	23.681	26.552	27.987	37.316	23.681	17.941	23.681

Table 3.1.5 Ability to resist impact; standard vs eco-CHB (shown in how much % stronger)

Standard	**9.392**								
Eco-CHB	**20.09339**	**14.35242**	**16.50529**	**17.94053**	**22.24625**	**30.85771**	**17.22291**	**11.48194**	**17.94053**
Standard	**17.223**								
Eco-CHB	**26.55198**	**22.24625**	**23.6815**	**26.55198**	**27.98722**	**37.3163**	**23.6815**	**17.94053**	**23.6815**
	Glass			Rubber			Plastic		
	1.00%	2.00%	3.00%	1.00%	2.00%	3.00%	1.00%	2.00%	3.00%
Initial	**113.94**	**52.82**	**75.74**	**91.02**	**136.86**	**228.55**	**83.38**	**22.25**	**91.02**
Final	**54.17**	**29.17**	**37.50**	**54.17**	**62.50**	**116.67**	**37.50**	**4.17**	**37.50**
Mean	**84.05**	**40.99**	**56.62**	**72.59**	**99.68**	**172.61**	**60.44**	**13.21**	**64.26**

Based on the result, the ability to resist impact energy shows us the block's ability to resist impact before it contains any damage, relatively. It was also proven in the experiment that when the block is damaged, another impact will most likely break the blocks entirely. Therefore, these results were used to determine how much stronger eco-CHBs are in comparison to standard CHB in terms of impact resistance.

The result also shows that a block with 3% amount of rubber, showed the highest ability to resist impact, both initial and final, which is computed to be specifically 172% stronger than a standard CHB. For the initial impact, the material that provides the most benefits in terms of impact resistance is rubber, which resisted an average of 23.75 joules of impact energy, followed by glass, which resisted impact energy of 16.98 joules. The weakest among all the eco-CHB was the blocks that consisted of plastic materials, which only endured impact energy of 15.55 joules. Although, all of the eco-CHB was able to perform much better when absorbing impact compared to standard blocks which were only able to resist an average of 9.39 joules.

Specifically, among the three mixtures with waste materials, in the rubber category, the eco-CHB with 3% rubber was the one that was able to resist the highest impact energy. As for the glass mixtures, the eco-CHB with 1% glass was the strongest within the specific category of materials, while for plastics, it was the eco-CHB with 3% plastic, but was only stronger than the 2% plastic eco-CHB by a very small margin.

The blocks that were able to resist impact energy until they ultimately crack were also recorded. Similarly, the eco-CHB with rubber components was still the strongest which was able to resist an average of 30.62 joules of impact energy; the second strongest eco-CHB similarly is the one consisting of glass components, which was able to resist an average of 24.16 joules of impact energy; and lastly, the eco-CHB with plastic components, which was able to resist an average of 21.77 joules of impact energy.

Among the mixtures within the material category, the eco-CHB with 3% rubber was able to resist the highest impact energy among the rubber category, therefore also among all mixtures. In the glass category, the mixture with 1% glass material was the strongest, and for plastics, the mixture with 1% and 3% plastic was able to resist the most impact energy.

3.2 Costing

Concrete hollow blocks consist of three main components mainly sand, water, and cement. Lahar Sand per truck load contains 18 cubic meters for 3,200 pesos and it can serve 35 bags of cement. Each bag of cement can produce 120 pieces for size 4" hollow block, 105 pieces for size 5", and 90 pieces for size 6".

Cement is a Portland type 1 cement in which it is especially design for hollow block use as it dries out faster than that of commercially available cement. Cement market price is 220 pesos per bag, and it weighs 40 kilograms.
Costing per part are the same for all the hollow blocks size. For cement, unit price per bag divided by the total number of blocks produced will obtain the cement price per unit of hollow blocks, for example the size 4 hollow blocks can produce 120 pieces of blocks per 1 bag of cement that cost 220 pesos, dividing 220 pesos to 120 pieces will obtain the cement price per unit. Same as it goes to the sand, it cost 3200 pesos per truck load and can serve 35 bags of cement, note that for size 4 of blocks it can produce 120 pieces of blocks per 1 bag of cement, to calculate for the sand price per 1 block, 35 bags of cement should be multiplied by the number of blocks produced, 35 multiplied by 120 you will get 4,200 pieces of blocks, then sand price of 3,200 divided by 4,200 pieces to get the sand price per 1 unit of hollow blocks, adding up the sand price per unit and cement sand per unit will give the unit price per hollow blocks.

Adding the costs of the waste materials needed, was the prices for recyclable materials that can be used for the CHB according to Environmental Management Bureau's website (2016). Notably, the three materials to be used are priced as shown in table 3.2.1

Table 3.2.1 Price cost of waste materials per kg (source: http://nswmc.emb.gov.ph)

Recyclable Materials	Junk Shop Price (per kg)	Factory Price (per kg)	Average Price
PET Bottles (Plastic)	P16.00	P20.00	P18.00
Glass Cullets	P1.00	P5.00	P3.00
Rubber Interiors	P27.50	P27.50	P27.50

The ratio computation used in determining the amount of scrap materials to put within the mixture is computed by its volume instead of its weight. Ratio distribution through the use of its weight would result to irregularities of the CHB since the weights of some of the wastes were very light, whereas the weight of the materials used for the blocks were heavy.

In the production of the eco-CHB, table 3.2.2 shows how much waste materials were needed for the group to be able to produce 20 pieces of each percentage from each type of materials.

Table 3.2.2 Material Costing Per Unit

	Glass			Rubber			Plastic		
	1%	2%	3%	1%	2%	3%	1%	2%	3%
1 pc (in kg/#)	0.020	0.030	0.040	0.035	0.051	0.070	0.015	0.030	0.045
20 pieces (in kg/#)	0.40	0.60	0.80	0.70	1.02	1.40	0.30	0.60	0.90
120 pieces (in kg/#)	2.40	3.60	4.80	4.20	6.12	8.40	1.80	3.60	5.40
Material price per #	₱0.06	₱0.09	₱0.12	₱0.96	₱1.40	₱1.93	₱0.27	₱0.54	₱0.81
Total price per CHB	PHP 2.65	PHP 2.68	PHP 2.71	PHP 3.55	PHP 3.99	PHP 4.52	PHP 2.86	PHP 3.13	PHP 3.40

3.3 Density

The measurement of all the blocks is consistent, which resulted to a fixed volume of 10,487.72 cm^3. With this, each block was weighted for the study to be able to compute for the density of each block. The recorded weight of each blocks is shown in the table 3.3.1.

Knowing the weight of the blocks in unit of grams, the density of the blocks can be computed using the density of formula where d = m/V, where m is the mass of the blocks, and V is the fixed volume recorded. The results are shown in table 3.3.2. Thus, the results show that there is relatively no difference in terms of the density of the blocks, for both standard CHB and all the eco-CHB.

Table 3.3.1 Recorded weight of each block

Product #	Standard	Glass			Rubber			Plastic		
		0.01	0.02	0.03	0.01	0.02	0.03	0.01	0.02	0.03
1	9230	9210	9310	9410	9310	9380	9450	9310	9380	9450
2	9210	9260	9280	9380	9350	9360	9380	9350	9330	9390
3	9250	9280	9290	9310	9370	9350	9360	9290	9360	9350
4	9260	9220	9330	9340	9320	9390	9350	9390	9330	9370
5	9310	9310	9240	9360	9370	9410	9340	9370	9350	9380
6	9260	9270	9220	9330	9410	9290	9380	9330	9360	9410
7	9320	9280	9270	9310	9350	9310	9320	9350	9410	9340
8	9220	9260	9260	9290	9380	9330	9330	9310	9370	9430
9	9250	9250	9250	9360	9360	9380	9340	9340	9390	9420
10	9280	9230	9320	9370	9350	9390	9380	9320	9340	9390
Mean	1300	9240	9290	9360	2500	3100	9410	2400	9360	9440
Std. Dev	36.0401	30.56868	35.91657	36.87818	28.69379	38.71549	37.43142	30.25815	26.16189	34.97618

Table 3.3.2 Density of each block

Product #	Standard	Glass			Rubber			Plastic		
		0.01	0.02	0.03	0.01	0.02	0.03	0.01	0.02	0.03
1	0.88	0.88	0.89	0.90	0.89	0.89	0.90	0.89	0.89	0.90
2	0.88	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.90
3	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
4	0.88	0.88	0.89	0.89	0.89	0.90	0.89	0.90	0.89	0.89
5	0.89	0.89	0.88	0.89	0.89	0.90	0.89	0.89	0.89	0.89
6	0.88	0.88	0.88	0.89	0.90	0.89	0.89	0.89	0.89	0.90
7	0.89	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.90	0.89
8	0.88	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.90
9	0.88	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.90	0.90
10	0.88	0.88	0.89	0.89	0.89	0.90	0.89	0.89	0.89	0.90
Mean	0.88	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.90
Std. Dev	0.003436	0.002915	0.003425	0.003516	0.002736	0.003692	0.003569	0.002885	0.002495	0.003335

3.4 One-Way ANOVA Test

Considering the results from all the experiments performed above, the researchers need to determine and analyze the variances between the results. The group will be using a one-way ANOVA test due to the experiment divided into three groups – Rubber, Plastic, and Glass. There was a consideration that a two-way test had to be performed due to the results having classifications – compressive strength and impact resistance. Instead, these are two entirely different conditions for the blocks. Therefore, a one-way ANOVA test is to be done for both conditions.

H_o: There is no significant difference on the means between each eco-CHB and a standard CHB
H_a: There is at least one differentiation from the means between each eco-CHB and a standard CHB

3.4.1 Compressive Strength Test

Based on table 3.4.1, compressive strength tests show a p-value of 2.53E-46, which is well below 0.05. This signifies that there is a significant difference with the results in terms of the compressive capabilities of each block from different categories.

Table 3.4.1 ANOVA One-way test for Compressive Strength

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	96661	9	10740.11	120.9775	2.53E-46	1.985595
Within Groups	7990	90	88.77778			

3.4.2 Impact Resistance

Based on table 3.4.2.1, a P-value of 3.08E-18, which is well below 0.05, means that there is a significant different with the results of each blocks that contains standard and ecological waste materials.

Table 3.4.2.1 ANOVA One-way test for Impact Resistance

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	62.36	9	6.928889	20.37908	3.08E-18	1.985595
Within Groups	30.6	90	0.34			
Total	92.96	99				

As for the results when the blocks ultimately cracked, table 3.3.2.2 show a p-value of 1.01E-14, which means that there is a smaller, significant difference in comparison to the results of compressive strength and impact resistance until the initial crack. However, the result still shows that there is a significant difference in all categories of waste materials used.

Table 3.4.2.2 ANOVA One-way test for the Ultimate Crack

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	55.84	9	6.204444	15.17391	1.01E-14	1.985595
Within Groups	36.8	90	0.408889			
Total	92.64	99				

By performing a one-way ANOVA test for all the criteria, figure 3.4.2.1 shows that there is a significant difference for all the factors involved in evaluating a CHB and eco-CHB, this is proven by having a p-value which is lower than 0.05 when the one-way test was performed.

ANOVA results reject the null-hypothesis due to the criterion having a significant difference among each other, which resulted to the need of further analysis

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	Cost (PHP), Compressive Strength (PSI), Impact Energy (Joules), Density (g/cm^3)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	504877	168292	859.89	0.000
Error	32	6263	196		
Total	35	511140			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
13.9898	98.77%	98.66%	98.45%

Figure 3.4.2.1 ANOVA One-way test for all Criterion: Cost (PHP), Compressive Strength (PSI), Impact Energy (Joules), Density (g/cm^3)

3.5 Tukey's Pairwise Comparison

By performing the Tukey's Pairwise Comparison, it provided the study the ability to differentiate the level of importance of each significant factor; this provides an insight on which among the factors is the most important; and the importance of one factor from another. Figure 3.5.1 shows that compressive strength has a very significant importance compared to all the other factors while impact energy has a less significant importance among the remaining factors which are shown to be equal.

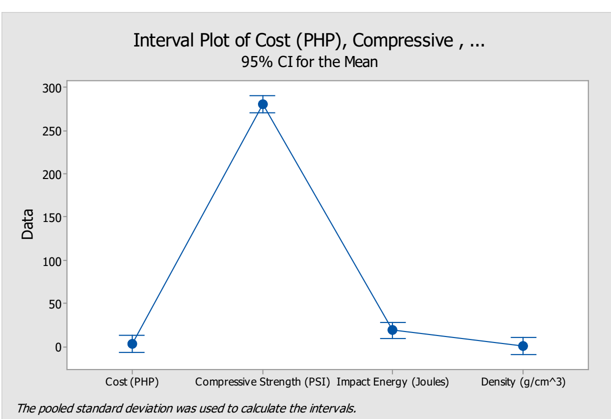

Figure 3.5.1 Interval plot of significant factors in CHB and eco-CHB

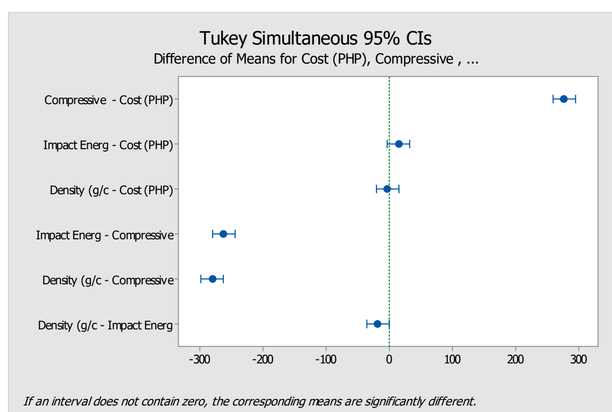

Figure 3.5.2 Tukey's Simultaneous 95% CIs

On the other hand, figure 3.5.2 now provides a paired comparison of each factor where one factor is compared with another, and the significant differences of the pair are evaluated. Results show that compressive-cost has a significant difference, which means that the compressive strength is much important than the cost. As for impact energy versus compressive strength and density versus compressive strength, shows that impact energy and density have less significant importance than compressive strength. The format of the comparison plays a role in determining the results. Meanwhile, impact energy has a minimal difference compared to density and cost, and density-cost having a value of zero means that there is no significant difference among the pair.

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Compressive Strength (PSI)	9	280.67	A
Impact Energy (Joules)	9	18.74	B
Cost (PHP)	9	3.277	B
Density (g/cm^3)	9	0.89046	B

Means that do not share a letter are significantly different.

Figure 3.5.3 Tukey's Pairwise Comparisons

Furthermore, using the pairwise comparisons as shown in figure 3.5.3, it provided the study a grouping data for the criterion that provides information on the rate of the importance of each factor involved in eco-CHB production. There were a total of two groups according to the result of pairwise comparison; group A being higher than group B in terms of importance.

Group A only consists of one factor which is compressive strength, and the rest of the factors fall to group B, which are impact energy, cost, and density. This does not mean that the three factors are equal to each other, but instead, it just means that compressive strength has a significant difference when compared to the others.

3.6 Cost-Benefit Analysis

Table 3.6.1 shows the differences of both costs and benefits for eco-CHB in comparison to a standard block. The table below shows how much the difference is for each category in terms of percentage.

In terms of costs, an eco-CHB with 3% of rubber has 74% more cost which is the highest in all the types and compared to a standard block. But it also shows that it has the highest increase in compressive strength which is 49% stronger than a standard CHB. Similarly, it was also the block that was able to resist as much hit until it cracks initially, and ultimately, with 231% and 117% respectively. The low-cost block is plastic with 1% of glass with an increase of 2% in cost but shows an increase in compressive strength and impact resistance by 27% and 115% respectively. The medium cost block is the 2% plastic. It increases by 21% in cost but with a 42% increase in compressive and a 23% increase in resistance.

Table 3.6.1 Cost-Benefit Analysis (difference of results in percentage)

	Glass			Rubber			Plastic		
	1%	2%	3%	1%	2%	3%	1%	2%	3%
Costs									
Eco-CHB	2.65	2.68	2.71	3.5525	3.9925	4.515	2.86	3.13	3.4
Standard	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59
Increase in costs vs standard	0.02	0.03	0.05	0.37	0.54	0.74	0.10	0.21	0.31
Benefits									
Stronger blocks									
Compressive strength (PSI)									
Eco-CHB	276	245	241	279	306	323	273	306	277
Standard	217	217	217	217	217	217	217	217	217
Increase in compressive strength vs standard	0.27	0.13	0.11	0.29	0.41	0.49	0.26	0.41	0.28
Impact Energy									
Eco-CHB	20.09339	14.35242	16.50529	17.94053	22.24625	30.85771	17.22291	11.48194	17.94053
Standard	9.329075	9.329075	9.329075	9.329075	9.329075	9.329075	9.329075	9.329075	9.329075
Increase in impact resistance vs standard	1.15	0.54	0.77	0.92	1.38	2.31	0.85	0.23	0.92
Density									
Eco-CHB	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.90
Standard	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Increase in density vs standard	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02

3.7 Analytical Hierarchy Process

Table 3.7.1 shows the result of each CHB mixture. The numbers in the red font color denote the score obtained for every type. 3% rubber mixture got the highest score of 0.143, meaning it is superior among all the types and is the most suitable mixture that can be introduce to the market considering all the factors and result gathered.

Table 3.7.1 Summary of final results for each specific CHB

Product		Compressive Strength		Impact Resistance		Cost		Density		Total Score
		Actual (PSI)	Score	Actual (Impact Energy)	Score	Actual (Cost of Production)	Score	Actual (g/cm3)	Score	
Glass	1%	276	0.023	20.09	0.011	2.65	0.014	0.88	0.04	**0.088**
	2%	245	0.023	14.35	0.005	2.68	0.014	0.88	0.04	**0.082**
	3%	241	0.023	16.51	0.005	2.71	0.024	0.89	0.04	**0.092**
Rubber	1%	279	0.023	17.94	0.011	3.55	0.014	0.89	0.04	**0.088**
	2%	306	0.043	22.25	0.011	4	0.007	0.89	0.04	**0.101**
	3%	323	0.08	30.86	0.02	4.52	0.003	0.89	0.04	**0.143**
Plastic	1%	273	0.043	17.22	0.005	2.87	0.024	0.89	0.04	**0.112**
	2%	306	0.043	11.48	0.003	3.13	0.014	0.89	0.04	**0.1**
	3%	277	0.043	17.94	0.005	3.4	0.014	0.90	0.04	**0.102**

A summary of the results for the analytic hierarchy process performed is show in table 3.7.2, provided with the corresponding rank for each material, and the overall ranking of the most viable mixture of eco-CHB.

Table 3.7.2 Summary of AHP Results

	Rubber	Glass	Plastic	Overall
1st	3%	3%	1%	3% Rubber
2nd	2%	1%	3%	2% Plastic
3rd	1%	2%	2%	3% Plastic

4. Conclusion

The results of the study have shown that the eco-CHB are all viable and can be used in the Philippine construction industry. It was just a matter of which among all the tested mixtures is the most optimal for use, which was also discovered through several assessments considering specific criteria. The data gathered from the assessment have shown that a mixture of CHB consisting of 3% rubber waste, in terms of its overall volume, yields the best results, both in terms of its specification and its costs.

These results were also backed up by other tests in which it had shown in the one-way ANOVA testing that there is a significant difference in results for each different mixture. This means that the waste materials added to the mixtures had a significant effect on the end product.

The cost-benefit analysis also made clear that even though the cost increases due to added raw materials, the increase in the benefits it provides compensates for how much the increase in cost was. This also means that manufacturers of these eco-CHBs can increase the selling price due to its added benefits. Therefore, the primary hypothesis of the study based on related studies from different countries can now be accepted, and possibly implemented in the Philippine construction industry setting.

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