Dr. Yanga's Colleges, Inc.
Office of the School President
Science Center for Innovation, Research, and Engagement

Scientia

The DYClan Research Journal on Emergent Themes in Science, Technology, Engineering, and Mathematics

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4 QUALITY EDUCATION

7 AFFORDABLE AND CLEAN ENERGY

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11 SUSTAINABLE CITIES AND COMMUNITIES

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Dr. Yanga's Colleges, Inc.
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Science Center for Innovation, Research, and Engagement (SCIRE)

Scientia: The DYCIan Research Journal on Emergent Themes in Science, Technology, Engineering, and Mathematics

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Volume 1, Issue 1, 2024 Edition by the DYCI SCIRE

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PREFACE

One of the mandates of the DYCI Science Center for Innovation, Research, and Engagement (SCIRE) is to produce high-quality research and disseminate important findings through scientific publications, fora, and conferences.

In relation to this, DYCI SCIRE, in partnership with the Science Learning Area of the High School Department, released the first-ever school-based student research publication containing the abstracts and shortened papers of innovative capstone and relevant research projects of our beloved DYCIans. This is entitled *Scientia: The DYCIan Research Journal on Emergent Themes in Science, Technology, Engineering, and Mathematics*.

The first issue of Scientia presents six DYCIan research papers recognized by various national and international conferences, competitions, and publications, contributing directly to various United Nations Sustainable Development Goals—*SDG 4: Quality Education, SDG 7: Affordable and Clean Energy, SDG 9: Industry, Innovation, and Infrastructure, SDG 11: Sustainable Cities and Communities,* and *SDG 15: Life on Land*.

This is just the start of DYCI SCIRE's promise of connecting science to the people by making it accessible and meaningful for all. The Center has a plethora of exciting surprises and announcements as the call for abstract submission for the next issue of Scientia will commence soon.

Stay curious, DYCIans! Together, let's connect science to the people!

Aces Joseph L. San Pedro, RCh
Director
Science Center for Innovation, Research, and Engagement

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Anthropomorphic Concrete: Facilitating Autogenous Self-Healing Through Hydration of Calcium Silicate

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The Most Innovative Capstone Research in Materials Chemistry

Competing Poster, 38th Philippine Chemistry Congress
Accepted for Presentation
2024 International Conference on Chemistry
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***Abstract* —** Concrete is a fundamental building material in modern construction which embodies adaptability, versatility, and durability. Despite its widespread use and inherent advantages, concrete is not resistant to defects such as cracking, deterioration due to environmental factors, and limited self-repair capabilities that can affect its integrity. Hence, the study aimed to induce and facilitate self-healing capabilities in concrete by integrating calcium hydroxide and micro-capsuled sodium silicate which, in the presence of water, forms calcium silicate that can act as an adhesive agent for cracked concrete zones. Through controlled experiments, the study evaluated the efficacy of this formulation in facilitating self-healing mechanisms within concrete. The obtained statistics of the crack depth ($p=0.00003$) and width ($p=0.0008$) healing are both $p<0.05$ indicating that calcium hydroxide and sodium silicate induces self-healing capabilities on concrete. Observed crack depth recovery rates varied between 75% and 80%, while the crack width witnessed complete healing. However, it was also observed that prolonged healing time decreases the healing magnitude exhibited by the concrete samples. These findings highlighted the potential of integrated concrete as a sustainable solution for infrastructure resilience and maintenance. However, its application in industrial contexts required further study of its other properties and limitations.

Keywords: autogenous self-healing, concrete, calcium silicate hydration

INTRODUCTION

Concrete, a composite material composed primarily of coarse aggregates bonded together with fluid cement that hardens over time, is a cornerstone of modern construction [1]. However, one primary problem with concrete is its low tensile strength. It is weak in tension and only exhibits tensile strengths that are 10% of its compressive strengths [2]. This weakness necessitates the use of reinforcements to bear tensile loads and prevent cracking. Susceptibility to various defects can further exacerbate the problem through cracking, spalling, and reinforcement corrosion [3]. In the United States alone, more than 200,000 bridge decks have experienced such issues [4], requiring around almost $21 billion just to repair and maintain the deteriorating concrete structures [5].

To address the inherent weaknesses in concrete, solutions that leverage on self-healing capabilities have been studied. In turn, self-healing concrete, which can repair its own cracks autonomously, was developed using various methods such as natural, chemical, biological, and external additions [6]. Natural self-healing methods have sealed cracks up to 0.2 mm in width by reacting unhydrated cement particles with water, but its effectiveness is limited, it is very slow, and is highly dependent on environmental conditions [7]. Chemical self-healing uses microencapsulated healing agents, such as epoxy resins or cyanoacrylates, that polymerize

upon crack formation, sealing cracks up to 0.5 mm, enhancing the longevity of the structure despite very high initial costs and susceptibility to incomplete crack filling and long-term stability [8]. Biological self-healing utilizes bacteria such as *Bacillus sphaericus* that precipitates calcium carbonate with exposure to water, effectively sealing cracks up to 0.8 mm while requiring the survival of bacteria in the concrete's alkaline environment, sufficient supply of nutrients, and favorable environmental conditions [9]. External additions, including polymer coatings with embedded healing agents, are effective for surface cracks and readily existing structures offering a moderate-cost solution, but are not capable of addressing deeper issues and often require repeated applications, more so with its non-existent longevity [10].

As such, this study suggests the addition of sodium silicate (Na_2SiO_3) and calcium hydroxide ($Ca(OH)_2$) in concrete production to induce a self-healing characteristic, along with the aim to contribute to the following: building resilient infrastructure, promote sustainable industrialization, and foster innovation, in line with *SDG 9: Industry, Innovation, and Infrastructure.*

On account of the aforementioned objectives, this study aimed to use the addition of sodium silicate and calcium hydroxide in concrete production to facilitate its hydration into calcium silicate ($CaSiO_3$), which served as the induced self-healing characteristic that can improve the low magnitude of healing and slow rate of healing observed in the past studies, thereby strengthening the longevity of concrete, decreasing the need for frequent maintenance, and ultimately reducing costs associated with concrete usage. Its effectiveness was also studied by investigating the rate at which the integrated concrete heals itself on a day-to-day basis. The study, which was conducted on the premises of Dr. Yanga's Colleges, Inc., Bocaue, Bulacan, was limited to measuring healing rate and magnitude, making the results purely focused on improving the healing capability of self-healing concretes. By doing so, the gaps present from the past studies were addressed while still upholding the cost-effectiveness characteristic of concrete production.

METHODOLOGY

A. Microencapsulated Na_2SiO_3 Preparation

Initially, 100 microcapsules of 0.68 mL volume were prepared, alongside a 1-liter stock solution of 11.5 M Na_2SiO_3. To comply with safety regulations regarding human exposure limits, 11.8 mL of the stock solution was diluted by adding 56.17 mL of water, resulting in the production of 68 mL of a 2 M Na_2SiO_3 solution [11] and this was then placed in each of the microcapsules.

B. $Ca(OH)_2$ & Na_2SiO_3 Integrated Concrete Production

The integrated concrete (IC) was produced following an M15 ratio of 1 part OPC33-Grade cement, 1 part $Ca(OH)_2$, 2 parts sand, and 4 parts gravel (1:1:2:4) to achieve standardization, cost-effectiveness, high workability, and moderate strength [12]. A 0.55 for 1:1:2:4 water-cement ratio by adding 30% weight of cement and 5% weight of total aggregates was used during the mixing to achieve complete hydration while adhering to Abram's water-cement law [13]. The process was repeated three more times to obtain a total of four concrete samples. The concrete mix was then prepared using a layer-by-layer method. Initially, 25% of the concrete mix was placed in the container, followed by the addition of 33 microencapsulated Na_2SiO_3. This procedure was repeated twice, and the final 25% of the concrete mix was added on top. Finally, all the containers were dried and cured for six days.

C. Product Testing

A visible microcrack with depths from 40 to 50 mm and widths from 1.5 to 2.5 mm that spans from the inside to the outside portion was induced in all the concrete samples (including the four non-integrated concrete (NIC) samples). Water was then poured on the microcrack to facilitate the formation of hydrated $CaSiO_3$ which serves as the healing agent of the concrete sample [14]. Daily monitoring of the healing rate and magnitude of the eight concrete samples were performed for nine days using a high-pixel DSLR camera and gauge wires [15,16].

RESULTS AND DISCUSSIONS

The depth and width of the microcracks (mm) induced on the eight concrete samples (four IC and four NIC samples) were measured and obtained (Table 1). The measurements of the microcracks were made daily for nine days and the final values were also tabulated.

Table 1. Exact crack depth and width measurements.

Sample Name	Initial Cracks		Healed after 9 days	
	Depth, mm	Width, mm	Depth, mm (%)	Width, mm (%)
IC #1	45	2.4	35.5 (79%)	2.4 (100%)
IC #2	49	1.9	39 (80%)	1.9 (100%)
IC #3	51	2.0	38 (75%)	2.0 (100%)
IC #4	44	2.2	34 (77%)	2.2 (100%)
NIC #1	49	2.6	0	0
NIC #2	45	2.3	0	0
NIC #3	42	1.8	0	0
NIC #4	42	2.4	0	0

A. Crack Healed Analysis

The findings in this section provide compelling evidence that the incorporation of $Ca(OH)_2$ and Na_2SiO_3 in concrete production induces a self-healing property that is absent in non-integrated concrete samples.

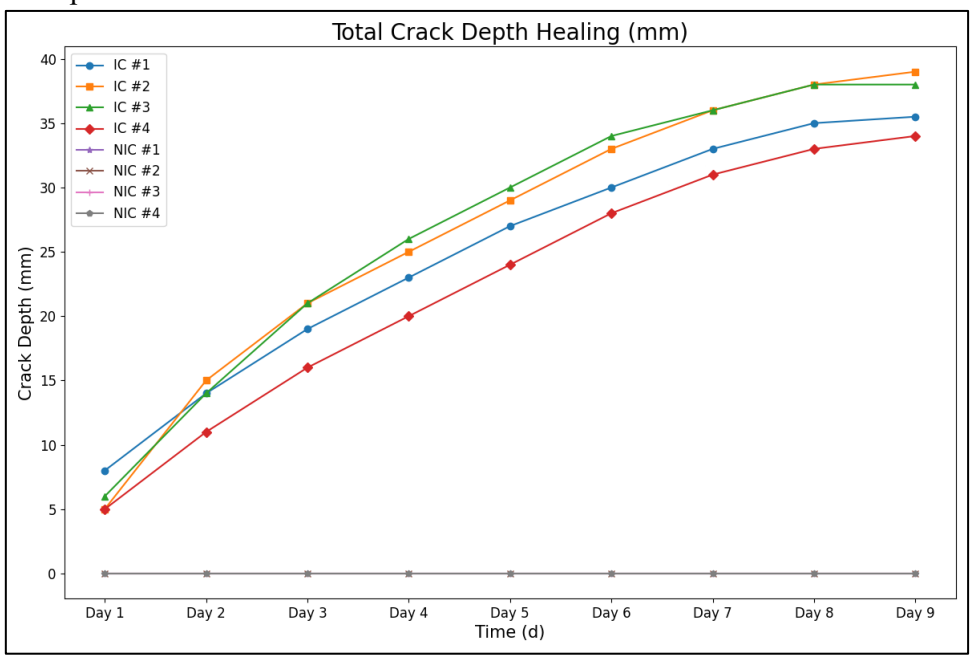


Figure 1. Line graph showing the comparison between the total crack depth healed by the four integrated (M=36.625, SD=2.22) and non-integrated (M=0, SD=0) samples, $t(3)=33.15$, $p<0.05$.

Figure 1 proved that IC samples experience crack depth healing compared to NIC samples. Specifically, samples IC #1 through IC #4 demonstrated an average daily crack healing depth of 3.44 mm, 4.25 mm, 4.00 mm, and 3.63 mm, respectively. In contrast, samples NIC #1 through NIC #4 did not exhibit any self-healing capabilities. Additionally, samples IC #1 - #4 achieved percent crack depth recovery values of 79%, 80%, 75%, and 77%, respectively.

Furthermore, the differences in crack depth healing between the IC and NIC samples were analyzed using statistical techniques to ensure data credibility and validity. A t-test assuming unequal variances (Figure A1) indicated a significant difference ($p=0.00003$) between the crack depth healed by the IC and NIC samples. This analysis confirms that the IC samples, incorporated with $Ca(OH)_2$ and Na_2SiO_3, exhibited significantly greater and faster healing than the NIC samples.

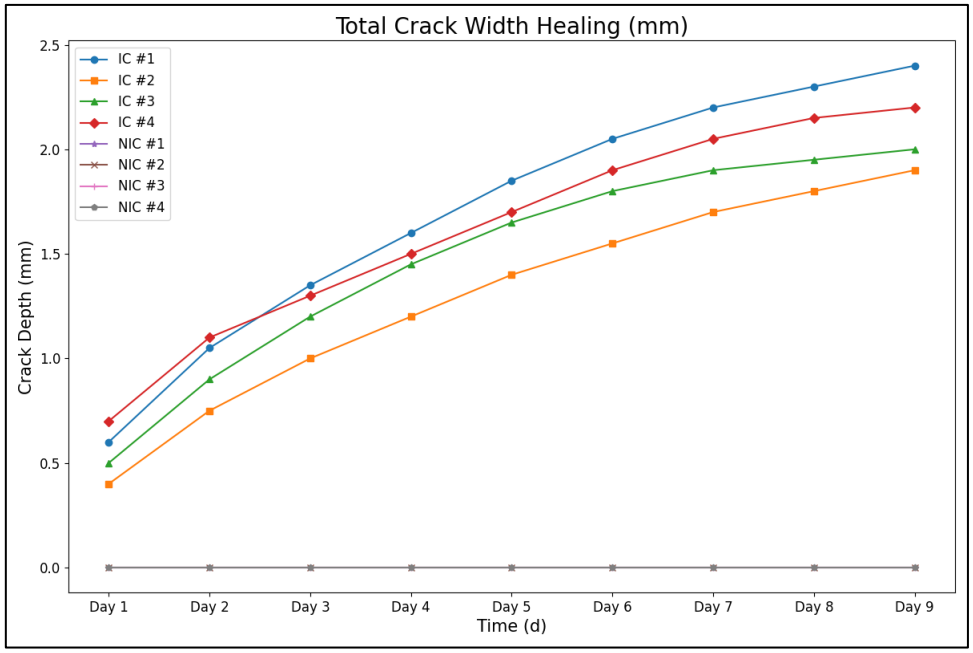


Figure 2. Line graph showing the comparison between the total crack width healed by the four integrated (M=1.07, SD=0.1) and non-integrated (M=0, SD=0) samples $t(3)=10.88$, $p<0.05$.

Figure 2, on the other hand, revealed that samples IC #1 through IC #4 exhibited an average daily crack healing width of 0.225 mm, 0.193 mm, 0.188 mm, and 0.188 mm, respectively. In contrast, samples NIC #1 through NIC #4 did not display any self-healing capabilities, like the crack depth healing assessment. Further analysis also revealed that samples IC #1 to IC #4 all showed a complete percent (100%) width crack recovery value.

Similar to Figure 1, the differences in crack width healing between the IC and NIC samples were analyzed using a t-test (Figure A2) assuming unequal variances, yielding a significant difference ($p=0.0008$) between the crack width healed by the IC and NIC samples.

The IC samples were formulated with both $Ca(OH)_2$ and Na_2SiO_3, which upon interaction, generates a binding agent termed CaSiO3 through the chemical reaction [17]:

$$Ca(OH)_2 + Na_2SiO_3 \rightarrow CaSiO_3 + 2NaOH$$

Furthermore, $CaSiO_3$ strengthens the longevity of the concrete samples by filling in pores and cracks within the concrete while lowering permeability at the same time [18,19], making it suitable for self-healing application in concrete technology.

B. Effect of healing time (d) on healing rate (mm/d) and magnitude (mm).

In this section, the healing rate [15] was computed using the equation:

$$Healing\ Rate\ on\ Day\ n = Ave.Healing\ on\ Day\ n - Ave.Healing\ on\ Day\ (n-1)$$

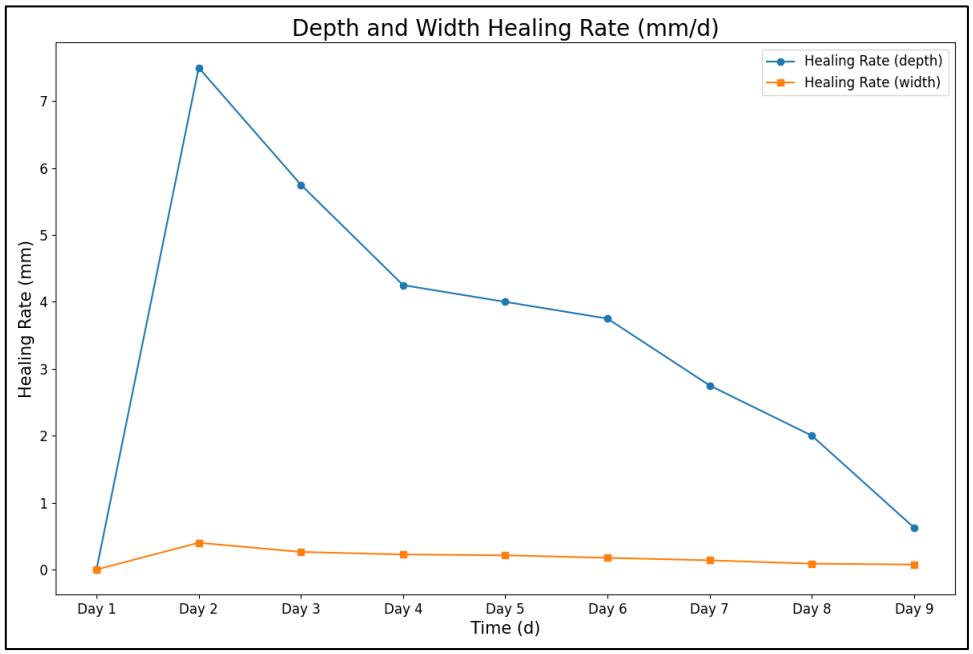


Figure 3. Line graph of the daily healing rate of the crack width and depth for all IC samples.

From Figure 3, the sharp initial increase followed by a gradual decline in the trajectory indicated a consistent healing pattern among the IC samples. Initially, the cracks exhibit rapid healing, with depth healing rates starting at 7.4 mm (Table A1) and width healing rates at 0.4 mm (Table A2) on Day 2. However, as the observation period progresses, the healing rates diminish to 0.625 mm for depth (Table A1) and 0.075 mm for width (Table A2) on Day 9. This trend, in line with the observations from past studies, suggests that the self-healing process is most effective in the early stages, gradually tapering off over time [18-20].

C. Comparison of recovery magnitude between current and past studies.

Significant improvements in crack recovery rates compared to past studies were observed. Most of the past studies with high crack recovery rates (Table 2) were dependent on either a long healing time ranging from 20 – 50 days or minuscule initial crack values in contrast with samples IC #1 to IC#4 which was only observed for 9 days and had significantly higher initial crack vales. Additionally, the crack recovery results obtained from the four IC samples, despite being subjected to shorter healing time and higher initial crack value, are still higher than the past studies (Table 2).

Table 2. Crack recovery comparison between current and past studies.

Method	Initial Crack Value	Crack Recovery (%)	Reference
Fiber Reinforcement	0.34 mm	70% (crack width)	(Cuenca & Serna, 2021) [21]
Calcium Carbonate Precipitation	0.32 mm	77% (crack width)	(Roig-Flores & Serna, 2020) [22]

Fly Ash	0.35 mm	14% (crack width)	(Mustafa et al., 2024) [23]
Carbonated Steel Slag	0.30 mm	6.7 x 10^{-5}% (crack width)	(Pang et al., 2016) [24]
Polyethylene Fiber	0.368 mm	20% (holes)	(Homma et al., 2009) [25]
Reactive Magnesium Oxide (MgO)	0.5 mm	74% - 99% (holes)	(Al-Tabbaa & Qureshi, 2016) [26]
Hauyne + Anhydrite + Calcium Sulfo-aluminate (CSA)	0.22 mm	27% (crack width)	(Ahn & Kishi, 2010) [27]
M CSA + CA + Hauyne + Anhydrite + Limestone	0.4 mm	99% (holes)	(Sisomphon et al., 2012) [28]
Bacterial Spores	~1 mm	99% (holes)	(Palin et al., 2016) [29]
Monofluorophospate & Sodium Fluorophosphate	2 mm	35% (crack width)	(Dong et al., 2018) [30]
Sodium Silicate + Calcium Hydroxide	44 – 51 mm (depth) 1.9 – 2.4 mm (width)	75% - 80% (crack depth) 100% (crack width)	This study.

CONCLUSION AND RECOMMENDATIONS

The integration of $Ca(OH)_2$ and microencapsulated Na_2SiO_3 as the main components of concrete production to induce a self-healing characteristic, leveraged with the presence of water to form hydrated $CaSiO_3$ as the healing agent was reflected in the results obtained from the statistical analyses and observations employed throughout the study. From the statistical tests employed on both the crack depth ($p=0.00003$) and width ($p=0.0008$) healed over the course of nine days, the results revealed significant differences ($p<0.05$) with the IC samples showing significant healing properties while the NIC samples showing none, conclusively proves that integrating $Ca(OH)_2$ and Na_2SiO_3 in concrete production induces a self-healing characteristic.

Additionally, an analysis of the trajectory of healing rates for both crack depth and width revealed a consistent regression. For instance, depth healing rates start at 7.4 mm and width at 0.4 mm, gradually decreasing as time progresses to 0.625 mm for depth and 0.075 mm for width. This diminishing trend suggests that while the self-healing process is most effective in the early stages, its efficacy gradually declines over time.

Ultimately, additional research and replication is imperative for the betterment of the study. As such, it is recommended to consider and explore other types of cement, sand, or aggregate in the process of creating the concrete mix to understand whether such changes influence the self-healing characteristic of the IC samples. Different concrete mix, $Ca(OH)_2$, and Na_2SiO_3 ratios should also be considered and explored as different amounts or concentrations of materials can yield different results that may positively or negatively affect the concrete produced. Further study of its other properties and limitations is also a necessity as increased vulnerability in abrasions and decrease in compressive strength were consequently observed. Finally, through continued research into potential complications and alternative materials, this study holds the potential of taking a sustainability-centered approach that can address the environmental issues associated with concrete science, thereby contributing to more sustainable practices in construction and infrastructure development.

APPENDIX

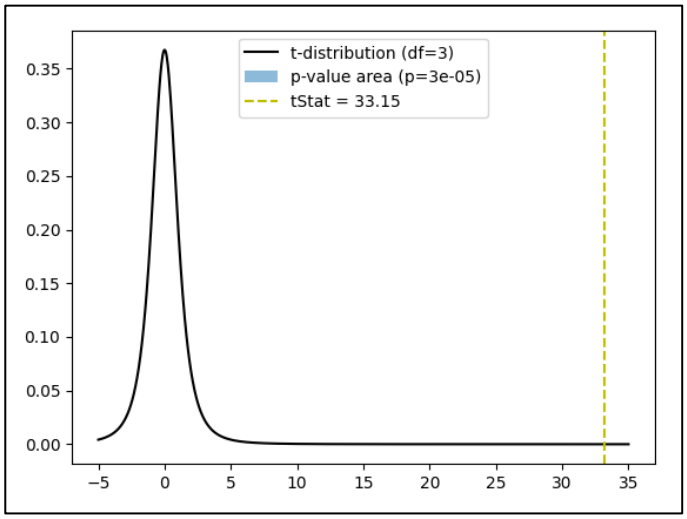


Figure A1. Crack Depth Healed One-Tailed Normal Curve Diagram for t-test (t=33.15; p=0.00003).

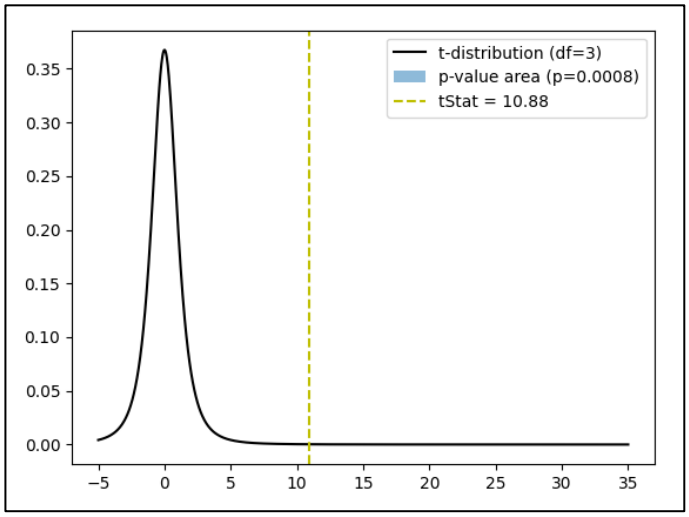


Figure A2. Crack Width Healed One-Tailed Normal Curve Diagram for t-test (t=10.88.15; p=0.0008).

Table A1. Exact average IC healing magnitude and rate measurements in terms of depth.

Healing Time (d)	Average IC Healing (mm)	Healing Rate (mm/d)
1 Day	6 mm	--
2 Days	13. 5 mm	7.5 mm/d
3 Days	19.25 mm	5.75 mm/d
4 Days	23.5 mm	4.25 mm/d
5 Days	27.5 mm	4.0 mm/d
6 Days	31.25 mm	3.75 mm/d
7 Days	34 mm	2.75 mm/d
8 Days	36 mm	2.0 mm/d
9 Days	36.625 mm	0.625 mm/d

Table A2. Exact average IC healing magnitude and rate measurements in terms of width.

Healing Time (d)	Average IC Healing (mm)	Healing Rate (mm/d)
1 Day	0.55 mm	--
2 Days	0.95 mm	0.4 mm/d
3 Days	1.2125 mm	0.2625 mm/d
4 Days	1.4375 mm	0.225 mm/d
5 Days	1.65 mm	0.2125 mm/d
6 Days	1.825 mm	0.175 mm/d
7 Days	1.9625 mm	0.1375 mm/d
8 Days	2.05 mm	0.0875 mm/d
9 Days	2.125 mm	0.075 mm/d

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Whisking Alikabok Away: Taming Dust with *Zea mays* (Corn) Straw and *Eucheuma cottonii* (Red Algae)-Based Bio-Dust Suppressants for Dirt Roads

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***Abstract* —** Dust pollution from unpaved roads poses health and environmental concerns prompting the search for effective suppressants. Hence, this study aimed to produce two formulations using *Zea mays* (corn) straw and *Eucheuma cottonii* (red algae) which are known to have dust suppressing abilities and soil benefits. These may serve as sustainable alternatives to conventional dust control methods often associated with adverse effects. The two bio-dust suppressant solutions underwent standardized testing to evaluate their effectiveness based on three vital properties of dust suppression: sedimentation, compaction, and evaporation. The corn straw-based suppressant had a stronger wetting property resulting in greater adhesion between the liquid and soil surface. SEM images also revealed that loam soil treated with corn straw formulation exhibited significant surface compaction, whereas the soil treated with red algae appeared more loosely structured. These results highlighted the advantage of corn straw in enhancing soil stability and mitigating dust dispersion compared to red algae. Meanwhile, their evaporation rates showed that the red algae-based suppressant had a more favorable stability for real life applications compared to corn straw. All in all, the findings suggest that corn straw and red algae-based bio-dust suppressants exhibit sustainable dust control potential. Corn straw has superior efficacy in dust suppression; however, further research is needed to optimize its properties.

Keywords: dust pollution, bio-dust suppressant, corn straw, red algae

INTRODUCTION

About four years ago, amidst the COVID-19 lockdown, notable improvements in the air quality of Mega Manila garnered attention, marking a pivotal moment, particularly for residents long exposed to elevated pollution levels. With the gradual resumption of daily activities, governmental efforts have been underway to sustain the observed decline in air pollution levels [1]. Nonetheless, the challenge persists with natural sources of air pollution, including volcanic emissions, combustion byproducts, botanical particulates, sea salt, suspended soil, and dust [2].

Dusty environment is prevalent and common struggles of many individuals especially to those who live in urban areas where unpaved or dirt roads still exist. This comprises fugitive dust of PM10 originating from construction sites, landfills, agricultural activities, wildfires, industrial operations, wind-driven soil erosion, pollen, and microbial fragments. This may seem insignificant because of its tiny and invisible property but can cause health-related illnesses when encountered and inhaled over the long run [3]. Unlike synthetic pollutants, natural dust

cannot be entirely eliminated; thus, the formulation of dust suppressants. These are liquid solutions applied to unpaved surfaces and dirt roads, aimed to control dust and maintain surfaces by compacting the fine dust particles to the ground and restricting the airborne dissemination of it for a longer time than just using ordinary water [4]. While these suppressants have been available for some time, their widespread adoption remains incomplete, particularly in nations such as the Philippines. Moreover, conventional dust suppressants have been associated with adverse environmental impacts, including deterioration of surface and groundwater quality, soil contamination, human health concerns, and ecological repercussions, prompting exploration of bio-based alternatives [5].

Biodegradable dust suppressants derived from renewable sources present a promising avenue for sustainable dust control. Corn straw, owing to its abundance and favorable characteristics, emerges as a prominent candidate due to its economic viability, film-forming properties, thermal adaptability, and resilience against wind erosion [6]. Similarly, red algae offer prospects for enhancing soil structure and hydrological management [7]. Noteworthy are findings indicating that combinations of glycerol with powdered red algae or wakame exhibit superior performance as dust suppressants, particularly in terms of biodegradability and efficacy [8].

Due to the topic's ongoing development, there is limited literature that evaluates the effectiveness of existing bio-dust suppressants. Hence, this study aims to produce two bio-dust suppressant formulations using *Zea mays* (corn) straw and *Eucheuma cottonii* (red algae) and examine their effectiveness based on their sedimentation, compaction, and evaporation on sandy loam soil. With this, the study has the potential to offer solutions in promoting a much healthier environment for the vulnerable communities by taming and minimizing dust circulation in the atmosphere and decreasing the likelihood of having undesirable diseases caused by it. The formulated bio-dust suppressants may also serve as sustainable alternatives to conventional dust control methods often associated with adverse effects, in line with *SDG 15: Life on Land.*

METHODOLOGY

A. Formulation of Bio-dust Suppressants

The raw corn straw and red algae were powdered, then 20 grams of each were separately placed into a container with 1000 mL of distilled water. Each mixture was then mixed for 30 minutes. Then, 10 grams of sodium carboxymethyl cellulose, 10 grams of sodium hydroxide, and 12 grams of glycerin were added one at a time, with an interval of 1-hour mixture time between each addition [8,9]. Lastly, the solutions were then placed into the designated spray bottles prior to testing.

B. Test for Sedimentation

The two test solutions were placed into separate 25-mL test tubes, with distilled water as the control group. After which, a dried 1-g test dust sample (sandy loam soil) was placed into the solutions. The time required for all the dust particles to settle at the bottom of the tube was then recorded and was done by triplicates. The average time was then recorded as the sedimentation wetting time [10].

C. Test for Compaction

Besides, to check for the compaction of the dust sample, loam soil was placed in three round-shaped dishes, each occupying a total surface area of 6 square inches, with a height of 0.5 inches and a diameter of 1.5 inches of soil. Five sprays of distilled water (A), corn straw-based

bio-dust suppressant (B), and red algae-based bio-dust suppressant (C) were placed on their respective set-ups. Analyzing the solidification of soil with water would serve as the basis for comparing the compaction results of the other two solutions to conclude which one is better to use in compacting dust and soil particles with the same ability as the water, however, surpassing its limitations. The surface of the test samples was then scanned using Hitachi SU3800 SEM.

D. Test for Evaporation

The water retention ability of the dust suppressants was tested by comparing the evaporation rates of 100-g soil samples, with an area of 0.04 meter, with and without the 5 mL liquid solutions. This involved recording the mass of the samples before and after exposure to sunlight for 5 hours and using a formula to calculate the evaporation rate [10].

$$\theta = \frac{M_0 - M_1}{AT} * 100$$

where θ is the evaporation rate, M_0 and M_1 are masses of soil sample in grams before and after evaporation respectively, A is the evaporation area of soil sample in meters, and T is the evaporation time in seconds.

RESULTS AND DISCUSSIONS

A. Sedimentation of the Soil Samples

The time required for all the dust particles to settle at the bottom of the tube for the sedimentation wetting time experiment was measured and obtained (Table 1).

Table 1. Sedimentation wetting time of the corn straw and red algae bio-dust suppressants with distilled water as the control group.

Trial	Sedimentation Wetting Time, s		
	Distilled Water	**Corn straw**	**Red algae**
1	800	603	720
2	825	596	745
3	764	630	758
Average	**796.3**	**609.7**	**741.0**

Table 1 presented the sedimentation wetting time average of the three test solutions, wherein the corn straw formulation had the strongest wetting property (609.7 s). This was then followed by the red algae formulation that exhibited median results (741.0 s), and the water had the least wetting capability (796.3 s).

Strong wetting ability allows liquid solutions to effectively penetrate porous materials such as soil resulting in stronger adhesion between the liquid and solid surface [10]. These results were supplemented by the SEM images in the next section.

B. Compaction of the Soil Samples

SEM images (Tables 2A and 2B) were utilized to validate the compaction of the dust particles to the samples after being exposed to different test solutions. The images clearly showed how the particles of the soil solidified and hardened as a whole, including dust. The whitish foreign objects that can be observed in the images are identified as dust particles due to their tiny and irregular appearances that are scattered around the surface of the soil sample. It is supported by a previous study stating that dust particles are smaller than 10 micrometers [11].

Table 2A. SEM Images (50 and 20 µm) of the corn straw and red algae bio-dust suppressants with distilled water as the control group.

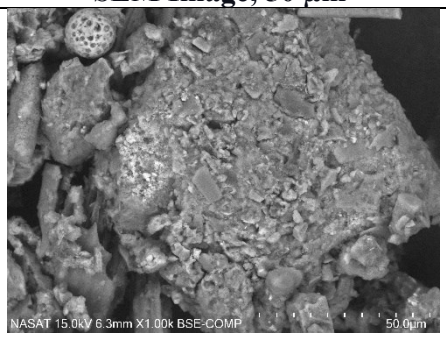
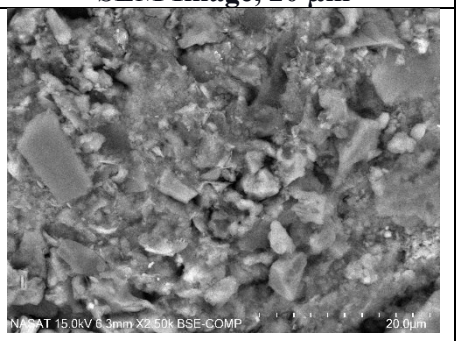
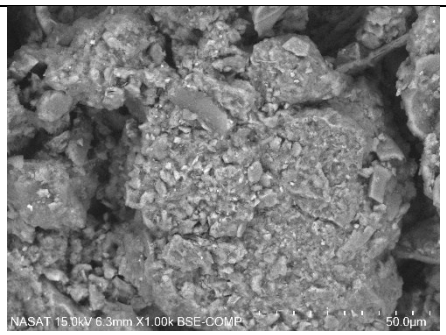
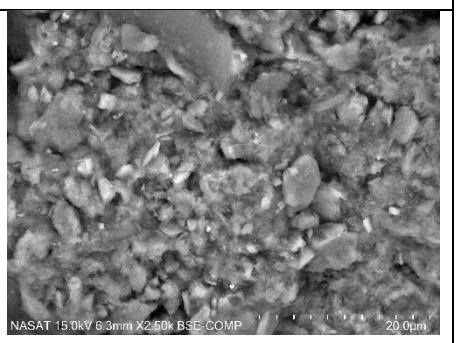
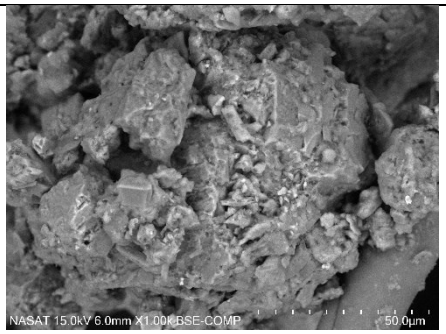
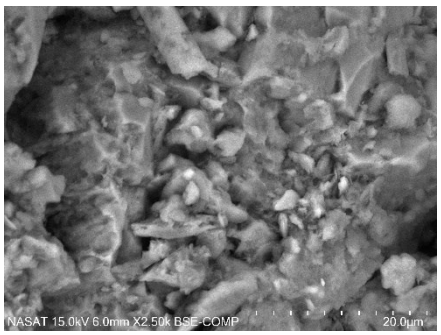
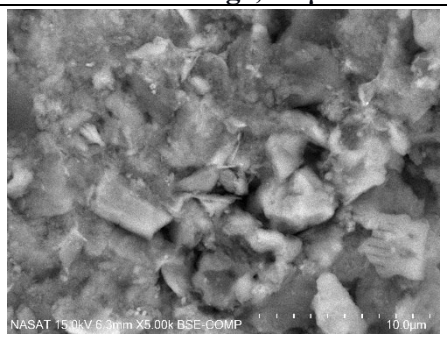
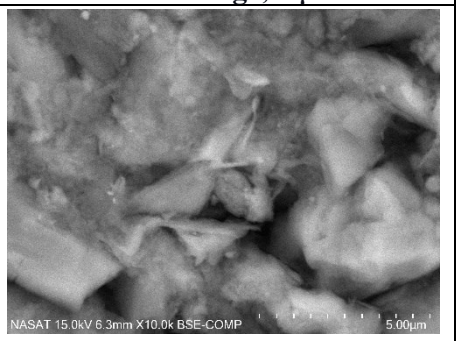
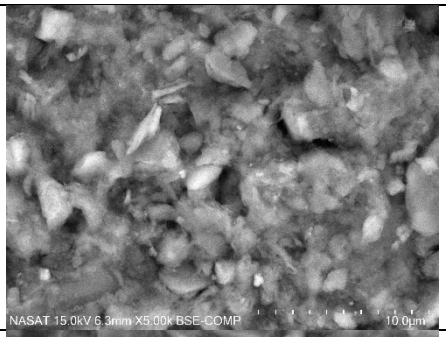
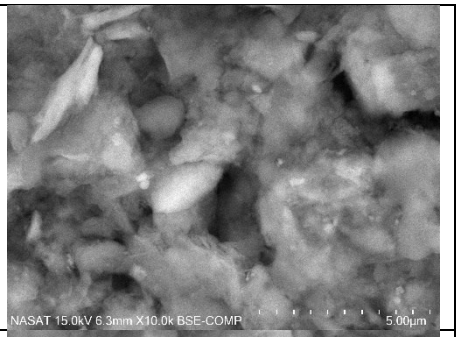
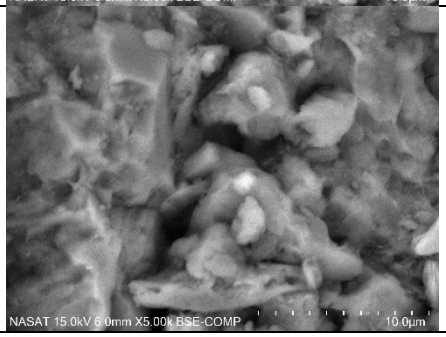
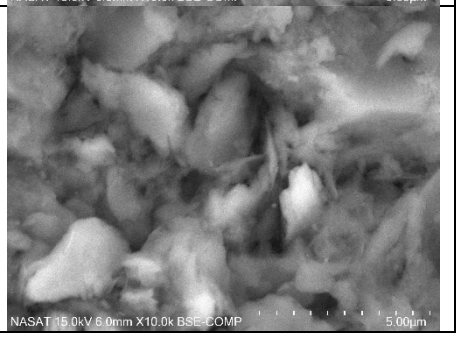
Test Solutions	SEM Image, 50 µm	SEM Image, 20 µm
Distilled water		
Corn straw		
Red algae		

Table 2B. SEM Images (10 and 5 µm) of the corn straw and red algae bio-dust suppressants with distilled water as the control group.

Test Solutions	SEM Image, 10 µm	SEM Image, 5 µm
Distilled water		

Corn straw		
Red algae		

For the SEM images involving water as the suppressant, it was observed that the particles of the soil are compact, and they bind with each other with several pore spaces in between (SEM, 5-10 µm). This can be attributed to the fact that enough water allows soil components to slide past each other and interlock closely together [12].

Similar remarks can be made from the SEM images involving corn straw as the test solution. Different particles embedded on its surface are notably connected and bind closely to one another, resulting in a solid surface. The images also revealed how each of the fine grains of particles, including dust, is packed together with smaller pore spaces compared to water (SEM, 5-10 µm). It is supported by a previous study in which applying corn straw cover can improve not just the fertility but the structure of the soil [13].

Lastly, for the test sample with red algae, its SEM images showed that it is closer to water than the corn straw in terms of its ability to compact dust into the soil as larger pore spaces can be seen (SEM, 5-10 µm). A previous study found out that inclusion of red algae fibers may lead to a decrease in the mechanical properties of the soil, possibly due to the voids created by the algae fibers inside the matrix leading to poor fiber or matrix adhesion [14].

Nonetheless, the initial results revealed that the corn straw-based bio-dust suppressant is the most effective formulation in taming and minimizing dust circulation in the atmosphere.

C. Evaporation of the Dust Suppressants

The mass of the loam soil before and after being subjected to heat (30°C – 34°C) under the sunlight for 5 hours (18,000 seconds) were recorded (Tables 3A to 3C) for the determination of the evaporation rate of the dust suppressants.

Table 3A. Evaporation rate of water as dust suppressant.

Trial	**Evaporation, Distilled Water (Control)**		
	Initial Mass, g	**Final Mass, g**	**Evaporation Rate, %**
Single	105.0	101.0	**0.555**

Table 3B. Evaporation rate of corn straw as dust suppressant.

Trial	Evaporation, Corn Straw		
	Initial Mass, g	**Final Mass, g**	**Evaporation Rate, %**
1	104.5	101.0	0.486
2	105.0	102.0	0.500
3	104.5	100.5	0.555
Average Evaporation Rate			**0.514**

Table 3C. Evaporation rate of red algae as dust suppressant.

Trial	Evaporation, Red Algae		
	Initial Mass, g	**Final Mass, g**	**Evaporation Rate, %**
1	105.2	103.0	0.306
2	105.1	103.0	0.292
3	105.1	103.5	0.222
Average Evaporation Rate			**0.273**

Tables 3A to 3C presented the measured and calculated data from the evaporation experiment involving samples treated with the three test solutions. Red algae-based solution yielded an evaporation rate of 0.273% meaning it has the longest time to achieve relative stability in evaporation [10]. A plausible explanation can stem from the ability of seaweed to absorb water and nutrients throughout their tissues, even after being removed from their natural habitat. They can continue to retain and absorb some water within their tissue for a certain period [15]. Meanwhile, as expected, water achieves evaporation stability the fastest with a rate of 0.555%, closely followed by the corn straw with 0.514%.

Upon comparison, it was noted that the average evaporation rate of the red algae bio-dust suppressant was substantially lower than that of the corn straw and water, making the evaporation stability of the red algae most favorable for real life applications. Nonetheless, the findings suggest that corn straw and red algae-based bio-dust suppressants exhibit sustainable dust control potential and are considered to have long-term effectiveness [16].

CONCLUSION AND RECOMMENDATIONS

The study successfully explored the potential of corn straw and red algae as main components of bio-dust suppressants focusing on their effectiveness in reducing dust-related issues in the atmosphere. Experiments focusing on sedimentation and compaction of the test samples as well as the evaporation of the dust suppressants were conducted.

The sedimentation and compaction results revealed that the corn straw-based bio-dust suppressant has superior efficacy in taming and minimizing dust circulation in the atmosphere. Meanwhile, it was noted that the evaporation rate of the red algae bio-dust suppressant was lower than that of the corn straw, making the evaporation stability of the red algae more favorable for real life applications. Nonetheless, the findings suggest that both formulations can be promising options for sustainable dust control.

Ultimately, for the further improvement of this study, it is recommended to explore other standardized methods to know more about the effectiveness and environmental hazards of the products. These tests include but are not limited to wind erosion rate, chemical toxicity, pH, and chemical corrosion [10]. It is also suggested to assess the formulated suppressants in varying concentrations to determine the most ideal concentration for dust suppression. Lastly, optimizing the properties of corn straw and red algae can also be explored to further their effectiveness in taming and minimizing dust circulation in the atmosphere.

APPENDIX



Figure A1. Preparation of the Bio-dust Suppressants.

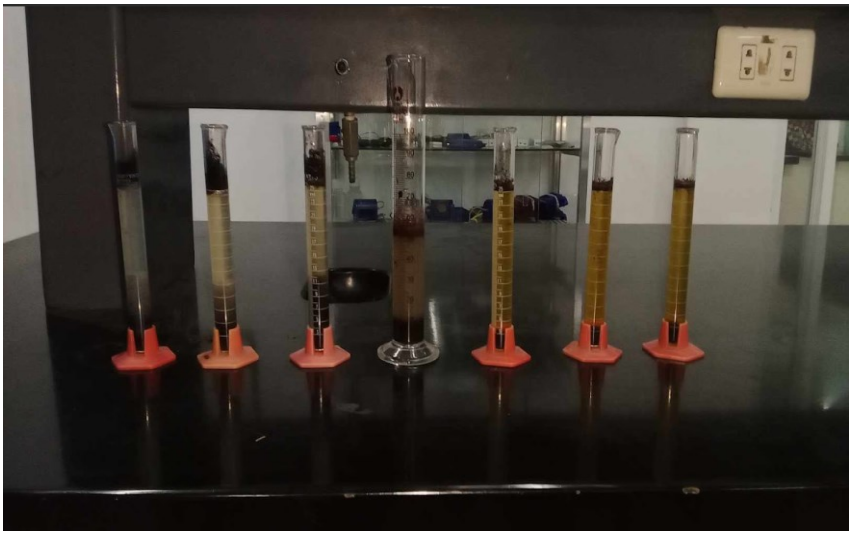


Figure A2. Set-up for the Test for Sedimentation.

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Scaling Electricity: Tilapia (*Oreochromis niloticus*) Scales as Piezoelectric Medium to Generate Energy

Chelsea Loreen H. Gaspar, Ashley Nicole I. Macaraig, Iesha Rhain G. Rodriguez, Quinn Lei C. San Pedro, Sophia Lorraine G. Venturina, Andre Jacques Tigno, Mary Grace D. Delos Santos, Aces Joseph L. San Pedro

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Submitted for Presentation and Publication
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Scaling Electricity: Tilapia (*Oreochromis niloticus*) Scales as Piezoelectric Medium to Generate Energy

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***Abstract* —** Tilapia (*Oreochromis niloticus*) is one of the most produced and consumed fish in the Philippines, thus posing a direct setback in yielding large quantities of organic wastes including its scales. The presence of Type I collagen allows this conventional waste to be repurposed into a material that produces energy through synthesis of piezoelectricity leading to the development of a bio-piezoelectric nanogenerator (BPNG) utilizing the mentioned scales as the primary material. Three variations of BPNG were assembled, each considering factors affecting the voltage emittance through observations, comparisons, and correlations. Prototypes 1, 2, and 3 exhibited average voltages of 1.3 mV, 0.1 mV, and 3.8 mV respectively, wherein 13.3 mV, 4.7 mV, and 99.8 mV were the maximum voltages garnered from constant mechanical stress. Based on voltage comparisons between Prototypes 1 and 2 per t-test, the structural complexity and materials used affected the amount of voltage that the BPNG produced ($p=0.0002$). Moreover, using Point-Biserial Correlation in Prototypes 2 and 3, there was a moderately strong relationship between the volume of fish scales and voltage emittance ($r_{pb}=0.4892$). Therefore, fish scales have an affecting factor to the BPNG's function and effectiveness as a source of electricity, which can contribute to alternative green energy production.

Keywords: fish scales, piezoelectricity, nanogenerators

INTRODUCTION

The aquaculture industry's standard classification of unwanted fish components such as scales—along with its skin, bones, fins, heads, and guts—are discarded through common disposal transport at seas. Although these are considered as organic wastes, it can still pose environmental harm over time. As of 2023, the Philippines' fisheries production registers 4.26 metric tons of output, making milkfish (*Chanos chanos*) with 8.3% and tilapia (*Oreochromis niloticus*) garnering 7.2% of the total volume the most produced fishes in the country [1]. Yielding large quantities of resources results in a vast number of wastes, accordingly, 27.4% of the average generated waste from the Philippines' local wet markets with a record of around 70.3 kg per day are occupied by fish scales [2].

Notably, tilapia (*O. niloticus*) scales contain hydroxyapatite and type I collagen that, apart from their importance in the cosmetics and biomedicine industry, can induce electrical charges in response to mechanical stresses known as piezoelectricity [3]. Specifically, collagens are

naturally occurring proteins that do not exhibit intrinsic electrical properties, but its piezoelectric effects can be [4]. This protein contains hydroxyl groups that are responsible for the formation of hydrogen bonds between collagen fibers and water molecules. Water's involvement changes the structure and mobility of the polypeptide chains, which leads to the formation of a triple helical structure that stabilizes the hydrogen bonding of hydroxyl and carbonyl groups. This in turn influences the electrical properties of proteins, inducing and improving collagen's conductivity and electric permittivity [5].

Meanwhile, the concept of piezoelectricity allows mechanical energy to be converted into electrical energy. Piezoelectricity works by external mechanical strain such as stretching, hitting, bending, or compression; the actual utilization of this contributes to the field of electronics and energy, healthcare, and agriculture, among others [6]. Moreover, nanotechnology with its connection to physical and electrical properties, demonstrates remarkable energy conversion efficiency and capability to generate power from natural sources such as human motions and environmental vibrations [7]. The capacity of nanogenerators to exhibit piezoelectric and triboelectric components results in the development of various applications across different fields that hold the promise of self-sufficient power solutions and innovations [8]. Tilapia fish scales that contain type I collagen are an ideal material to create a biodegradable and sustainable bio-piezoelectric nanogenerator (BPNG), thereby producing eco-friendly and bio-waste power sources [9].

As such, this study suggests the utilization of tilapia fish scales to power nanogenerators along with the aim to provide and further justify the sustainability of piezoelectric technology through contributing to the following: waste reduction, waste repurposing, and alternative green energy production, in line with *SDG 7: Affordable and Clean Energy*.

Taking everything into account, this study aimed to use tilapia (*O. niloticus*) scales as a piezoelectric material and to determine the amount of electricity that such a bio-piezoelectric nanogenerator can produce through prototypes with varying structures and features. Its effectiveness was also investigated by studying the factors affecting the voltage emittance of the tilapia scale device such as its structural complexity and volume or layer of the piezoelectric material. The study, which was conducted on the premises of Dr. Yanga's Colleges, Inc., Bocaue, Bulacan, was limited to a single fish species, making the results focused on descriptions and directions for improvement. Maximizing the full potential of tilapia scales to contrive a piezoelectric nanogenerator not only opens opportunities but also establishes a pathway to the development of natural self-sufficient power solutions and sustainable electrical resources, thus harnessing the potential of bio-waste products present in the environment.

METHODOLOGY

A. Fish Scale Treatment

The tilapia scales were initially subjected to a two-hour hydroxyapatite extraction using 0.1 to 0.5 M sodium hydroxide solution to eliminate unwanted components [10]. Then, a preservation treatment using 0.2 M to 4.0 M ethylenediaminetetraacetic acid (EDTA) solution was executed for four hours to ensure a longer product lifespan [11]. Lastly, the fish scales were immersed in a 0.1 to 0.5 M glacial acetic acid solution for ten minutes to achieve transparency and flexibility [12,13].

B. Bio-Piezoelectric Nanogenerator Set-Up

The study proposed three prototypes (Figure 1) to analyze the factors affecting the voltage emittance of the bio-piezoelectric nanogenerator.

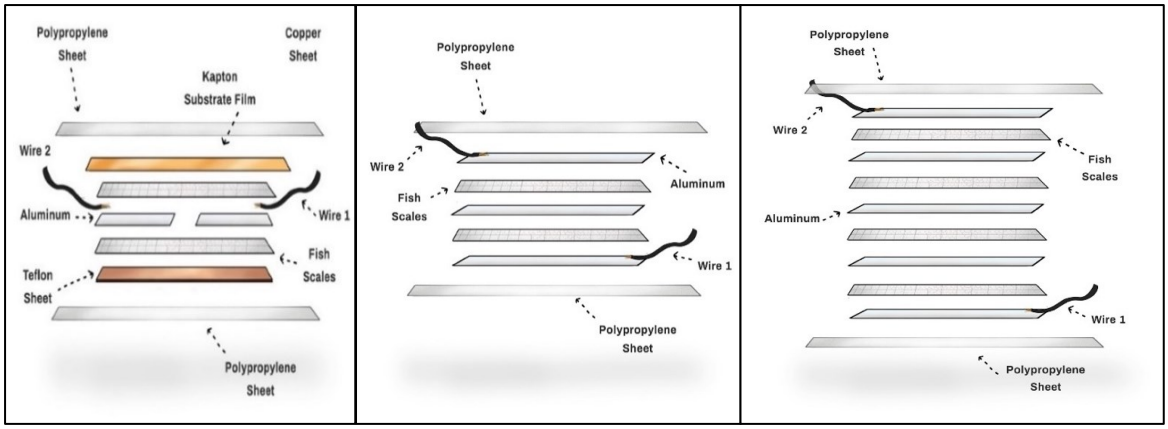


Figure 1. (Left to right) Schematic Drawing of the Layers in Prototypes 1, 2, and 3.

The proposed Prototype 1 was the merging of ideas of previous studies with their own set-ups as well as with the research of alternative materials that posed great effect with the concept of a BPNG set-up [14-16]. The treated fish scales (FS) were compressed into thin sheets to serve as the piezoelectric layer inside the BPNG set-up. The fish scales were trimmed into tile-like shapes for a tenacious and neat piezoelectric layer to unleash the full conductivity potential of it. Kapton substrate (KS) and polytetrafluoroethylene (PTFE, commonly known as Teflon sheets, TS) were used as layers insulating the dielectric layer inside. Subsequently, a pair of aluminum (Al) was inserted between two dielectric layers of fish scales. Two short wires with exposed conductor wires were added last before the prototype is sealed with a polypropylene sheet.

Both Prototypes 2 and 3 were aluminum-based prototypes adapted from a previous investigation [9]. Specifically, these two prototypes only differ with the magnitude of piezoelectric layers used in the set-up having two and four layers respectively. A similar process from Prototype 1 was implemented on these set-ups. The only difference was the tile-like trimmed fish scales were attached to the adhesive side of aluminum forming an alternating pattern of fish scale and aluminum layers.

C. Product Testing

The three BPNG set-ups were connected to a voltmeter to measure the average and maximum voltages produced. To activate the piezoelectric layer and generate piezoelectricity, an external mechanical stress was applied to the prototypes. The researchers directly assembled each prototype with a voltmeter along with a timer and usage of the tempo, 300 beats per minute (bpm) as a guide for the speed, producing a constant external mechanical stress by human hand. Then, the piezoelectricity generated by each BPNG prototype was recorded every second passed with a unit of mV.

RESULTS AND DISCUSSIONS

Figure 2 presents the voltages (mV) of the three prototypes generated when exposed to a constant external mechanical stress of 300 bpm. Oscillations in the graph were obtained from the detected positive and negative mV of the voltmeter, wherein the positive values represent the actual mV produced by the BPNG set-ups while the negative values represent the loss of mV experienced in between the intervals of hand lifting. The maximum and average voltages of the three prototypes were also obtained (Table 1).

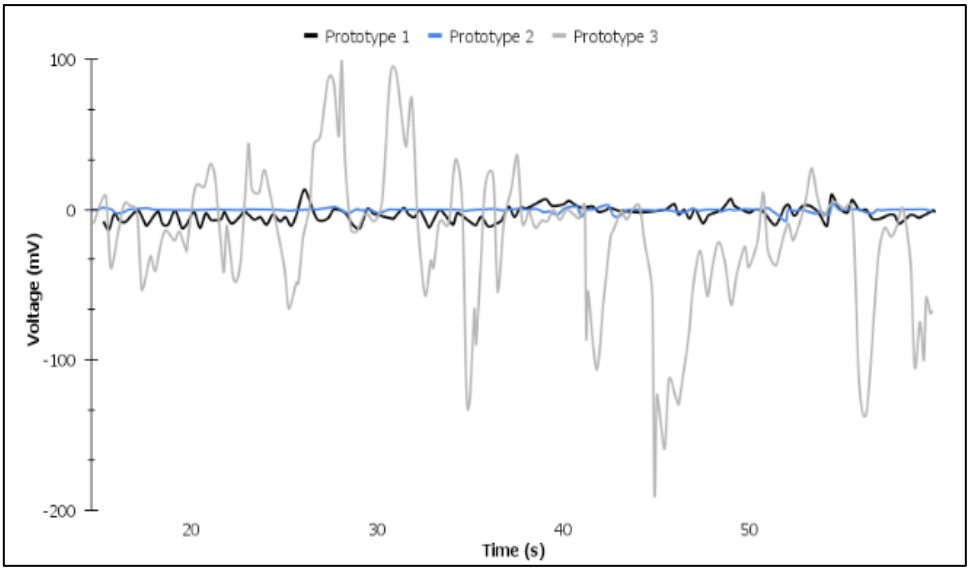


Figure 2. Line graph showing the voltages (mV) generated by the three prototypes per time (s).

Table 1. Average and maximum voltage emittance of the three prototypes.

Prototype	Specifications/Layers	Ave. Voltage (mV)	Max. Voltage (mV)
1	KS/**FS**/Al-Al/**FS**/TS	1.3	13.3
2	Al/**FS**/Al/**FS**/Al	0.1	4.7
3	Al/**FS**/Al/**FS**/Al/**FS**/Al/**FS**/Al	3.8	99.8

From Table 1, it was observed that the third prototype achieved the highest maximum voltage of 99.8 mV and achieved the highest average voltage of 3.8 mV. Through this information, the potential of each prototype can be compared with one another with regards to the magnitude of frequency generated, consistency, average and maximum voltage generated, and general impression of its efficiency and effectiveness.

A. Structural Complexity

Prototypes 1 and 2 with varying structural set-ups but with identical amounts of fish scale layers were compared to identify if the materials and assemblages affect the performance of the product. Prototype 1 exhibited greater oscillations than Prototype 2 as observed in Figure 2. These variables were further explained by the gap exhibited between the average voltages of the positive and negative charge values of each observation, to which the common values of Prototype 1 ranges from -1.7 mV to 1.3 mV, compared with Prototype 2 that varies from -0.1 mV to 0.1 mV, interpreting the difference in the samples' amplitudes.

The differences between the structural samples were further tested using statistical techniques to ensure validity of data. A t-test assuming unequal variances (Figure A1) establishes a significant difference ($p=0.0002$) between the variable of voltages. Thus, Prototype 2 presents lesser value than Prototype 1, making the specification of materials and complexity of the set-up an influence of the intensity of voltage emittance of the bio-piezoelectric device.

Prototype 1 included insulators of both Teflon sheet (PTFE) and Kapton substrate which have good dielectric strength [17]. The presence and proper installment of such insulating materials has a relation with charge distribution as they are responsible for controlling the direction of charge [18]. Therefore, the exposed conductors of Prototype 2 allow the charges to transfer with stressor or other external conductive objects through friction, reducing its produced

voltage on an intended area considering human palms were the medium used to provide the mechanical stress on the BPNG [19].

Furthermore, the Kapton substrate is an ideal material responsible for the prototype's flexibility, insulation, lightness, and corrosion resistance [20]. On the other hand, in the field of electronics, Teflon sheets can be paired with an active electrode material such as the fish scales layer in this present study; it can be a film that firmly supports conduction of electricity through the generated PTFE fibrils that can prevent stray current effects in a set-up [21]. In addition, aluminum was added to increase the current flow expected from the dielectric layers [22]. The whole set-up was sealed with a polypropylene sheet that served as an insulation cover and made the prototype water resistant. It was ensured that the plastic casing utilized did not significantly affect the generating capacity of the prototype as it must be subjected to an external mechanical stress [23].

The position of the aluminum—the highly conductive material of the product—where a pair is installed on the same layer in Prototype 1, along with an ensured distance from each other, contributed to the indication of the anodal and cathodal areas of the BPNG. Unlike Prototype 2, wherein larger chances of contact between the positive and negative electrodes result in a unified direction of charges which lessens the ability to flow accordingly.

B. Effect of Volume of Fish Scales (Type I Collagen) to Voltage Emittance

The Point-Biserial Correlation Analysis (Figure 3) revealed that the correlation between the volume of fish scales and voltage emittance in a BPNG set-up equated to the r_{pb} coefficient of 0.4892 (Figure 3; $p<0.05$). With the computed value in mind, the variables mentioned were interpreted to have a very strong correlation with one another. Therefore, there is a significant relationship on the volume of fish scales with the voltage emittance of the bio-piezoelectric nanogenerator.

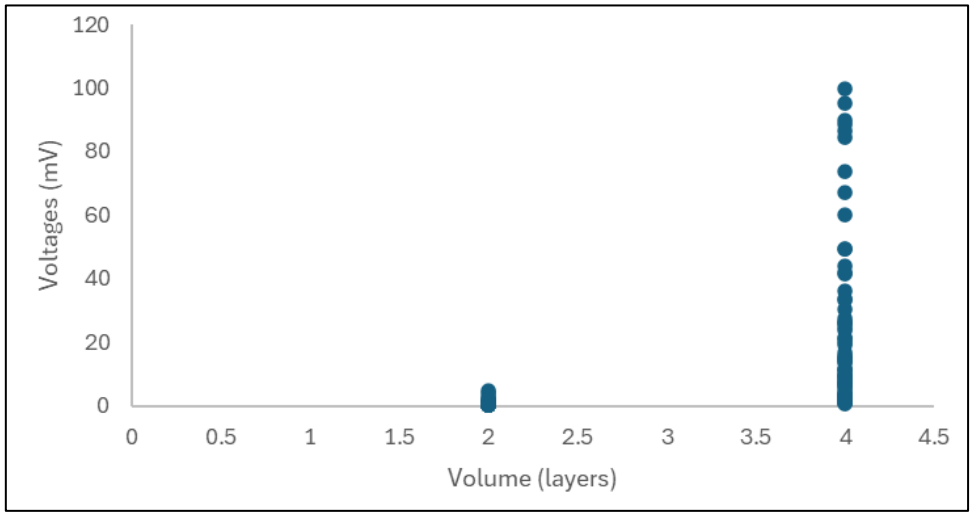


Figure 2. Point biserial scatter diagram showing the relationship between the fish scale volume (no. of fish scale layers; 2 or 4) and voltage (mV) (r_{pb}=0.4892; $p<0.05$).

An additional t-test of two samples assuming unequal variances (Figure A2) concluded that there is a significant difference ($p<0.0001$) between Prototypes 2 and 3 in terms of voltage yielded. This may provide an implication behind the relationship between the volume of fish scales and the said variable.

Further observations were considered, such as the average and maximum voltages generated by two similarly structured prototypes that differ in the magnitude, where four piezoelectric

layers were utilized successfully, generating an average of 3.8 mV and a maximum of 99.8 mV respectively. The researchers concluded that voltage emittance of a BPNG set-up is significantly affected by the amount of fish scales incorporated and the amount of type I collagen utilized in it. Beholding to the fact that there is 3.2% concentration of type I collagen in tilapia (*O. niloticus*) scales [24].

Tilapia (*O. niloticus*) scales are classified as ctenoid types of scales which are characterized to have small comb-like projections along their edges. These are frequently seen in most varieties of bony fish and exhibit comb-like, spiny posterior edges. Also, the external surface of the ctenoid scale offers protection to the fish while the inner layer gives flexibility because of its softness and aids movement of the fish [25]. Furthermore, it exhibited 40% to 55% of type I collagen, hydroxyapatite and calcium carbonate fat, lecithin, and scleroprotein, wherein 3.2% came from type I collagen [26]. The collagen extracted from tilapia scales consists of a combination of protein hydrolysate and collagen peptide. However, the extraction of collagen in tilapia scales which highly contributes to its piezoelectric properties is denoted by components and processes of extraction it undergoes. A study specifically noted that the type of fish, amount of collagen presented on its scale, type of scales, treatment, and amount (or layer) of fish scale applied all have a great contribution to the effectiveness of generating electrical charge [27]. With this, the proposed prototypes logically adhered to this as the set-up with more piezoelectric layers used yielded higher average and maximum voltages compared to others.

Taking another perspective of this matter, both Prototypes 2 and 3 utilized almost the same amount of piezoelectric and aluminum layers. The conductivity of aluminum was proved that it does not significantly dominate in the results shown in such field of study [9]. A previous investigation has designed their BPNG set-up similarly with the structure utilized in this study wherein aluminum and fish scales were layered alternately [9]. However, their Prototype 1 and Prototype 2 had both three layers of fish scales and differed with regards to the aluminum layers used, having two and four aluminum layers, respectively. The results showed that their Prototype 1 produced 30 mV while Prototype 2 yielded only 20 mV. Therefore, the amount of aluminum layers did not directly influence voltage emittance of a BPNG prototype. This proved that the results identified in the current study were influenced by tilapia (*O. niloticus*) scales that are dominant in type I collagen.

CONCLUSION AND RECOMMENDATIONS

The utilization of tilapia (*O. niloticus*) scales as a main component of a BPNG device in this study stemmed from the abundance of the said fish in the Philippines, its long decomposition period, and its sufficient type I collagen content. Three prototypes with varying structures and features were developed to determine the amount of electricity that can be produced and to investigate the factors affecting the voltage emittance of the tilapia scale BPNG such as structural complexity and fish scale volume. Prototypes 1 and 2 had the same volume of fish scale layers with varied structural complexity, while Prototypes 2 and 3 had the same structures but different fish scale layers.

Statistical analyses using t-test were employed and revealed significant differences. Prototype 1 with the more complex set-up was able to produce greater voltages than Prototype 2. As such, a BPNG composed of both dielectric and conductive layer provided better flow of charges. Besides, the volume or layer of piezoelectric material was also directly related to the amount of voltage, per correlation from Prototypes 2 and 3; the coefficient results to r_{pb}=0.4892, which indicated a moderate positive relationship.

Ultimately, for the further improvement of the study, it is recommended to test for the compatibility of other fish scales such as in milkfish (*Chanos chanos*) or other types of fishes as the collagen yield differs from one species to another [28]. Besides, utilization of other instruments to test the electric voltage such as an oscilloscope is advised to ensure accuracy and precision of the obtained results. Moreover, the concept of nanogenerators is very ideal to be employed as a detachable product with the innovations regarding wearable devices that are often used with body parts where motions and vibrations are situated [29]. Lastly, this study holds a higher potential of taking an environment-friendly approach by choosing wisely the materials to be used in designing prototypes that would ideally alleviate pollution and other on-going environmental crises to make relevant and significant impacts to our society.

APPENDIX

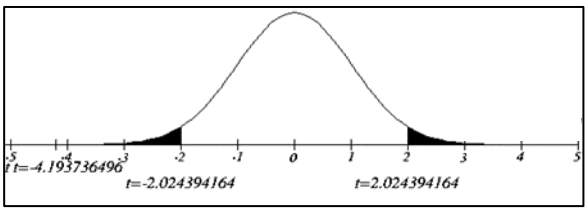


Figure A1. Prototype 1 & 2 Two-Tailed Normal Curve Diagram for t-test (t=4.19; p=0.0002).

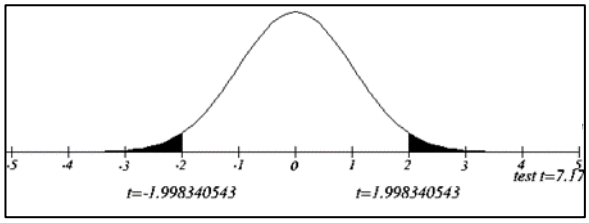


Figure A2. Prototype 2 & 3 Two-Tailed Normal Curve Diagram for t-test (t=7.17; p=1.12815x10^{-9}).

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Mathematics Without Borders: A Dive into Ethnomathematics of the Dumagat Tribe at Pinag-Anakan Integrated School

Jehl Christine E. De Castro, Mikaella F. Silvestre, Andrei Jeshawn M. Estrella, Xianelle Grace A. Subestia, Renedict B. De Leon

Institutional Excellence in Research Award

Accepted for Oral Presentation
7th International Conference on Asian and Philippine Studies
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Submitted for Publication
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Abstract — The field of ethnomathematics and its related practices are still fairly unknown in the Philippines, despite the presence of multiple tribes in the country. This stems from the isolation of Indigenous People (IP) from urbanized civilizations and a lack of awareness regarding ethnomathematics. These factors resulted in a low number of IPs receiving culturally relevant education that heavily affected their achievement in formal education. Thus, this paper discusses the ethnomathematics practices unique to the elementary students of the Dumagat Tribe and investigates its efficiency and effect on their mathematical performance by examining the impact of the connection between local context and mathematics. This is analyzed through a mixed-method approach by first conducting interviews before proceeding with the pre-test and post-test that aims to determine the significance of ethnomathematics' relationship towards the performance of students in mathematics. In accordance with this, the findings of the study were divided into qualitative and quantitative phases, wherein three themes that depicted the *Adaptability in Teaching Approach*, *Integration of Cultural Context in Teaching*, and *Utilization of Local Resources* were identified from the interviews that explained the fundamentals of Dumagat Tribe's ethnomathematics. On the other hand, the quantitative phase demonstrated a consistent trend across all grade levels with a large effect size and substantial improvement in the scores of elementary students which are supported by theories of ethnomodeling and social constructivism that identify the cruciality of integrating cultural backgrounds in education. The study determined that the common cultural practices that were applied in teaching are fishing and *pagyayantok*, while both the surroundings and everyday experiences of the elementary students aid them in the visualization of concepts in mathematics. Hence, ethnomathematics has been concluded to enhance the learning of elementary students from the Dumagat tribe and is beneficial towards their mathematical foundation and academic progress in school.

Keywords: Dumagat Tribe, Indigenous People, elementary students, ethnomathematics, culture, mathematics

INTRODUCTION

"If the shoe fits, then wear it" is a famous motto that encourages people to embrace something that suits them rather than rejecting it. This saying is similar to how mathematics is often perceived as a one-size-fits-all concept. However, what if, even though the shoe fits, the person wearing it is not familiar with how it works or does not feel comfortable with it? Is there a solution to this dilemma? For instance, in mathematics education, "mathematical classrooms

work on the assumption that students should receive the same mathematical context at the same time and in the same way" [1]. This assumption lacks inclusivity for individuals from various ethnic groups. Ethnic groups have unique ways of life, including their systems, culture, language, attire, and even the role of mathematics within their communities. Indigenous students often struggle when encountering mathematical problems with unfamiliar terms like trains, cars, or fast-food chains because these concepts are foreign to their experiences [1,2].

Ethnomathematics addresses this issue by preserving the cultural practices inherent in indigenous students to enhance their mathematical performance. It is a field that aims to give education according to the diverse cultural backgrounds of IPs by mathematizing the realities of their everyday life to create an educational curriculum that is culturally responsive [1]. This bridges the gap between traditional mathematics education and the unique needs of ethnically diverse students, enabling them to thrive academically while maintaining their cultural identities. The experiences of IPs are recognized as unique from those belonging to non-indigenous students which was introduced by Brazilian mathematician Ubiratan D'Ambrosio [2]. The institutionalizing of ethnomathematics in education is originally a movement that came from Western countries particularly Brazil, however, in the Philippines, the documentation of ethnomathematics that is being practiced by IPs that have been published in recent years has provided insight into the current standing of IPs education with regards to ethnomathematics [3,4]. Although, despite the progress of ethnomathematics in the country, there is still a lack of research on how this is being practiced in specific tribes such as the Dumagats, which is the focus of this study. The tribe incorporates ethnomathematics into their school curriculum, but its functioning and effectiveness have never been disclosed leading to a lack of understanding of how it is being practiced. Even so, the inclusion of ethnomathematics in the curriculum of Dumagats from Bulacan is evidence of progress in attaining a more culturally responsive education.

By adapting ethnomathematics into the educational curriculum of indigenous students, a positive impact can be provided due to cultural integration. It can be a tool to better understand the materials that are being taught based on previous research findings [5-7]. As such, this research focuses on understanding the effectiveness of using an inclusive way of teaching mathematics through the application of ethnomathematics in the learning process of the Dumagat tribe at Pinag-Anakan Elementary School in Doña Remedios Trinidad, Bulacan, Philippines. Additionally, through an evaluation of ethnomathematics' efficiency from the scores of the students, the researchers test how attributing a learner's culture contributes to their ability to better grasp the principles and concepts that are being taught in school, which is in line with *SDG 4: Quality Education.*

METHODOLOGY

This study was conducted at Pinag-anakan Integrated School located in Doña Remedios Trinidad, Bulacan, Philippines wherein the research participants in the qualitative phase of the study consisted of elementary math teachers from Pinag-anakan Integrated School. The inclusion criteria for the teachers involve having at least two years of teaching experience in elementary math subjects and the willingness to share insights about their experiences with ethnomathematics.

Meanwhile, the population of the study for the quantitative phase was the elementary students practicing ethnomathematics wherein the statistic is currently unknown, however, the sample size included the Dumagat elementary students from Grades 1 to 6 at Pinag-anakan Integrated School. The indigenous students who belong to these specified levels that practice ethnomathematics are still developing their mathematical foundation which makes them suited for the pre-test and post-test assessments.

A purposive sampling technique was employed to select both teachers and students based on specific criteria relevant to the study. This intentional selection aims to ensure a targeted and in-depth exploration of the impact of ethnomathematics interventions on individuals with unique characteristics. This technique seeks to strengthen the study's overall rigor and the reliability of the information gathered and the conclusions drawn from it. It can capture a wide range of viewpoints and experiences from both teachers and students.

The teachers' perspectives on the ethnomathematics practices within the Dumagat Tribe were explored through a validated interview questionnaire. On the other hand, an adopted 10-item pre-test and post-test that is aligned with the Department of Education Most Essential Learning Competencies (MELCs) and Indigenous Knowledge System and Practices (IKSP) were utilized for the research participants through activities developed by the teachers from Pinag-anakan Integrated School. The coverage of the tests taken by the students differ according to their curriculum wherein basic mathematical operations were answered by grades 1 to 3, while these lessons were applied by the grades 4 to 6 in solving fractions, decimals and percentages. The assessment was also validated to be culturally responsive by the elders of the tribe. This method aimed to measure the effectiveness of ethnomathematics interventions on students' mathematical understanding. The selection of questions was based on the teachers' familiarity with the curriculum, ensuring a seamless integration of their teaching practices and the reliability of the tests.

Afterward, the scores of each student were gathered by the researchers where the Wilcoxon Signed Rank test was applied to assess whether a significant difference exists in the data before and after treatment for the same group of individuals. This type of test was determined to be appropriate since there is no exact data regarding the number of students practicing ethnomathematics, which means that the study population still needs to be determined, making it impossible to define probability distribution. Furthermore**,** the assumptions of normality are tested through the Shapiro-Wilk Test to ensure that it satisfies the requirements of a Wilcoxon Signed Rank Test [8].

RESULTS AND DISCUSSION

This section of the study was divided into qualitative (A-C) and quantitative (D) parts. The qualitative phase addressed the relevant statements gathered from the interview that will be essential in the objectives of the study. In which, it was classified into three themes: (1) *Adaptability in Teaching Approach*, (2) *Integration of Cultural Context in Teaching*, and (3) *Utilization of Local Resources*.

A. Adaptability in Teaching Approach

The cluster of statements provided by the informants explained the impacts of level flexibility, material consultation, and learning progress toward ethnomathematics. This is reflected by the capability of teachers to adjust their teaching practices accordingly to address the specific needs of each student in their learning journey, as to wit:

> *"So 'yung mga pagtutuos, halimbawa 'yung mga kilo ng isda, kung ilan 'yung presyo, 'yun po ang gagawin nating example lalo sa mga problem solving.*"
> (In calculations, for example, the kilogram of fish and how much it costs, that is the kind of example that we will use especially in problem solving.)
> (Transcript 1, lines 13-14)

This method associates the local culture with mathematics and can lead students to accept and appreciate mathematics more [9]. Through this association, the Dumagat students can perceive problems in their own context.

The informants also cooperated with the elders of the tribe in ensuring that the students' education corresponded to the culture of the Dumagat. This ascertained that it only included elements that exist within their world that are being mathematically modeled. The supervision and approval of the materials that the teachers will use for the lectures and activities was also a protocol in the *Paaralang Mangyan na Angkop sa Kulturang Aalagaan*, a school for Mangyan students that also interviews the elders for validation [3].

> *"Siyempre sa paggawa namin ng lesson plan, especially sa classroom observation, kailangan bago kami mag demo, i-vavalidate muna 'yan ng elders sa community."*
>
> (In making a lesson plan, especially in classroom observation, before we conduct a demo, it would be validated by the elders of the community first.)
>
> (Transcript No. 2, lines 106-108)

> *"Halimbawa aso, asong nakababa 'yung tenga, so iva-validate nila 'yon, wala namang aso sa kanila na nakababa 'yung tenga so kailangan mong baguhin."*
>
> (For example, a dog, a dog with droopy ears, so they will validate that, and they do not have dogs with droopy ears, so you need to change that.)
>
> (Transcript No. 2, lines 109-111)

Material consultation allows the teachers to affirm the relatability and relevancy of the knowledge that will be taught to students. These two factors help ascertain that the students gained an initial understanding of the principles as it employed information they already know and can be a foundation in building their knowledge on the subject [10]. This is similar to how it is found that the understanding of the mathematical motives of the woven cloth used by the Mbojo tribe in Indonesia is instrumental in the learning process of the students. It also concluded that the teachers could avoid making the materials boring or difficult due to the meaning it creates for them [11].

Lastly, the engagement of the students to the ethnomathematics curriculum is ensured through learning progress monitoring that assures comprehension and mastery of subjects. The teachers track students' progress through assessments and evaluations, providing feedback and support where it was needed. In instances where the student struggles to meet learning objectives, remedial activities were implemented to help them better understand the material.

> *"Siyempre sa 'pag respond nila at siyempre doon sa ginagawa naming assessment. Kapag siyempre mataas, ibig sabihin nakuha nila 'yung tinuturo namin. And kapag ka naman, maraming nakaka-zero ibig sabihin kailangan namin ulitin 'yung tinuturo namin at mag-provide kami ng panibagong examples, panibagong assessments sa kanila."*
>
> (Of course, in their responses and in the assessments we are doing. When, of course, they get high scores, it means they understand what we are teaching. And on the other hand, when the majority get zero, it means we need to repeat what we are teaching and provide them with new examples or new assessments.)
>
> (Transcript No. 2, lines 96-101)

This type of strategy implemented by teachers was also advocated by a previous study as it leads to higher engagement and comprehension [12]. These practices collectively contributed to a holistic approach to contextualized learning, enhancing problem-solving skills and

promoting a deeper understanding of mathematical concepts among the Dumagat students. The continuous incorporation of these methods helped the educators in the tribe to create a conducive school setting that caters to the diverse needs and learning styles of the Dumagat students.

B. Integration of Cultural Context in Teaching

This highlighted the significance of cultural integration in education by discussing the contribution of culture and indigenization in increasing the performance of students in mathematics. According to the statements of the informants, students were shown to better grasp concepts and retain information in learning mathematics when it is culturally responsive. This emphasized the importance of forming connections between the lesson content and the tribe's daily life and environment.

> *"Hangga't maaari po kasi para mas madali nilang maintindihan 'yung math, kasi nga mahirap na subject siya, lahat ng mga examples kailangan nakarelate sa culture nila and [sa] mga ginagawa nila araw-araw."*
>
> (As much as possible, for them to easily understand math, as it is a difficult subject, examples must be related to their culture and what they do every day.)
>
> (Transcript No. 1, line 8-11)

> *"Guma[ga]wa pa kami ng mga examples, na kung saan mas maiintindihan nila kasi hindi nila masasagot yon lalo na't, halimbawa 'yung tren, hindi pa naman sila nakakakita ng tren, so hindi nila kayang sagutan 'yon. Di nila maiintidihan kaya gagawa po kami ng mga bago, wherein yung example, dun lang makikita sa kanila kung ano 'yung nasusubaybayan nila, kung ano 'yung nagagawa nila, 'yun po ang ilalagay namin."*
>
> (We create examples that they can better understand because they will not be able to answer otherwise. Especially, for example, trains. They have not seen that yet, so they will not be able to answer that. They will not understand it, so we will create new ones, wherein the examples are based on what they can observe and what they do, that is what we will include.)
>
> (Transcript No. 1, lines 58-64)

> *"Halimbawa po sa hanapbuhay po nila, nandiyan po yung pangingisda, pagyayantok, paggiginto then 'yung pag-travel nila kailangan yung mga distance, kasi [ang] transportation nila [ay] bangka po, puwede po nating gamitin 'yun."*
>
> (For example, in their livelihood, they do fishing, *pagyayantok, paggiginto* then in traveling, they need the distance since their mode of transportation is boat, we can use these things.)
>
> (Transcript No. 1, lines 65-69)

These teaching scenarios for Dumagat students strengthened the idea of ethnomathematics as a pedagogical tool in learning the subject through cultural rationality. It argued that the cultural contexts embedded within mathematics should not be isolated, as it is instrumental in the schooling process of a student [13]. For instance, pagyayantok (Figure A1) is a technique used to solve a math activity involving adding two one-digit numbers with sums up to 18. This involves the use of small sticks from tree branches to visualize numbers effectively and is one of the common ethnomathematical practices as it leads to improved speed and accuracy in adding and counting.

In addition, the researchers have also analyzed the importance of curriculum indigenization in teaching methodologies as a way to assimilate the cultural background of the students in order to improve their math-related skills.

> "*Ina-align lang namin 'yung competency, tapos gagawa kami ng sa community competency, tapos i-indigenize namin siya, tapos i-aalign namin siya sa IKSP, which is 'yung Indigenous Knowledge System and Practices na kailangan na ito yung competency 'yung sa DepEd nga, 'yung sa mainstream."*
>
> (We just align the competency, then we create a community competency, and then we indigenize it, after that we align it with the IKSP, which is the Indigenous Knowledge System and Practices that is necessary to be in agreement to DepEd's competency that is in the mainstream.)
>
> (Transcript No. 2, lines 115-119)

> *"Kapag gumawa ka ng indigenize lesson plan, iyon na 'yong parang mag fo-focus ka sa IKSP. For example, nasa gantong month sila, 'yung period na 'yon ay 'yung sa [pagsa]saka, 'yung sa pagtatanim. Kaya kailangan i-aalign mo 'yung pagtatanim."*
>
> (If you are creating an indigenize lesson plan, you are focusing on the IKSP. For example, they are in this month and that period is farming or planting. You need to align that to your lessons.)
>
> (Transcript No. 2, lines 124-127)

By incorporating culturally responsive content, examples, and instructional materials into their lessons, educators can make learning more meaningful and accessible to students. Culturally appropriate pedagogy must be incorporated into the current mathematics' curriculum, since it indicated that educators contextualize students' understanding of mathematics by connecting it to their real-life experiences [14]. In particular, the consideration of ethnomathematics teachers regarding the yearly activities of the Dumagat tribe such as designing lesson plans in accordance with their farming season plans is similar to what has been observed from Gohang National High School in Ifugao which considers the agricultural cycle when it comes to planning the school calendar [3].

C. Utilization of Local Resources

This recognized the value of leveraging the unique cultural, natural, and human resources available within the local scene to further enhance educational experiences and outcomes of the indigenous students. Teachers sourced their materials by using specific things that can only be accessed by the tribe in their community instead of the standardized modules from DepEd with foreign examples. This is because the teaching materials utilized for Dumagat students should already be a part of their everyday lives. This implied that the students learn better when the examples used are something that they can envision.

> *"Meron naman pong provided 'yung DepEd na mga materials, 'yung para sa mga halimbawa, mga counters, 'yung mga para sa place value, pero mas maganda kasi kung ang gagamitin ay 'yung nandoon lang."*
>
> (There are materials provided by DepEd like counters for place value, but it is better if we use materials that are readily available there.)
>
> (Transcript No. 1, lines 26-29)

> *"Pag gagamitin natin 'yung pang national talaga, halimbawa 'yung sa mga modules, di ba po nung nakaraan naging modular dahil sa pandemic so hindi applicable 'yun sa mga Dumagat kasi hindi naman nila alam 'yung mga examples na nilagay doon. So, nag-formulate kami ng ibang modules."*

(If we will be utilizing the ones for national use, the modules as an example, since last time, it became modular due to the pandemic; it will not be applicable to the Dumagats since they do not know the examples listed in there, so we formulated other modules.)

(Transcript No. 1, lines 54-58)

"Gumagamit kami ng mga instruments like 'yung mga makikita namin dun sa community, 'yun lang 'yung ginagamit namin."

(We use instruments like the ones we see in the community, those are the only ones that we use.)

(Transcript No. 2, lines 89-90)

Students gained a better comprehension of what was being taught as it was directly tied to their daily communal activities [11]. This method allowed the Dumagats to form a stronger connection to their identities thereby making it easier to understand mathematics from their own point of view. Moreover, aside from accessibility, the materials were also described to be utilized in the context of using local resources in education which were readily available in the environment where the Dumagats learn.

"Then sa mga counters 'yung sanga-sanga lang mga ganon, tas gagawa lang ng mga yantok puputulin lang, puwede na rin siyang counters. Tapos 'yung mga, may tinatawag po sila doon na kudlasan, parang maliliit siyang buto, puwede din siya gawing instructional materials lalo sa mga lower grade."

(For the counters, we can simply use branches, then utilize *yantok* and cut them into pieces, which can serve as counters. They also have things called *kudlasan* which look like small seeds that can be utilized as instructional materials, especially for lower grades.)

(Transcript No. 1, lines 69-74)

"For example, 'yung mga prutas, 'yung mga kahoy, 'yung bato. Iyan lang [ang] ginagamit naming, mga sticks, yantok."

(For example, the fruits, the trees, the rocks. Those are the only things that we use, such as sticks, and *yantok*.)

(Transcript No. 2, lines 91-92)

The utilization of counting and measuring materials unique to the needs of the tribe such as *kudlasan* (Figure A2) and *bakuyo* (Figure A3) reinforces their ability to process lessons in mathematics. It is also evident in a study that the students who received instruction through ethnomathematics showed more effective outcomes than the students who were taught using the conventional manner [15]. Therefore, the utilization of local resources is not a hindrance to learning; rather, it is a way of transforming everything into a source of learning for the Dumagat students.

D. Mathematical Performance of Dumagat Elementary Students

The quantitative phase analyzed the relationship of the statistical scores of Dumagat students to their mathematical performance and its implications for the study's hypotheses. The Shapiro-Wilk test was done before conducting the statistical analysis and treatment to check the assumption of normality between two-paired samples, where the low value of p proved that it was violated, $W=0.915$, $p<0.001$ and satisfies the requirement for a Wilcoxon Signed Rank test.

Table 1. Effectivity of ethnomathematics in Dumagat elementary students.

			Statistic	p		Effect Size
POST-TEST	PRE-TEST	Wilcoxon W	1653	<.001	Rank biserial correlation	1.00

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} \neq 0$

Normality Test (Shapiro-Wilk)

			W	p
POST-TEST	-	PRE-TEST	0.915	<.001

Note. A low p-value suggests a violation of the assumption of normality

Descriptives

	N	Mean	Median	SD	SE
POST-TEST	57	7.30	7	0.925	0.123
PRE-TEST	57	3.25	3	0.969	0.128

From Table 1, the results of the Wilcoxon signed rank test conducted on Dumagat elementary students indicated a statistically significant difference in the median (Md) of the student's performance in mathematics before (Md = 3) and after (Md = 7) the implementation of the treatment, with W=1653 and p<0.001. Furthermore, a large effect size is observed for this statistical analysis (r=1.00). These findings suggested that ethnomathematics exerts a substantial impact on the mathematics performance of Dumagat elementary students. Specifically, integrating Dumagat cultural elements, language, and practices enhanced the students' mathematics proficiency.

The overall results of the study (Figure 1) showed significant improvement per grade level that displayed the level of effectiveness of using cultural experiences to foster a sense of relativity and familiarity with each lesson. It showed how ethnomathematics played a consistent pivotal role in enhancing students' comprehension of mathematical concepts, as proven by their performance that were within the expectations of the study. This is also in accordance with the findings in Zimbabwe students that were taught using the ethnomathematics approach which resulted in a higher achievement in contrast to those who received the traditional teaching in consumer arithmetic, a branch of mathematics [16]. Additionally, other studies also reported similar findings [5, 17].

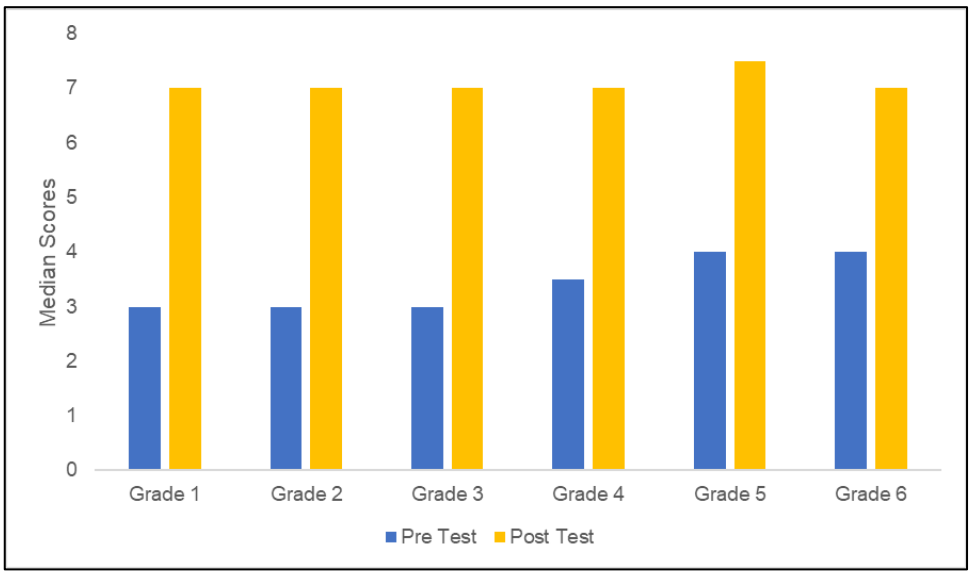


Figure 1. Median Scores of Dumagat Elementary Students.

There was a clear trend where the median score after treatment surpassed the before treatment across all grade levels as seen in Figure 1. This trend supported the idea that integrating ethnomathematics improved students' math performance across various topics at each grade level. Additionally, the figure included a visual representation of linear regression analysis, illustrating the correlation between median scores of each grade level separately for both the pre-test and post-test conditions.

In summary, the statistical analysis confirmed the significant role of ethnomathematics in enhancing the performance of Dumagat elementary students, with a concrete effect size ($r = 1.00$) observed across all grade levels. Thus, the researchers accepted the alternative hypothesis of the study, indicating that ethnomathematics has a significant effect on the mathematics performance of Dumagat elementary students. It serves as a strong foundation for their mathematical skills and a solution for the dilemmas that the indigenous students are experiencing, while promoting inclusive learning at the same time. With that said, ethnomathematics acted not just as a shoe that fits the Dumagat elementary students but also as a shoe that provides comfort, aiding them in navigating the world of mathematics comfortably.

CONCLUSIONS AND RECOMMENDATIONS

The promotion of understanding inclusivity within the context of education, specifically in mathematics highlights the elements that surround indigenous communities as key factors in their education. Nature, cultural traditions, and everyday lifestyle are essential in the Dumagat tribe's visualization of mathematical concepts. It serves as a link between reality and the mathematical world of the IPs which creates a stronger connection and relationship between their experience and the subject matter.

The realities of IPs are merged with lessons in mathematics which is seen in their uses of fishing and *pagyayantok* as prime examples in most of their practical tests and classroom discussions. Teachers take into consideration what the IPs already know as their foundation to build knowledge on to develop ethnomathematical practices that are unique to their tribe. Subsequently, the effects of this learning approach were directly observed in the mathematical performance of Dumagat elementary students with substantial increase in their median score from the pre- and post-test assessments.

In line with these, for the further improvement of the study, a firsthand experience of the daily life of the Dumagat students is recommended to facilitate a more efficient study process and to gather data with a higher level of authenticity. Indigenous students should also take an active role in associating the teachings they receive to their own experiences, as mathematics is not a subject with a singular context but has multiple facets, especially in classroom settings. Moreover, indigenizing the methods and materials used in teaching is vital to accommodate every student, especially the IPs. Lastly, researching the Dumagat tribes from other geographical locations will be instrumental in creating a more inclusive education as they may also have a different version of ethnomathematics. These actions can significantly contribute to fostering greater awareness regarding the needs of IPs to improve the quality of education in the country.

APPENDIX



Figure A1. *Pagyayantok*



Figure A2. *Kudlasan*



Figure A3. *Bakuyo*.



Figure A4. Boat Oars.

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S.A.G.I.P. (Smart Automated Gadget for Instant Protection) Initiative: An Enhanced Emergency Response System

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***Abstract* —** Innovation has advanced to an extent where internet-connected devices and systems are being integrated into emergency management and response, resulting in enhanced public safety by addressing the shortcomings of the traditional emergency response system. The S.A.G.I.P. (Smart Automated Gadget for Instant Protection) Initiative aims to improve emergency response effectiveness and speed, particularly in remote locations and areas with frequent events, thereby enhancing public safety and security. To evaluate the efficacy of the S.A.G.I.P. Initiative prototype, frontline emergency responders such as firefighters, police officers, and medical professionals were invited to assess the product. The acquired data was then subjected to descriptive and inferential statistical analysis. The results showed an average weighted mean of 4.778 and a standard deviation of 0.54, indicating significant potential for the S.A.G.I.P. Initiative. Furthermore, the comparison of the overall efficacy of the SAGIP Initiative and the Traditional Emergency Response System revealed that the two approaches differ significantly ($p=0.0222$). This implies that the S.A.G.I.P. Initiative surpasses traditional emergency call services regarding communication and information dissemination, adaptability and flexibility, scalability, features and accessibility, and reactive optimization. The findings demonstrate that modern technology can improve frontline practitioners' emergency response capacity, reducing delays and optimizing resource utilization.

Keywords: S.A.G.I.P. Initiative, emergency response system, delayed reports

INTRODUCTION

Accidents and crimes are common occurrences; they are dynamic social phenomena that vary in quantity and quality over time. The alarming rise in global crime rates in recent years has underscored the need for a thorough investigation into the root causes and the development of practical solutions to address this escalating threat [1]. In addition to disrupting a community's social cohesion, crime and accidents endanger public safety, economic development, and people's overall well-being. A study shows that in 2023, over 30 thousand crime incidents were recorded in the Philippines alone [2]. The major crimes in the Philippines are namely murder, homicide, physical injury, car theft, robbery, theft, and rape [3]. This rising crime rate should serve as a call to action for authorities worldwide to act promptly.

Given the increasing incidence of crime and accidents, it is crucial to enhance the emergency response system, as such events are often beyond avoidance [4]. Integrating technology has a significant impact on safety because of its rapid advancement. The Internet of Things (IoT) raises society's standard of living, making real-time information possible in many spheres of life. Technology offers creative ways to protect people and lessen the possibility of accidents and harm [5]. Ensuring safety requires resolving problems with the emergency response system. Prompt intervention, close surveillance, and casualty management are necessary to

save lives and protect property. Furthermore, people's perceptions of safety and environmental factors determine whether they are comfortable or uncomfortable in a particular situation [6].

Changes in the population, whether in an urban or rural area, can also have a significant impact on the rate of crime rising. A study conducted in 2023 examined the police response in Zamboanga City and highlighted the critical importance of maintaining a short response time [7]. However, this finding contrasts with the current challenges faced by the country, where the location of an incident significantly impacts response time, particularly in rural areas with limited or no access to technology. Population trends, including the number and composition of the population, inevitably influence the quantity of crime reported [8].

Furthermore, safety is vital in every aspect of life. People make enormous efforts to protect and ensure their safety. As a result, this endeavor strives to provide safety with the use of technology. Improving the emergency response system is significant for initiating an immediate effort to save a life. S.A.G.I.P. (Smart Automated Gadget for Instant Protection) Initiative aims to help mitigate the problem with the emergency response that the country is currently facing. The introduction of push buttons strategically placed in public areas that, when activated, will automatically initiate a call to the nearest police station, hospital, or fire department depending on the user's selection and their current location, facilitated by an integral GPS (Global Positioning System) tracker.

The initiative targets the critical issue of delayed reporting of crimes and accidents in high-incidence areas far from emergency services, aiming to drastically improve public safety and security through faster, more efficient emergency response. By fortifying local emergency response systems, this endeavor not only significantly enhances public safety but also contributes to the broader development goal of making cities and human settlements inclusive, safe, resilient, and sustainable, in line with *SGD 11: Sustainable Cities and Communities*.

METHODOLOGY

A. Flowchart Diagram of the Proposed Product

The diagram (Figure 1) provides the detailed process of integrating the GSM (Global System for Mobile communication) module and various components with the Arduino UNO Board, which involves meticulous connections through jumper wires and a breadboard.



Figure 1. Mechanism Flow Chart Diagram.

The camera, microphone, and speaker activate seamlessly after powering up the system. The camera initiates its automatic functionality by promptly streaming live-feed video through the application when connected to Wi-Fi. Meanwhile, the other components remain on standby mode until interaction with one of the three designated buttons. The three buttons serve distinct emergency purposes: button 1 initiates a call to the police station, button 2 connects to the hospital station, and button 3 dials the fire station.

Pressing any of these buttons triggers an automatic call initiation to the corresponding emergency unit, and the GPS Module sends the data for the automatic sending of SMS location. Following initiation, the LCD shows the transmitted data status of the call. The system remains on call until the user decides to end the call. Subsequently, the system returns to standby mode, awaiting the next button press to repeat the entire process.

B. Circuit Diagram of the Proposed Product

The diagram (Figure 2) displays the circuitry required to connect the GSM module to an Arduino. The 16x2 LCD pins RS, EN, D4, D5, D6, and D7 must be connected meticulously to Arduino pins 14, 15, 16, 17, 18, and 19, respectively. A precise connection was essential to ensure the LCD works correctly.

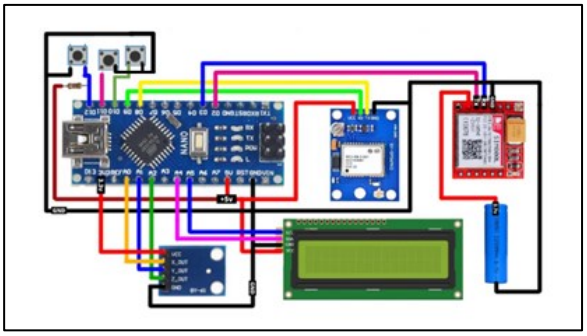


Figure 2. S.A.G.I.P. Initiative's Circuit Diagram.

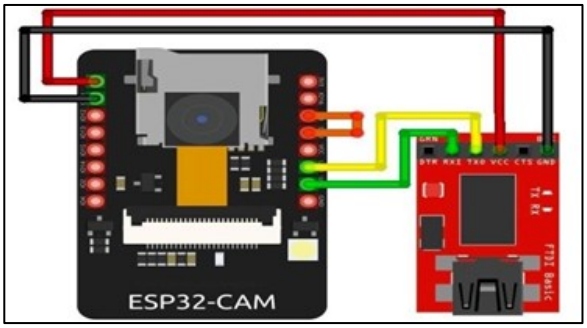


Figure 3. Circuit Diagram from Circuit Digest [9].

The circuit diagram in Figure 3 showed that the GSM Module's RX (receive) and TX (transmit) pins were directly connected to Arduino pins D3 and D2, respectively. It was crucial to note that the ground terminals of both the Arduino and the GSM module must be linked together to create a common ground. This guaranteed effective communication and a stable electrical reference between the two components. Furthermore, to establish communication between the GPS module and the Arduino Nano, connections were made for the TX pin of the GPS module to digital pin D8 of the Arduino Nano, and the RX pin of the GPS module to digital pin D9 of the Arduino Nano. Also, the VCC (power supply) and GND (Ground) pins of the GPS module were attached to the appropriate power and ground pins on the Arduino Nano.

The circuit also included tactile buttons connected to Arduino pins 4, 7, and 8. These buttons were crucial in the user interface, enabling interaction and control over the system. The

microphone (MIC) was connected directly to the mic+ and mic- terminals of the GSM module, while the speaker (SP) was linked to the SP+ and SP- pins on the GSM module. These connections were vital for seamless audio input and output functionalities, ensuring effective communication during emergency calls.

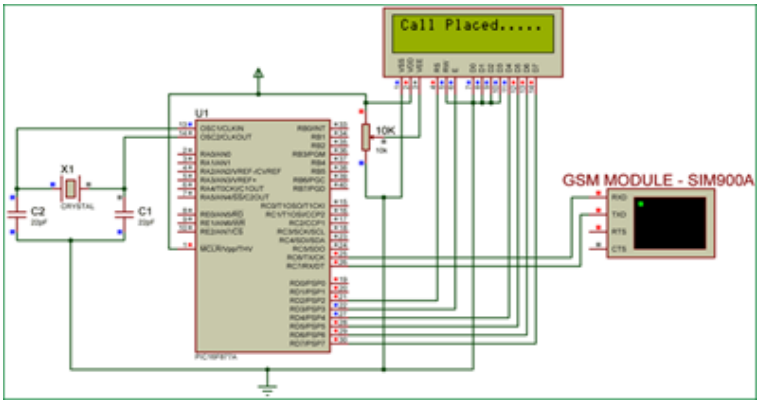


Figure 4. Live Feed Circuit Diagram.

For the circuit diagram of the live feed camera (Figure 4), the first step involved the VCC Power Supply Connection, where the VCC pin of the ESP32 CAM module (camera) was carefully interconnected with the 5V pin of the FTDI (USB to serial adapter). This meticulous connection guaranteed a stable and sufficient power source for the ESP32 CAM, thereby enabling its optimal performance.

The Ground Reference Connection was the subsequent essential step, forging a robust ground connection by linking the GND pin of the ESP32 CAM to the corresponding GND pin of the FTDI. This pivotal action created a common ground reference point, fostering stability in the electrical environment and promoting effective communication between the interconnected components.

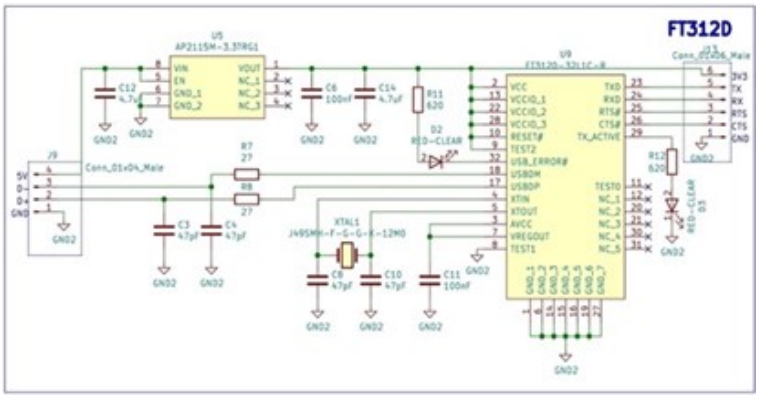


Figure 5. Circuit Diagram from Circuit Digest [9].

The Serial Communication Pins (RX and TX) were then addressed to facilitate bidirectional data transfer (Figure 5). This involved connecting the RX pin of the ESP32 CAM to the TX pin of the FTDI. Simultaneously, a connection was established from the TX pin of the ESP32 CAM to the RX pin of the FTDI. These connections were vital in ensuring seamless serial communication between the ESP32 CAM module and the FTDI adapter.

The Programming Mode Activation (GPIO0) was implemented by establishing a direct connection from the GPIO0 pin of the ESP32 CAM to the GND. This specific configuration ensured that the ESP32 CAM entered programming mode, a crucial step that facilitated the effortless uploading of code and supported efficient software development.

C. Features and Prototype of the S.A.G.I.P. Initiative



Figure 6. S.A.G.I.P. Initiative Prototype.

The researchers then developed a prototype (Figure 6) that was of similar size to pedestrian buttons, measuring 120 x 270 x 84 mm. This size has been chosen because it is suitable for placement in pedestrian areas, which are known to be accident-prone zones. The prototype was equipped with a camera, microphone, speaker, and three tact buttons. The buttons were color-coded, with each one assigned to a separate emergency unit for calling. They also have a graphic design to prevent confusion and help users quickly understand what each button was for. The blue button with the cop icon was intended for contacting the nearest police station for law enforcement assistance, the green button with the hospital icon connected the user to nearby hospitals for urgent medical attention, and the red button with the fire icon facilitated instant communication with fire stations in case of fire emergencies.

Moreover, the S.A.G.I.P. Initiative was planned to position 200-300 meters from every pedestrian post. This proximity was meant to expand the possibilities to enhance people's safety by incorporating localization and suitability to improve accessibility in everyday life [10].

To ensure the product's weather resistance, researchers have opted for an electrical box made of outdoor stainless steel IP65 waterproof distribution box as the body of their prototype. This enclosure has a hinged construction and measures 25 x 30 x 15 cm. The material protected vital electrical equipment from the elements, and choosing the appropriate weatherproof box will assist in maintaining the electrical system operational in all-weather circumstances.

Ultimately, the design of the prototype was compact, as it will be installed on pedestrian posts and other locations with high incidents of emergencies and crimes. The researchers have ensured that the materials used are cost-effective yet highly durable, making the initiative feasible and sustainable.

D. Prototype Testing

The S.A.G.I.P. Initiative was then subjected to rigorous field trials to evaluate its functionality and performance in real-world scenarios. During these trials, researchers utilized a 5-point Likert Scale to systematically assess various factors such as communication facilitation, dispatcher response times, adaptability to dynamic situations, and scalability across diverse environments. Quantitative data from the Likert Scale was complemented by qualitative insights gathered through semi-structured interviews with frontline practitioners, including police officers, firefighters, and hospital staff. This comprehensive evaluation, supported by both descriptive and inferential statistical analyses, provided a robust assessment of the S.A.G.I.P. Initiative's efficacy in enhancing emergency incident reporting compared to traditional emergency call services.

RESULTS AND DISCUSSIONS

A. Quantitative Assessments of the S.A.G.I.P. Initiative and the Traditional Emergency Response.

The effectiveness of the S.A.G.I.P. Initiative was evaluated using weighted mean and standard deviation. Weighted mean considers varying weights assigned to different data points, providing a nuanced understanding of experts' assessments of the initiative's effectiveness [11]. In contrast, standard deviation measures the dispersion of scores around their mean, indicating the typical distance of each score from the average [12,13].

This study employed descriptive statistics to compare the modern emergency response system with traditional emergency call services and to assess experts' evaluations using a 5-point Likert scale [14]. Additionally, the study utilized a two-sample t-test to directly examine potential differences between these systems, aiming to enhance the accuracy of its findings. This statistical approach objectively measures opinions, attitudes, or behaviors, thereby offering valuable insights into the effectiveness of the emergency response systems being evaluated [15]. Furthermore, inferential statistics enabled the researchers to draw conclusions and make predictions about the broader population based on the sample data collected [16].

Experts in various fields used a 5-point Likert scale to evaluate the program's overall effectiveness, focusing on six key factors: *Communication and Information Dissemination*, assessing the clarity and transparency of information exchange; *Response Rate*, evaluating the speed and efficiency of responses from the dispatchers; *Adaptability and Flexibility*, examining the prototype's ability to adjust to evolving situations and unforeseen challenges; *Scalability*, considering the ease of deployment and utilization in diverse environments; *Features and Accessibility*, analyzing the overall design, user-friendliness, and convenience; and *Reactive Optimization*, measuring the prototype's capacity to be as ideal, functional, or efficient.

The satisfaction levels of the experts (n=6) with the different aspects of the S.A.G.I.P. Initiative program were obtained and compared with the traditional emergency response using weighted mean (Table 1) and standard deviation (Table 2) analyses.

Table 1. Effectiveness of the S.A.G.I.P. Initiative against the Traditional Emergency Response (Weighted Mean, n=6).

Factors	S.A.G.I.P. Initiative	Traditional Response	Verbal Interpretation for the SAGIP Initiative*
Communication and Information Dissemination	4.667	3.667	Outstanding Functional
Response Rate	4.667	4.167	Outstanding Functional
Adaptability and Flexibility	4.833	3.833	Outstanding Functional
Scalability	4.833	3.500	Outstanding Functional
Features and Accessibility	4.833	3.833	Outstanding Functional
Reactive Optimization	4.833	3.833	Outstanding Functional
Weighted Mean of the Six Factors	**4.778**	**3.806**	Outstanding Functional

**Verbal Interpretation (Mean Scores): Outstanding Functional (4.50-5.00), Very Functional (3.50-4.49), Functional (2.50-3.49), Less Functional (1.50-2.49), Not Functional (1.00-1.49)* [17].

From Table 1, it is worth noting that the calculated weighted mean for each aspect of the S.A.G.I.P. Initiative consistently ranges between 4.667 and 4.833, highlighting the strong potential and effectiveness of the proposed product. Furthermore, the overall weighted mean for the S.A.G.I.P. Initiative is 4.778 against the 3.806 average of the traditional emergency

response, indicating that it is an efficient and promising tool for improving the emergency response system, resulting in an outstanding functional interpretation.

Table 2. Consistency or Disparity of the Dataset for the S.A.G.I.P. Initiative against the Traditional Emergency Response (Standard Deviation, n = 6).

Factors	S.A.G.I.P. Initiative	Traditional Response
1. Communication and Information Dissemination	0.816	0.816
2. Response Rate	0.816	0.753
3. Adaptability and Flexibility	0.408	0.983
4. Scalability	0.408	0.548
5. Features and Accessibility	0.408	0.408
6. Reactive Optimization	0.408	0.753
Data Set's Standard Deviation	**0.54**	**0.71**

From Table 2, the standard deviation values were provided to gauge the consistency or disparity within the dataset which complemented the mean values from Table 1. For instance, *Communication and Information Dissemination* and *Response Rate* garnered an average rating of 4.667, with a standard deviation of 0.816, indicating some variabilities in assessments among professionals. Meanwhile, *Adaptability and Flexibility, Scalability, Features and Accessibility*, and *Reactive Optimization* all shared a mean rating of 4.833, with standard deviations of 0.408 each, indicating a relatively higher level of agreement among professionals among these aspects.

Moreover, the dataset's overall standard deviation is 0.54, with a mean rating of 4.778. This shows a low level of dispersion among professionals' ratings across all evaluated factors, indicating a coherent understanding of the S.A.G.I.P. Initiative's functionality. The data consistently supports assessing the initiative's impact and effectiveness, enabling researchers to compare it with traditional emergency response systems, with lower mean rating of 3.806 and higher standard deviation of 0.71, and affirming its potential as a supplement or even an alternative approach.

From the initial findings, the S.A.G.I.P. Initiative surpasses traditional response methods across various critical factors, demonstrating superior effectiveness and benefits. The results also suggest that the S.A.G.I.P. Initiative offers a more robust and innovative approach, significantly enhancing response capabilities and delivering more sustainable and positive results compared to conventional methods. To further these assertions, Table 3 shows the summary of statistical results using two sample t-test analysis with the following criterions:

If p-value ≤ 0.05, reject null hypothesis then acknowledge the claim

If p-value > 0.05, accept null hypothesis then concede to the claim

Table 3. Summary of Statistical Results (Two Sample T-test, n=6).

Functionality of Each Solution Per Factor	p-Value	Interpretation
1. Communication and Information Dissemination	0.0436	Acknowledge the claim
2. Response Rate	0.1599	Concede to the claim
3. Adaptability and Flexibility	0.0348	Acknowledge the claim
4. Scalability	0.0025	Acknowledge the claim
5. Features and Accessibility	0.0041	Acknowledge the claim
6. Reactive Optimization	0.0177	Acknowledge the claim
Overall Effectiveness	0.0222	Acknowledge the claim

From Table 3, the comparative analysis between the S.A.G.I.P. Initiative and the Traditional Emergency Response across multiple factors revealed significant advantages for the former in various critical dimensions of emergency management. In terms of *Communication and Information Dissemination*, the S.A.G.I.P. Initiative demonstrated superior effectiveness, fostering clearer and more transparent exchanges during emergencies compared to traditional methods. This advantage supports quicker and more informed decision-making processes, crucial for effective emergency response.

Regarding *Response Rate*, while the S.A.G.I.P. Initiative showed comparable performance to the Traditional Emergency Response, no statistically significant difference was found. However, the S.A.G.I.P. Initiative excels notably in *Adaptability and Flexibility*, crucial attributes for dynamically responding to diverse and evolving emergency scenarios. This adaptability underscores its ability to adjust promptly to changing circumstances and cater to the varied needs of callers more effectively than traditional systems.

Moreover, *Scalability* emerges as a significant strength of the S.A.G.I.P. Initiative, enabling it to perform reliably across different scales and settings. This scalability advantage ensures that the system can handle a wide range of emergency scenarios without compromising efficiency or effectiveness. Additionally, the S.A.G.I.P. Initiative proves to be more user-friendly and accessible, boasting features that enhance ease of use and system navigation, thereby facilitating quicker deployment and utilization during emergencies.

In terms of *Reactive Optimization*, the S.A.G.I.P. Initiative shows superior functionality, optimizing responsiveness and efficiency in emergency situations. This advantage translates into improved incident reporting capabilities and resource utilization, contributing to better overall emergency response outcomes in the Philippines. Collectively, these findings underscore the S.A.G.I.P. Initiative's potential to enhance emergency response frameworks significantly, complementing and surpassing traditional approaches in critical functionality factors.

B. Qualitative Evaluations of the S.A.G.I.P. Initiative and the Traditional Emergency Response.

In addition to collecting quantitative data, the researchers interviewed frontline practitioners involved in emergency responses, including police officers, firefighters, and hospital staff. These interviews provided valuable insights into the frequency and nature of crimes and accidents within the community, as well as their insights about the overall effectiveness of the S.A.G.I.P. Initiative and in what places or areas the researchers place their proposed product to maximize its efficiency and minimize the misuse of it.

According to the police officers, the proposed product is an excellent innovation that can help the community in terms of emergency response and responding to different kinds of accidents. They also suggested specific areas where the product can be effectively installed, such as accident-prone areas and places with CCTV cameras. Supported by this assertion, The World Bank has reported that around 70% of all traffic-related fatalities in the world occur in less developed countries, with 65% of these involving pedestrians [18].

Subsequently, medical staff also shared their thoughts on how the current technology could be used to improve emergency response systems and reduce delays in reporting crimes and accidents using the S.A.G.I.P. Initiative. First responders often face challenges locating emergency sites when they have limited details and information, which can be time-consuming and demanding, especially in critical situations where time is of the essence [19]. Therefore, they have appreciated the initiative as it provides an immediate response with just one click, unlike the traditional method of dialing a number, which takes longer. The hospital staff

recommended implementing the S.A.G.I.P. Initiative on highways where vehicular accidents are frequent.

Moreover, the Bocaue Fire Station also supported the proposed product, stating that it is effective and innovative given the technological advancements in society. Correspondingly in an article, incorporating technological advancements in emergency response has a number of positive effects. Modern technologies, such as Geographic Information Systems (GIS) and emergency apps, can facilitate assessing threats, sharing locations, and coordination [20]. They have also recommended using different colors of buttons to align with other departments, such as blue for police stations, red for fire stations, and green for hospitals. Additionally, they suggested locating the product in major establishments like public markets, malls, plazas, and other highly populated areas, which would be considered strategic locations.

In summary, emergency response personnel provided critiques on the prevalence of crimes and accidents in the community. They addressed the effectiveness of the S.A.G.I.P. Initiative and recommended where to locate the proposed product best to maximize its value while reducing misuse. Police officers, hospital staff, and the Bocaue Fire Station all support the S.A.G.I.P. Initiative as an innovative, long-term solution to efficient response to emergencies and crime report backlog. As a result, their responses enable the S.A.G.I.P. Initiative to work effectively and ensure the initiative's success.

CONCLUSION AND RECOMMENDATIONS

The S.A.G.I.P. Initiative integrated modern technology in enhancing emergency response systems with features like GPS tracking, hotline connectivity, and prank call detection, recognized for its potential to improve crisis management. Its scalability and adaptability, praised by experts, enable the system to meet diverse needs more effectively than traditional methods. Built-in cameras, speakers, and GPS tracking facilitate informed decision-making and better coordination, seamlessly integrating into existing infrastructures and enhancing overall emergency response efficiency.

Statistical analyses were carried out and revealed significant differences. The S.A.G.I.P. Initiative on emergency reporting efficiency shows notable improvements compared to Traditional Emergency Response, particularly in communication, adaptability & flexibility, scalability, features & accessibility, and reactive optimization. The integration of advanced technology enhances frontline responders' capabilities, minimizing delays and maximizing resources. With strategic device placement, the initiative has the potential to reduce reporting delays, enhancing overall emergency preparedness and public safety, making it a modern and practical approach to emergency response.

Ultimately, for the further improvement of the study, it is recommended to develop emergency response tools that can be easily integrated into compact keychains or AirTags, improving their accessibility and usability during times of crisis. Besides, incorporating solar energy as an alternative power source is also suggested to complement existing 5V battery systems and promote sustainable and reliable emergency response solutions within the community. By integrating solar energy, organizations can enhance their capacity to respond to emergencies while reducing their reliance on non-renewable energy sources. This approach can bring about significant benefits, including reducing carbon emissions and promoting environmental sustainability.

APPENDIX

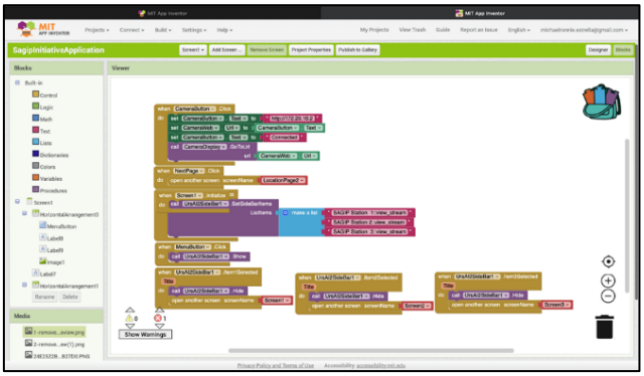


Figure A1. S.A.G.I.P. Initiative's Application Block-based Code.



Figure A2. S.A.G.I.P. Initiative's Application – Designer's View.

Table A2. Calculated and Critical t-Value, and Statistical Interpretation of the Six Key Factors.

Factors	Calculated t-Value	Critical t-Value (df=6, p=0.05)	Interpretation of the Difference
1. Communication and Information Dissemination	2.123	2.015	Significant
2. Response Rate	1.104		Not significant
3. Adaptability and Flexibility	2.301		Significant
4. Scalability	4.779		Significant
5. Features and Accessibility	4.245		Significant
6. Reactive Optimization	2.86		Significant
Overall Effectiveness	**2.669**		Significant

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Tensegriture: Integrating Tensile Integrity into Furniture to Reduce Earthquake Damage

Dessa Bulaong, Andreus Rodge S. Cordova, Alvin S. Eusebio, Princess Elise R. Fernando, Thimothy James R. Marquez, Clark Kent S. Santiago, Asly Danaya M. Santos, Maria Isabelle D.C. Santos, Mary Grace Delos Santos

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Tensegriture: Integrating Tensile Integrity into Furniture to Reduce Earthquake Damage

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ABSTRACT

Few furniture designs are built around the concept of withstanding earthquakes. This capstone project aims to integrate tensegrity into furniture to replicate the earthquake safety measures used on larger scales with seismic isolation and withstand earthquakes better than traditional furniture. The researchers tested the product at the Philippine Institute of Volcanology and Seismology (PHIVOLCS), located at Diliman, Quezon City. The researchers made use of the institute's earthquake simulator to have the earthquake intensities scaled accurately. They made use of true experimental research design, which gave them access to the scientific method in making the designs for the furniture. The researchers conducted the experiment in four phases, denoted as the research phase, the design phase, the experiment phase, and the evaluation phase. The results showed that the calculated t-value of 35.317 is greater than the critical t-value of 2.56. This meant that tensegrity-integrated furniture is significantly more earthquake-resistant than traditional household furniture. Measures such as adding weights to the structure's base increase further increase its stability. Tensile integrity integrated into furniture is a modern take on earthquake safety measures, similar to existing ones like seismic isolation. And with the proper setup and more improvements, its earthquake resistance factor can save lives.

INTRODUCTION

Natural disasters have given struggles to humanity since the beginning. Inventions and discoveries have helped humans predict when calamities like storms will occur, allowing them to prepare and mitigate the damage they caused. However, there are still unpredictable disasters that have devastating impacts on human lives, with earthquakes being the most well-known.

Earthquakes are sudden shaking of the earth due to seismic or volcanic activities. Their nature makes them unpredictable even to seismologists, or experts on geological occurrences. Due to the lack of understanding of the fundamental physics of earthquakes, experts are unable to tell when an earthquake will strike (Kelety, 2023). The most humans can do is mitigate the damage they deal with when it happens.

Humans have already taken measures on reducing the damage caused by earthquakes. Whether it would be using seismic isolators or using shock absorbers on larger scales, buildings can be made earthquake-proof (BigRentz, 2022). These have all achieved their purpose of preventing buildings from crumbling down. However, earthquakes also cause damage to the interiors of buildings.

While collapsing buildings cause the majority of the damage during earthquakes, falling heavy furniture and household objects can cause major injuries and even casualties (California Earthquake Authority, 2020). In the event of an earthquake, it has been advised to stay far from tall shelves as they can collapse on people.

Tips on earthquake-proofing the interior of houses involve either fastening or nailing large furniture to walls (Butler, 2021). Applying anti-earthquake measures in traditional households can be effective. There are also products that exist which can be installed in household furniture to minimize their chances of collapsing. Yet, there are only a few accounts of furniture that are built around the concept of withstanding earthquakes.

A structural principle exists which is applied not only in architecture but also exists in human anatomy. This principle is known as tensile integrity or "tensegrity" for short. Structures with this principle have components under continuous tension that causes their other components to experience constant compression, thus holding up the structure (Ansys, 2020).

Applying this principle to furniture causes the furniture's base to move less due the top layers moving more freely and the chord networks isolating the weight, causing it to sway relative to any ground movement as opposed to it toppling over. It shares similarities with seismic isolation, in which rubber-bearing isolators and dissipators cause buildings to sway relative to earthquakes, protecting their structural integrity (Antoniou, 2022).

This type of furniture not only provides more safety but may also appeal to those that want more modern-looking aesthetics for their homes. The chord structures that hold up the furniture make it seem as if it is floating, giving an unnatural look to it that some may consider appealing.

This capstone project aims to integrate tensegrity into household furniture such as tables and shelves to replicate the earthquake safety measures used on larger scales with seismic isolation for them to withstand earthquakes stronger than traditional furniture, thus mitigating earthquake damage.

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Hypothesis

The earthquake resistance of the furniture also serves as the baseline for the hypotheses of the project, with the two hypotheses stating the following:

H_0 – There is no significant difference in the earthquake resistance of tensegrity-integrated furniture and traditional household furniture.

H_1 – Tensegrity-integrated furniture is significantly more earthquake-resistant than traditional furniture.

The researchers will simulate earthquakes to know if they hold up during these disasters. These furniture items incorporated with tensile integrity will be called "tensegriture".

Research Questions

The researchers seek to create furniture integrated with the structural principle that is tensile integrity and to make the system optimal by answering the following research questions:

1) How much earthquake intensity can the furniture withstand?

2) How to further increase the earthquake resistance in the structure?

With this, there can be more options when it comes to earthquake preparedness in households, causing less damage and potentially saving lives.

LITERATURE REVIEW

Earthquake Damage

The Philippines, which has more than 7,000 islands, and is the second-largest archipelago in the world, is situated in the northwestern Pacific Ocean, in the direct path of the storm surges, landslides, and floods that are brought on by the world's most powerful tropical cyclones. Periodic earthquakes and volcanic eruptions also take place within the Pacific Ring of Fire's edge. People are more vulnerable and ill-prepared because earthquakes are unpredictable (Naval & Carig, 2017).

According to Causapin (2018), in the Philippines, earthquakes typically occur daily. There are likely to be weak earthquakes every month that the general population does not feel. Regarding earthquake occurrences, it suggests that a quake will typically happen at any moment in the area, albeit with a weak magnitude.

As of now, it is known that the tectonic faulting in the Earth's crust's brittle regions, which are concentrated along plate borders, is the only cause of the largest earthquakes, as determined by the seismic moment release energy (Dominguez *et al.*, 2017).

Added by Naval and Carig (2017), it is extremely likely that these terrible earthquakes will happen again in the future. Large urban earthquakes have the potential to devastate the built and natural surroundings, as well as to inflict significant economic loss and social unrest. The severity of the danger—such as ground motion and ground rupture—as well as the economic worth and susceptibility of the built environment and the occupants to the hazard all play a role in determining how much will be lost and how much will be disrupted. During the earthquake, man-made structures' collapse posed the biggest risk to people.

In the findings of Centeno *et al.* (2022), they found that many man-made factors frequently increase the risk associated with natural hazards in the Philippines. These include inadequate infrastructures that raise risks; environmental degradation brought on by unethical or corrupt activities like careless mining, quarrying, and illegal logging; inadequate community land-use planning; an increase in unauthorized settlers in urban and suburban areas; and a lack of disaster preparedness among many Filipinos.

The most effective method for avoiding earthquake-related fatalities is the creation and implementation of seismic safety codes. It is highly recommended to survive earthquake disasters to provide the public with the necessary information regarding earthquakes, such as the location of fault lines, earthquake preparedness, mitigation, and drills.

However, according to the findings of Baquiran *et al.* (2017), disaster preparedness strategies are either implemented intermittently or only when a crisis actually occurs. The frequency of a natural catastrophe and disaster readiness were found to be directly correlated. Disaster managers are less likely to plan for a natural disaster if it happens less frequently.

Impossibility of Earthquake Prediction

Earthquakes have been known for their damage and unpredictability. Due to its destructive potential, humanity has long sought a method for predicting earthquake trends. Predicting an earthquake entail stating the precise time, magnitude, and location of a forthcoming earthquake. Prediction models are classified as either short-term, long-term, or intermediate-term. Despite the scientific community's efforts, no valid and reliable method has yet been discovered due to the phenomenon's inherent unpredictability. (Vardaan, 2019) . Earthquake prediction was deemed impossible due to either the limitations of current and foreseeable knowledge or the chaotic nature of seismic phenomena. This was accompanied by a sense that efforts toward prediction were a waste of money and time. Predictions were viewed as exhibiting poor scientific rigor, which, when combined with false alarms, could harm the reputation of earthquake science by inciting mass hysteria and the resulting loss of life. Forecasting, as opposed to prediction, was deemed worthwhile because it could aid in earthquake preparation and mitigation efforts. As a result, the majority of participants explicitly avoided earthquake prediction in favor of forecasting. As a result, earthquake prediction became a stigmatized subject; associating with the concept of earthquake prediction could be detrimental to one's career prospects. (Joffe, 2018)

Furthermore, seismic activities are mostly located in the crust lithosphere or asthenosphere, it is not possible to simulate the accumulating process of matter and energy during the seism genic process. Therefore, making

earthquake prediction a significant scientific problem. Even if remote sensing technology is used for earthquake prediction for almost 30 years, an in-depth study of remote sensing technology still is required to reduce the external disturbances that may accumulate noise to remotely sensed data. Major problems in earthquake prediction include; The unobservability of the seismic source since it's impossible to sense the interior of the earth. The uncertainty of precursor signals in meteorological and geographical environments has a huge impact on earthquake prediction. The uncertainty of remote sensing data and algorithms; the volume, type, and accuracy of the data. The complexity of predictive models such as deformation, gravity, electromagnetic signals, etc. Rareness of violent earthquakes, although earthquakes are common. Violent ones are quite rare. (Zhao, 2021)

Thus, earthquake occurrences in complex environments with uncertain elements are incorporated into point-process modeling, which results in stochastic predictions. A large uncertainty exists, in particular, in determining whether abnormal phenomena are precursors to large earthquakes, as well as in assigning urgency to a given earthquake prediction. (Ogata, 2017)

Is prediction utterly impossible or just extremely difficult? Observing subtle phenomena, forming hypotheses, and meticulously testing them against future earthquakes would require enormous effort over several decades, with no assurance that it will succeed. As a result, it appears unwise to invest heavily in monitoring potential precursors. (Geller, 2017)

As of now, seismology can help with earthquake hazard mitigation. Statistical estimates of the seismicity expected in a general region on a time scale of 30-100 years and statistical estimates of the strong ground motion are important data for designing earthquake-resistant structures. (Geller, 2017)

Earthquake Safety Procedures

The Philippines has been identified as one of the most disaster-prone countries in the world, owing primarily to its geographical and geological location as well as its physical characteristics. As a developing country, the Philippines has been conducting safety planning and developing strategies to address the complex challenges posed by earthquakes. The government encourages authorities, private companies, groups, and schools to conduct concrete planning and earthquake drills on an annual basis to practice what to do before, during, and after an earthquake to increase the chances of survival while minimizing its dangers and damage.

According to a study conducted by Baylon *et al.* (2021), the Philippines, being part of the Pacific Ring of Fire, faces significant threats of massive infrastructure damage as a result of extensive earthquakes. The most vulnerable infrastructures are public school buildings, which are deemed significant structures due to them being places for education and shelters for times of need. Implementation of rapid visual assessments using the Safer Communities through Safer Schools (SCOSSO) shows that a peak in ground movements cause causes school buildings to crumble.

In addition, the simulation study conducted by Naval, R. C., and Carig, E. T. (2017) called Rapid Earthquake Damage Assessment System (REDAS) was used to assess earthquake risk in Gundaway, a barangay in the municipality of Cabarroguis, province of Quirino. The simulation revealed that at an intensity of 7.8, Gundaway would have the highest total damaged floor area, covering 10,818 sq. m., and a damage cost of Php 69.8 million, with schools, commercial buildings, and some residential areas suffering major damage.

School plays an important role in the education of a community's next generation, who are still in the developmental stages of their lives. Safer and more resilient schools can save children's lives, provide a haven for the local community, serve as a temporary shelter, and help restore normalcy to society in times of disaster. Nassirpour *et al.* (2018) conducted the study, introducing a set of tools for rapid yet dependable visual multi-hazard vulnerability prioritization of school infrastructure against potentially destructive natural hazards such as earthquakes, typhoons, and floods.

Altovar, A. T. (2017) found that using the Shortest Route Algorithm to find the shortest way out of the building during earthquakes, floor plans with indoor measurements can be used to construct a viable earthquake evacuation route plan. The findings of this study are aimed at helping schools, particularly students, by providing information that will increase their awareness and sensitivity to earthquake preparedness.

Limlengco *et al.* (2016) conducted a study that aimed to create software that can send a message to a police station, hospital, and other related agencies in an emergency situation such as a fire or earthquake. To assist the user in an emergency, the application will find the shortest route out of the building, block a path, and send a distress message to help the user during an emergency. In accordance with the findings of this study, Centeno *et al.* (2022) also conduct a study that concludes that respondents' communication behaviors, as well as their media and non-media information sources, are significantly related to their level of knowledge and attitude toward disasters, as well as their practices before, after, and during disasters.

Seismic Isolation

A structure can be isolated from the ground to be protected against the devastating effects of earthquake vibrations, which is the basis for the design method known as seismic isolation. Additional flexibility tends to be included at the base of the structure to attain this result and satisfy all in-service functional requirements. To manage the deflections that occur across the isolation interface, additional damping is also offered. (Acero, 2018)

The Seismic Isolator is an anti-seismic device that ensures

zero damage to a building in the event of an earthquake. Its objective is to isolate the building from the detrimental ground movement. Because destructive earthquake movements are horizontal rather than vertical, a building with seismic isolators will simply sway rather than vibrate back and forth in varied directions due to inertial pressures, causing deformation and damage.

Seismic isolators are typically cylindrical or square in shape, frequently made of natural or high-damping rubber with a lead core, and can take on any shape according to the needs of the building. While the rubber functions as a spring, the lead core dampens and eliminates vibrations. Because it absorbs seismic energy, floor acceleration will be decreased, preventing damage to the building's structure and ultimately the building's contents from being damaged. (Luna, 2021)

The use of base isolation is a particularly efficient method for reducing the seismic response of civil engineering constructions. This method is based on the idea that decreasing a structure's seismic demand is more effective than increasing its capability for earthquake protection. The primary principle of base isolation is to reduce the stresses caused by earthquakes that are transferred to the superstructure. Decoupling the structure from ground motion reduces the need for ductility and lowers inter-storey drifts, preventing seismic energy from entering the building. This decoupling is done by introducing the structural elements with low horizontal stiffness between foundation and superstructure which minimize the fundamental frequency of structural vibration to a lower value than the leading energy containing frequencies of earthquake ground motions and it also offers a means of energy dissipation which decreases the propagated acceleration to the superstructure. The Base Isolation protects the structure and its non-structural elements against seismic damage in this way. (Solita donami and Dr. Ajay Sharma, 2016)

Only the horizontal components of ground shaking are isolated by traditional elastomeric and lead-rubber seismic isolation bearings. Lead-rubber bearings are similar to elastomeric bearings in that the vertical stiffness is generally thousands of times greater than the horizontal stiffness.

On the other hand, sliding bearings have far higher vertical rigidity than elastomeric bearings. Additionally, heating has an impact on the typical strength of friction pendulum bearings. In general, previous attempts to establish three-dimensional isolation have not resulted in a system that is workable and economical. Tensegrity structures are made up of axially loaded components, typically cables and bars, and have distinct geometrical forms that are self-stressed. They are thus mechanically and materially effective structures. Depending on the imposed prestress, the system's shape, and the size of the external load, the elastic response of the investigated structure may change from stiffening to softening.

A tensegrity system is a strong link between two axially loaded elements. A Class K tensegrity structure has at most k compressive components attached to each node. (Skelton, n.d) The state of a continuous network of members in tension has been preserved implicitly.

It is currently evident that there are cable-bar cells with a discontinuous network of cables among the tensegrity systems. A self-stress state of balance can be created inside the tensegrity elementary cell by inserting a different set of connections. The author of the current solution proposed assuming a new Class (Theta) of tensegrity systems in this regard.

The current answer deals with an isolator that has a Class $\theta = 1$ triangular tensegrity prism form. Only one compressive member is connected to each node if $\theta = 1$. The static indeterminacy of Class = 1 tensegrity prisms is one, and the kinematic indeterminacy is ten. In general, they can be efficiently stabilized by applying pre-tensioning forces. Following the initial load efforts of the mechanical models, it is evident that a good theoretical form of the single isolator will be a super-stable and soft configuration, i.e. without self-stress. The prismatic isolator's triangular bases allow for large relative mobility in both plane and rotary directions. (Rzeszów, 2019)

To meet the requirements of the current seismic design criteria, infrastructure and buildings must be sufficiently protected against earthquake excitations at the design level while minimizing serious damage. This study investigates the computational modeling of an energy-dissipating brace that prevents inter-story drifts and is based on tensegrity. The suggested brace combines Shape-Memory Alloy (SMA) cables or tendons with a rhombus-shaped D-bar tensegrity structure. Even after repeated mechanical cycles requiring stresses of up to 6%–8%, these tendons develop austenitic-martensitic austenitic (solid to solid) transitions, making them more vulnerable to mechanical stress when accepting strain and magnifying the stress into broad superelastic hysteresis. Additionally, this page discusses the 2D and 3D braces, two unique types of tensegrities. Due to their increased ability for energy dissipation and increased safety from buckling, 3D braces have been shown to be more effective. The intended bracing effectiveness opens the door for the creation of ground-breaking seismic energy dissipation devices that use tensegrity principles and superelasticity. (N.Singh, *et al.*,2020)

Anti-Earthquake Furniture

The Great Hanshin-Awaji Earthquake of 1995 resulted in many injuries to persons inside buildings, even though the buildings themselves did not receive significant damage. This tumbling of furniture was the cause of over 50% of the injuries sustained indoors. Direct human injury is likely to occur during an earthquake with long-period ground motion, especially in high-rise structures. To decrease the number of victims inside, it is crucial to understand how furniture moves during seismic excitations. E-Defense of the National Research Institute for Earth Science and Disaster Resilience (NIED) has been confirming the movement and destruction of non-structural elements

such as furniture, exterior walls, ceilings, and glass under these circumstances. (Isobe, 2018)

Furniture that is not correctly fastened, particularly on the higher floors of tall structures that are subject to prolonged ground motion, can be fatal to people. Furniture that has fallen, like chairs and desks, could constitute lethal obstructions that obstruct effective evacuation. An efficient numerical code was created in this study to analyze how furniture moved while it was subjected to seismic excitations. The numerical code is based on the Gauss technique of adaptively shifted integration, a finite element scheme that offers more computational efficiency than the standard code. By using a sophisticated penalty technique, the frictional contact between the items was fully taken into account. On a shake table, several furniture excitation tests were run. In the trials, seismic waves were used to stimulate steel cabinets, and a device was used to record displacement data. (Isobe, 2018)

As stated in the study conducted by Felin (2022). The Lifeshell premise can provide a safe refuge during an earthquake in an efficient, cost-effective, and quickly deployable natural-based manner. Despite the fact that its features have been successfully demonstrated with a shock absorption test, the researchers do not suggest this technology as a substitute for proper anti-seismic building technology. Whenever the socioeconomic context prevents the effective application of anti-seismic building engineering standards, this technology should be used temporarily. (Fellin, 2022)

Furthermore, non-structural elements can be hazardous to people during seismic events. Building elements such as glazing or suspended ceilings shattering or collapsing, or building contents being flung around, cause injuries. Filing cabinets and equipment collapse, hazardous material containers burst open, and gas from ruptured pipes ignites. Damage scenarios differ from one building to the next and from one room to the next. (Hussain, 2017)

The purpose of the research was to critically analyze the state of the art of life-saving furnishing projects in the event of an earthquake, for already developed public and private contexts, whether they are commercialized products, patents, prototypes, or concepts, in order to bring out the design aspects deemed most relevant to implementing the life-saving performance in the event of an earthquake, as well as to highlight any latent needs not defined previously. Therefore, strengthening our claim that furniture can indeed survive an earthquake and in some cases save lives. (Galloppo, 2019)

Cabinet doors frequently swing open during earthquakes, spilling everything inside, making a huge mess in the best case and causing major harm or injury in the worst. Well, I suppose a new innovative creation (or, if the earthquake coincides with an electrical storm, perhaps a new life form) could result from it, but it's generally a good situation to avoid. Take into account not only the breakable dishes and glasses in those cabinets, but also the numerous oils, vinegars, liqueurs, condiments, and jars-of-that that could fall out and smash onto the floor. It's a good idea to install earthquake-resistant cabinet latches, especially in a kitchen's high cabinets.

Numerous products advertise themselves as being earthquake-resistant latches. Push latches (also known as touch locks) are something I've long advocated for and have implemented in numerous flats and condos over the past 25 years or so. These are the latches that keep the cabinet doors from opening until the door is first pushed in to disengage them; the door is then pushed in again to close; and then the latches re-engage. In 2012, I posted a lengthy piece that was briefly the most popular post on this blog on installing these latches. The issue of whether an earthquake could shake the door just enough to cause it to bounce inward and open has been brought up on occasion. (Springer, 2018)

Tensile Integrity

Tensile integrity also known as tensegrity is a system of a stable network that is a compression of bass and struts and has tension on strings or cables. The system's most foundational property is that it has one-dimensional elements of the structure that are axially loaded. Since bars are recognized as the strongest at withstanding tension, structures can be constructed together with load paths to make the most of each structural path. There is a study as well where Wang *et al.* provided a framework studies and minimal mass active tensegrity structures. A structure member's uncertainty is only across its length due to the absence of material bending in the member that gives a more accurate model. By the tuning of the lengths of the strings, the shape of the structure can be easily changed, and as the strings are prestressed, the inclemency of the structure can be properly tuned. This study of Shuo Ma et. al (2022) has confined dynamics developed from a system-level that is required for the field of structural control so as to get insight into the nonlinear tensegrity dynamics. It organized how the bar and string coordinated and connected with notations in the physical properties of the tensegrity system with the compact of vector forms. How the shape will function with the element was also formulated. And, with the use of the Lagrangian method, the tensegrity dynamics were derived with or without constraints. (Shuo Ma et. al 2020)

Goyal *et al.* (2019) say in their study that tensegrity structures can also be prestressed to have unidirectional loading for all individual members, allowing tension and compression members to be designed independently. Tensegrity structures can also benefit from this freedom because they have a high strength-to-mass ratio. There is also a particular tensegrity structure topology that can provide a variety of self-equilibrium solutions corresponding to different prestresses values in the structure. The different stable prestress values provide a domain set for minimizing the structure's mass. It has been proven that tensegrity is to be an optimal mass solution for various loading conditions as a result of this minimization. To categorize the whole analysis of

a tensegrity structure, Modeling of Tensegrity Structures (MOTES) was used and has two categories for this. The first one is the static analysis that determines the tensegrity's minimal mass optimizing the tensile and compressive forces in the structure's bars and strings when certain external forces are present and when no external forces are present. Second, using a second-order matrix differential equation, the dynamic analysis simulates the dynamics of any tensegrity structure complexity (Goyal & Skelton, 2019). This dynamic model assumes that the bars are rigid and the strings are linear elastic.

According to Palmieri *et al.* (2021)'s study, by combining an arch-supported membrane system and a diamond-type tensegrity system, it will result a tensile-integrity system that is a nature of cables and membrane in addition to the arches' so-called "floating-bending ." It was observed that in addition to compression and bending, the arches also experience torsion. Although arches do not actively bend, they have a curved shape at rest and experience minor deformations at the prestressed equilibrium state. In the initial attempt to merge these two structures, the traditional triangular tensegrity prism, or T3, was said to be "patched" with three arch-supported membranes. This demonstrated the transformation process and the finished system that consists of three arches suspended against one another by membranes and cables to create a free-standing structure. In comparison to typical tensegrity systems, especially those with few struts, they can be generated from traditional diamond-type tensegrity systems and used as deployable or transformable structures enclosing a wider space. In this study, the first process serves as a first step to demonstrate the viability of the floating-bending concept, while the second procedure offers a strong tool for constructing a floating-bending structure in an interesting practical case.

A study was made by Singh *et al.* (2020) wherein buildings and infrastructures must provide sufficient protection for site condition earthquake excitations with limited levels of damage to optimize the seismic performance prescribed by modern structural codes. The study discusses the computational modeling of a bracing system with tensegrity architecture that acts as a compact mechanical amplifier of longitudinal displacements in the transverse direction, trying to limit interstory drifts while dissipating energy. A rhomboidal shape comprising Shape-Memory Alloy (SMA) tendons together with D-bar tensegrity structure, the brace was proposed. To account for re-centering capabilities, SMA components within bracing systems have been extensively studied. Moreover, the objective of the study is to create a seismic bracing system with tensegrity architecture that can be used as a passive energy dissipation (PED) device by merging noticeable displacement amplification qualities with the superelastic response of SMA tendons. This structure incorporates a distinctive strategy, and a system with D-Bars has been formed, displaying the Scissor-Jack damper device equipped with SMA tendons. This design allows us to operate in a way that enables the element to be stretched while trying to move vertically.

A study conducted by Fernandez-Ruiz *et al.* (2022) that the Octahedron family's topology is displayed in tensegrity structures. Based on their topology, new tensegrity structures that fit into this family are identified. The procedure for determining a self-equilibrated configuration (also known as the form-finding process) is critical in the design of tensegrity structures. Tibert and Pellegrino conducted a review of tensegrity form-finding methods. In a recent paper, the authors proposed an analytical form-finding method for tensegrity structures based on the FDM (Force Density Method). This method entails locating a set of force:length ratios in a symbolic space. The analysis results in a tensegrity structure with an equilibrium shape. The DR (Dynamic Relaxation) method is said to be based on a pseudo-dynamic process that considers tensegrity structures to be a collection of nodal masses and damping elements. Another critical aspect in the design of tensegrity structures is stability. Super-stability is a stability criterion for tensegrity structures with which, regardless of the level of self-stress, the tensegrity is always stable and material properties are taken into account. Geometric intuition or topology can be used to build tensegrity structures. The Octahedron family is made up of three octahedrons: the expanded octahedron, the double-expanded octahedron, and the triple-expanded octahedron. The connection presented by Fernandez-Ruiz *et al.* for the Octahedron family can only be used to define the first three members of the family. This work defines the topology of the family by studying the folding process from one member to the next.

METHODOLOGY

The researchers made use of the true experimental research design, which gave them access to the scientific method in making the designs for the furniture. The experimental approach allowed the researchers to reach the most optimal procedures and troubleshoot any procedures that did not work. According to Bevans (2022), the experimental design makes use of systematic procedures in testing the hypothesis of a study through the manipulation of the variables present.

As for the procedures of the project, the researchers conducted the experiment in four (4) phases. The phases are denoted as the research phase, the design phase, the experiment phase, and the evaluation phase.

The research phase mainly consisted of figuring out the basics of tensegrity, and how the tension holds up the structures. After observation of existing models and the structures that exhibit this principle, the researchers were able to make a figure showing how it works.

The observations of existing tensegrity builds led the researchers to figure out the main components of a basic tensegrity structure and how they behave together. The structure has layers that include the base and the top layer. Beams are attached to the layers and cables connect them all to make the structure. The central cable serves as the cable that carries the weight of the table whilst the corner cables'

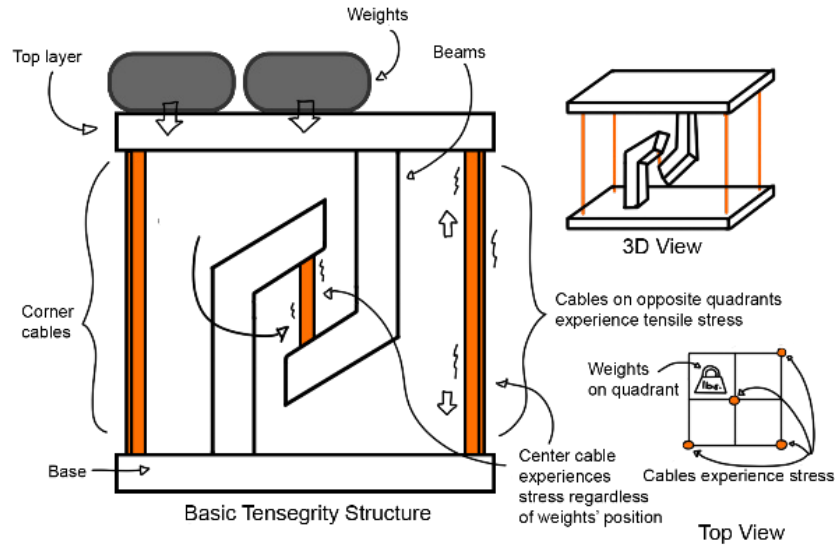


Figure 1: Basic Tensegrity Concept

main purpose is to balance the structure and keep it upright. The observations showed that only the tension holds up the weight of the platform and the weights on top, meaning that the initial tension that is present on the ropes must not be too high when constructing the design, to give enough room for more tensile stress that would be applied to the cables when more weight is exerted. The application of force in weight on the structure was also observed to be different from how it is with traditional furniture. Due to the fact that the cables on the four corners are meant to keep the structure balanced, any added weight on one corner of the structure will translate to the middle cable and the three cables outside its quadrant experiencing tensile stress. Researching for the designs also involved observing how tensegrity structures behave in the presence of ground shaking. The researchers were able to make a figure showing how the furniture would act in the presence of ground shaking.

As opposed to traditional furniture with a solid foundation that has the chance to topple over or collapse during an earthquake, tensegrity structures have bases anchored to the ground, making it so that the cables hold up the structure, causing it not to topple over during earthquakes, but instead making the top layers move horizontally instead. After understanding the concepts behind structures with tensegrity, the researchers moved on to the design phase in which the researchers made improvements upon the basic tensegrity structure. The factors that needed to be kept in mind concerning the research questions were the dimensions of the structure, the cables to be used, and its earthquake-resistance factor. The longevity had to be considered through the correct amount of tension it initially had. The movements could make it sway too much to the point of it collapsing. This meant that the cables had to not be too loose to add stability to the structures. However, when considering the tensile strength, it also cannot be too tight. The weight that would be placed on top of the structure directly translates to more tension that is needed to keep it

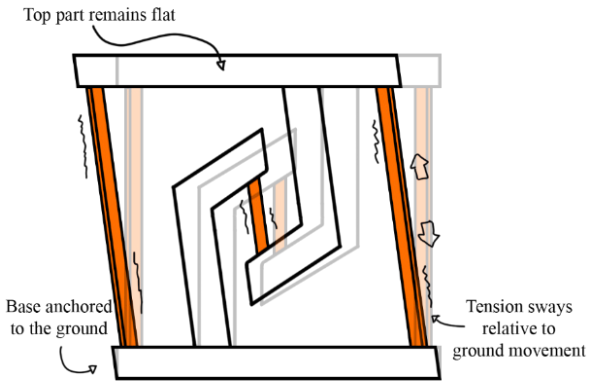


Figure 2: Tensegrity in the Presence of Ground Movement

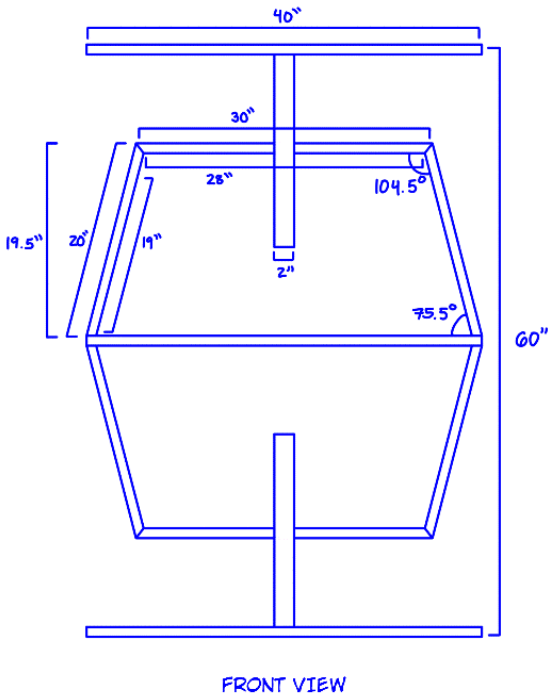


Figure 3: Front View of Base Components

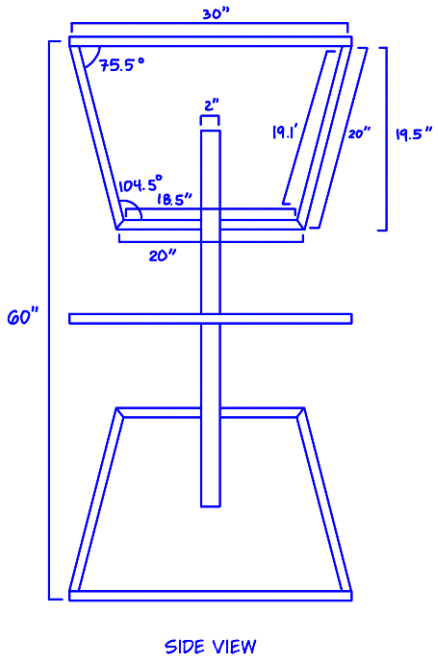


Figure 4: Side View of Base Components

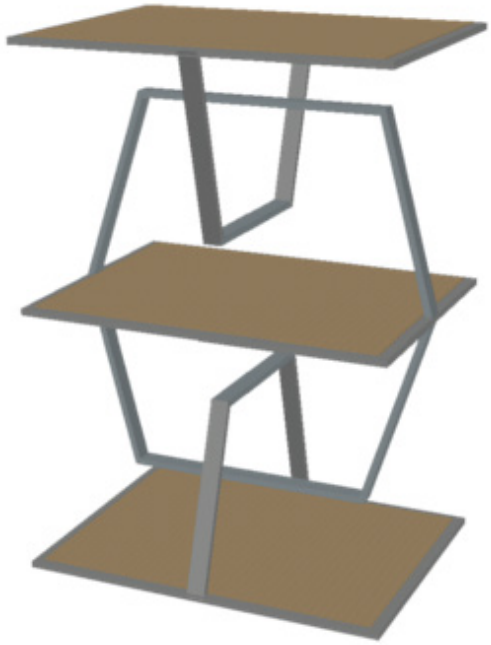


Figure 5: 3D Render of Structure Base

standing. Having too much tension initially could make the cables rupture once weight has been added to the system. Due to this, the researchers had to find a middle ground for the initial tension so that it may have room for extra tensile stress, but also so it does not sway too much when there would be ground movement. This was done by using a turnbuckle for each corner cable to not only have adjustable tension but to also make the surface of the layers flat and not tilted.

Designing the structure also involved conceptualizing the dimensions. To mitigate the movement involved during ground shaking, the shapes of the base needed to be as equilateral as possible, meaning they needed to have almost equal dimensions for their bases. Having one side longer than the other meant that it would sway more in one axis, potentially causing it to fall over or have the tension rupture.

After figuring out the factors to be kept in mind, the type of furniture also had to be considered. Tensegrity tables were the basis of the study and were easy to design. However, existing tensegrity structures could be made into tables or chairs easily. The researchers therefore focused on shelves as the furniture to be designed.

During the design process, the researchers came up with the design of a three-layered tensegrity shelf with the layer's dimensions having a 4×3 ratio. The exact dimensions of the base and the other layers are 40"×30"×1", with the structure being 60" tall. The base of the structure was made of plywood with steel framing. The design process ended with the researchers picking the best suited material to be used for the cables. The two factors that the researchers kept in mind when choosing the cables were the cables' tensile strength and accessibility. The researchers ended up choosing three possible cables that are most suitable for the project: nylon rope, galvanized iron wire, and low-carbon steel chains. In the end, the researchers used 3/16" low-carbon steel chains for their affordability and good working load limits of 800 lbs. The working load limit of a system is how much weight can be exerted without the risk of it failing. This is determined by getting 1/3 of the product's breaking strength (Halvorsen, 2021).

After figuring out the design, the researchers moved on to the experiment phase. The structure had to be tested for its earthquake endurance, or its ability to remain intact during an earthquake. This meant that the structure had to endure high-intensity earthquakes, intensity levels that would cause traditional furniture to be displaced and collapse.

Research Locale

The data collection of the research took place in the office of the Philippine Institute of Volcanology and Seismology (PHIVOLCS) located at Diliman, Quezon City (11.8 km from Manila). The researchers made use of the institute's earthquake simulation device to gather data.

Statistical Treatment

Testing the earthquake endurance of the structure involved testing how well it endures higher intensity levels of earthquakes compared to regular household furniture. For reference, the Modified Mercalli Intensity Scale (MMI) was used, which states that heavy furniture tends to be shifted during an intensity 6 earthquake, and collapse or overturn during an intensity 7 earthquake (Wood & Neumann, 1931).

The researchers used the earthquake simulator in testing the structure to have the earthquake intensities be scaled accurately. The earthquake simulator could only go to an intensity level of 8.4, which was already above the limit that the structure had to reach.

In gathering the data, the simulated earthquake intensity was gradually increased until the structure started moving dramatically. The researchers conducted three (3) identical tests on the structure to get the mean score and standard deviation of the earthquake intensity levels endured by the structure.

The data gathered was then tested using a one-sample t-test due to the existing hypothesized value of intensity 7.0. One-sample t-tests are used when a calculated mean from gathered data is compared to a standard value (Bevans, 2020). The t-test used was right-tailed, as the researchers were trying to prove that the structure is significantly more earthquake-resistant than traditional furniture. The data was used to get a calculated t-value using the formula below:

$t=(\bar{x}- \mu)/(s/\sqrt{n})$

t – Calculated t value

μ – Hypothesized mean (7)

$\bar{x}$ – Sample mean

s – Sample standard deviation

n – Amount of Observations

Equation 1 - One Sample t-calculated Value Formula

After getting the calculated t-value, it needed to be compared to the sample's critical t-value. The critical t-value is found in the one-tailed P-table by getting the degree of freedom of a population, which is achieved by subtracting 1 from the number of observations, with consideration of the alpha level, 5% or 0.05.

If t-calc = t-crit, then reject H_0

If t-calc > t-crit, then accept H_1

During the design process, the researchers came up with three (3) setups to possibly further increase the structure's earthquake-resistance. Setup 1 was by replacing the center cable with a tensioner spring to enable the layers to oscillate more freely. Setup 2 was adding 50 kg of weight to the base or the bottom layer to lower the structure's center of gravity, causing less movement of the base. Setup 4 was combining the two previous setups. The default setup was denoted as 'Setup 1'.

T-tests were also used in comparing the means of the endured intensity of the three setups with the default setup to see if they are significantly more earthquake-resistant. However, instead one-sample t-tests, independent sampling t-tests were used to get the calculated t-values (Bevans, 2022). The calculated t-value needed to be great than a critical t-value to prove that the setup is effective.

$t=(\bar{x}_1- \bar{x}_2)/\sqrt{((s_1^2)/n_1 +(s_2^2)/n_2)}$

Equation 2 - Independent Sampling t-calculated Value Formula

RESULTS

The section shows the results of the earthquake simulation testing done with the different setups. Each setup was tested three (3) times and their mean scores and variances were given the statistical treatment for the study.

Setup 1 Earthquake Intensity Testing

t-calc > t-crit → Reject H_0

Table 1 deals with earthquake intensity level that the structure endured for three tests to get the mean and comparing it to the intensity level 7 from the Modified Mercalli Scale using t tests to see test if tensegrity-integrated furniture are more earthquake-resistant than regular furniture. The calculated t-value of 35.317 is greater than the critical t-value of 2.56. This makes it fall under the rejection region, meaning that the researchers must reject the null hypothesis and accept the alternative hypothesis. With this, the researchers conclude that tensegrity-integrated furniture are significantly more earthquake-resistant than regular household furniture.

Table 1: T-Test (Setup 1)

	Mean	St.Dev	T-Calc	T-Crit	df	P-Value
Setup 1	7.97	0.047	35.518	2.920	2	0.0005935
Traditional Furniture	7					

Setup 2 Earthquake Intensity Testing

t-calc < t-crit → Fail to Reject H_0

Table 2 deals with the means of the earthquake intensity levels endured by the structure before (Setup 1) and after (Setup 2) replacing the center cables with tensioner springs and comparing them to see if it significantly increases the earthquake-resistance of the structure. The results came back with the calculated t-value of -3.4631 which is less than the critical value of 2.132, meaning that the researchers failed to reject the null hypothesis. The researchers therefore conclude that there is no significant difference in the earthquake resistance of the structure with the center cable being replaced with tensioner springs.

Table 2: T-Test (Setup 2 & Setup 1)

	Mean	St.Dev	T-Calc	T-Crit	df	P-Value
Setup 2	7.8333	0.0471	-3.464	2.132	4	0.0285955
Setup 1	7.9667	0.0471				

Setup 3 Earthquake Intensity Testing

t-calc > t-crit → Reject H_0

Table 3 deals with the means of the earthquake intensity levels endured by the structure before (Setup 1) and after (Setup 3) adding weights to the structure's base and comparing them to see if it significantly increases

Table 3: T-Test (Setup 3 & Setup 1)

	Mean	St.Dev	T-Calc	T-Crit	df	P-Value
Setup 3	8.4000	0.0000	15.9217	2.132	4	0.0029326
Setup 1	7.9667	0.0471				

the earthquake-resistance of the structure. The results came back with the calculated t-value of 15.9216 which is greater than the critical value of 2.132, meaning that the researchers must reject the null hypothesis. The researchers, therefore, conclude that adding weights to the base of the structure makes it more earthquake-resistant.

Setup 4 Earthquake Intensity Testing
t-calc > t-crit → Reject H_0

Table 4 deals with the means of the earthquake intensity levels endured by the structure before (Setup 1) and after (Setup 4) doing both measures of replacing the center cable with a tensioner spring and adding weights to the base, and comparing them to see if the two setups combined significantly increases the earthquake-resistance of the structure. The results came back with the calculated t-value of 3.8971 which is greater than the critical value of 2.132, meaning that the researchers must reject the null hypothesis. The researchers therefore conclude that doing both measures of replacing the center cable with tensioner springs and adding weights to the bottom, but not to the same extent as having only the weights added.

Table 4: T-Test (Setup 4 & Setup 1)

	Mean	St.Dev	T-Calc	T-Crit	df	P-Value
Setup 4	8.2667	0.1247	3.8971	2.132	4	0.0608450
Setup 1	7.9667	0.0471				

DISCUSSIONS

The results of the study showed the effectiveness of tensegrity-integrated furniture as the prototype survived the high-intensity earthquake simulations. However, some may question if its earthquake-resistance can result in the mitigation of earthquake damage in households.

In the event of an earthquake, it is common occurrence for heavy furniture like shelves to collapse on people, potentially leading to loss of lives. With tensegrity-integrated furniture, the risk of the structure toppling over and causing harm is shown to be lower due to the way they behave during earthquakes. And in higher intensity levels where they do collapse, the absence of a solid foundation makes it so that they would not cause severe injuries due to them being lighter in weight. This type of furniture has also extra shown useful features during the simulations. One of them is the fact that the structure oscillates even in weaker intensity levels. This could be useful in scenarios where the occupants of a household see the furniture's movement, indicating that an earthquake is occurring at that moment. A potential weakness of this system is the chance of the cables rupturing, which is why the researchers chose the most cost-effective cables that are available, which are chains. During the testing, there were no instances of the cables snapping because of the sudden ground movement. The only way that the structure started to fail was when the base started getting shifted. This is the reason why the researchers came up with the three setups to increase the stability of the structure. Setup 2 was shown to have no significant difference in the structure's earthquake resistance when compared to Setup 1. In fact, this setup managed to perform slightly worse than the default setup without the tensioner springs as the center cables. The researchers initially hypothesized that the base would move less due to the more free-moving layers. However, the tests showed that the oscillation only caused the base to move more due to the movement of the top layers, adding motion to the inertial base and causing get displaced in slightly lower intensity levels.

Further observations also revealed that this setup would not be practical since the free-moving layers may cause the inertial objects on top of the shelf to fall off quicker than they would with Setup 1 or even just traditional household furniture.

Setup 3, however, significantly increased the earthquake-resistance of the structure. The hypothesized results of the structure having less movement due to the lower center of mass and a more anchored base was observed during the simulations. This behavior can also be observed in traditional household furniture. However, doing it in tensegrity-integrated furniture is more effective due to the structure weighing less overall, thus making it easier for the center of gravity to be lowered. An alternative option exists where future designs are anchored more to the ground through different means such as being bolted or even through adhesion. Overall, Setup 3 ended up being the most optimal setup during the simulations.

Setup 4 served as the middle ground between the previous setups, having both the tensioner springs and the added weights on the base. This was reflected in the results wherein it had greater earthquake resistance than both Setup 1 and Setup 2, but not to the same extent as Setup 3. The added weights at the bottom helped stabilize it but the oscillation of the top layers caused it to move. Overall, the tensioner springs failed to replicate the measures used in seismic isolation.

More factors could be measured or tested with future research and designs of the furniture. Properly testing

factors such as tensile strength, base dimensions, additional layers, friction of the layers' surfaces, and base anchoring could be done as additional ways to make the structure more effective.

CONCLUSIONS

To summarize, tensile integrity integrated into furniture is a modern take on earthquake safety measures, similar to existing ones like seismic isolation. And with the proper setup and more improvements, its earthquake resistance factor can save lives.

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