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The Use of Bamboo Facades' Frequency to Improve Apartment User's Well-Being

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Abstract

Noise from the road exceeding 40 dB disturbs the room atmosphere and quality of rest in an apartment. The aim of this research will utilize the wind to swing the facade to create background noise that supports the user's well-being. To achieve this, the research utilizes wind to blow facades to produce background noise which also reduces glare from sunlight thereby improving well-being. Experiments were carried out by comparing the results of measuring frequencies of bamboo musical instruments with solfeggio frequencies. The bamboo musical instruments analyzed included 18 *angklungs*, 3 windchimes and 21 variations of bamboo models. The frequencies obtained by the final model are close to that of solfeggio frequencies, namely 432Hz, 639Hz, 747Hz and 852 Hz.

INTRODUCTION

Quality rest occurs if the place we live is comfortable and safe enough for our well-being. Unfortunately, this quality rest does not happen in residential high-rise buildings, including apartments in Surabaya. This is due to the construction boundary line limit of 12% building height resulting in distances between apartment and main road/area being very close. The proximity of the apartment to the main road and area makes it crowded which can disturb users (Agmelina & Ariastita, 2017). Noise from the main road which exceeds 40 dB disturbs the atmosphere of the room and quality of rest including sleep. While sleeping, the room should have a maximum of 30dB of background noise (Jagniatinskis et al, 2021).

The noise problem in apartment units can be solved by using high-speed winds which are naturally occurring in the high-rise buildings. Utilizing the high wind potential with loose façades might be a solution. While façade movements produce noise that humans can hear. If the background noise (*BN)* doesn't exceed a certain level, it does not have an effect (Cowan, 1993). With this in mind, this research endeavors to recycle kinetic façade noise by producing sound that can improve the user's well-being according to sustainable principles (Kuri, 2022).

According to Crotti (2017), when humans hear harmonious sounds going around them (birds singing, and friction of trees) they will feel peace, release and increased well-being. This shows that using natural sounds as background noise which evokes relaxation is better than noise reduction because these sounds can evoke the user's perceptions and emotions. (Mackrill et al, 2014; Kuri, 2022). Iyendo (2016) also said that sound has been shown to reduce stress, blood pressure, and postoperative trauma when compared to silence. Several studies of kinetic façades related to acoustics on façades have been carried out (Jagniatinskis et al, 2021; Alonso et al, 2021) but those studies focused on using façades that are able to reduce noise but not produce sound. While there is previous research that discussed producing sounds with façades (Granville, 2012), most of them utilize static façades (permanent) on a podium which is more for public space and not private space such as in a residential high rise building. The research also has not highlighted the relation to user well-being.

There have been several studies discussing the relationship between acoustics and well-being. (Bates et al, 2022; Andrews et al, 2014; MacDonald et al, 2012) that have focused on the role of music which means using musical instruments or speakers where humans need to operate. These researches, however, have not yet discussed the well-being of humans as objects listening to natural sounds. Smalley research (2022) carried out similar research in a landscape where it is considered easy to hear natural environmental biodiversity such as the sound of water, birds, the scraping of branches related to well-being and human relations with nature. High-rise buildings as residences, however, was not the main focus of the research. As such, there is a knowledge gap discussing kinetic façades that produce natural calming sounds while eliminating glare to improve user's well-being in high-rise buildings.

This study aims to find and improve façade systems that produces sound and also to find out how effective the design is in reducing glare from the sun with the hopes of improving user well-being. This façade system is also designed to be comfortable to look at so that architects can use this technology and façade systems to improve residential well-being without the downside of unpleasant view.

SOLFEGGIO FREQUENCY

Dr Joseph Puleo has done research in traditional healing using music in 1974. He discovered the healing sound in solfeggio frequency. Solfeggio frequency can be used to support the evolution of the human body, mind and spirit (Prince, nd). All solfeggio frequencies have specific healing effects when interacting with the vibrational energy of the human body. The science of sound is useful as a tool to increase human's vibrations and process high energy frequencies for physical or emotional healing (Joseph, 2019).

In table 1, there are 8 solfeggio frequencies. The first frequency is 174Hz is claimed as a natural anesthetic because it tends to reduce physical pain. Next, the frequency of 285Hz is known to influence the energy field and it makes the body refreshed and energized (Hulse, 2009). At 396Hz, it helps provide a sense of security and eliminate subconscious fears, worries and anxieties (Joseph, 2019; Pereira, 2016). According to Aravena (2020) 432Hz frequency provides calm, fun and harmony. Calamassi (2020) explains further, listening to 432Hz music can lower heart rate and have a positive effect on sleep quality. Results of research and experiments by Aravena (2020) and Russo (2017) have shown that 432Hz has good side effects such as providing peaceful, pleasant and harmonious feeling. It even significantly reduces the level of clinical anxiety

Table 1. Effects of Solfeggio Frequencies on Well-Being

Freq. (Hz)	Effects	Source
174	Natural anesthetics because it tends to reduce physical pain	Hulse, 2009
285	Helps in expanding consciousness. Affects the energy field which can make the body refreshed and energized	Hulse, 2009
396	Gives a sense of security and helps to get rid of subconscious fears, worries and anxieties	Joseph, 2019; Pereira, 2016
432	Proven to lower heart rate, increase feelings of peace, joy and harmony. Improve sleep quality.	Aravena, 2020; Russo, 2017; Calamassi, 2020
528	Increases energy, clarity of mind, awareness, creativity, feelings of joy, activates the user's imagination, intention and intuition, relieves stress, and positive energy in life, can extend the life of cells by about 20% in specimens treated with ethanol so it may have healing properties.	Hulse, 2009; Akimoto, 2018; Pereira, 2016; Linsteadt, 2013; Prince, n.d
639	Creating community, strengthening harmonious relationships and building interpersonal relationships. Improve communication, mood, emotion, understanding, tolerance and love. Has an influence on balance, health and tranquility	Hulse, 2009; Pereira, 2016; Linsteadt, 2013
741	Detoxification frequency, increase self-expression, and help problem solving.	Joseph, 2019
852	Helps relieve nervousness and anxiety, helps awaken intuition.	Joseph, 2019; Pereira, 2016

(Source: Hulse, 2009; Joseph, 2019; Pereira, 2016; Aravena, 2020; Russo, 2017; Calamassi, 2020; Akimoto, 2018; Linsteadt, 2013; Prince, nd)

The frequency of 528Hz is known as healing music because it is related to the environment and life on earth. The ancient Egyptians used the Solfeggio frequency scale of 528Hz throughout space to produce specific effects on individuals (Hulse, 2009). Part of the reason is because the frequency of 528Hz is deeply rooted in nature and can be found in oxygen, rainbows, grass, and the buzzing of bees, making it a powerful tool for connecting to the world around us (Akimoto et al, 2018). The frequency of 528Hz is also known to reduce stress levels (Akimoto et al, 2018), increase energy, clarity of mind, awareness, awakened or activated creativity, feelings of joy, activate one's imagination, intention and intuition (Pereira, 2016; Linsteadt, 2013). Prince (nd) show that at a frequency of 528Hz has been shown to repair DNA. The study by Akimoto (2018) found that this frequency can extend cell life by about 20% in ethanol-treated specimens.

Frequencies of 639Hz, allows the creation of a harmonious community and builds interpersonal relationships (Hulse, 2009). Healers and meditators use this frequency on individuals when dealing with relationship problems such as within the family, between partners, friends or social issues. This Solfeggio frequency promotes communication, understanding, tolerance and love. Psychiatrists and psychologists refer to this frequency as harmonizing relationships, in a way that fills the listener's private mind and influences balance, health, and calm.(Linsteadt, 2013; Pereira, 2016).

Sounds and music at 741Hz can help detoxify because this frequency helps for self-expression, and can improve problem solving (Joseph, 2019). While 852Hz is a frequency that is related to the ability to see through one's illusions and intuition. As well as helping to relieve nervousness and anxiety (Joseph, 2019; Pereira, 2016).

METHODOLOGY

The research method this time, is quantitative with experiments and design simulations through Sketchup and IESVE. This is in accordance with the opinion of Jaedun (2011), that experimental research is generally laboratory based on a quantitative paradigm. Quantitative research is mostly applied to hard-science research, such as biology and physics.

This research uses previous studies as a baseline, such as the precedents of bamboo musical instruments (*angklung* and wind chimes) measured frequency, dimensions, length, cutting and thickness. There are 18 *angklung*s that are measured, from G4 to C6. Frequency measurement is done by playing the *angklung* or vibrating the *angklung* with human power.

Afterwards the frequency of 3 dimensions of local bamboo wind chimes is measured. These wind chimes are rung using natural wind so it's frequency is dependent on certain wind speeds. The two baselines were analyzed as the basis for the 6 variations of the first experimental model which were carried out in an experiment with a scale of 1:1. The six variations are distinguished from dimensions (30 cm, 40 cm, 50 cm), 2 axes (top and middle), and bamboo joints (rubber and rope). As a result, there are twelve in the first experiment.

The results of the first experiment were analyzed and the best result was used for the second experimental model. The second experiment has six more variations of the focused model of the first experiment. Experiments were carried out using natural wind to ensure that the bamboo could move and make sounds. The experimental results are documented and analyzed to determine the focus of the third experimental model. In the third experiment, there were 2 similar bamboos with variable shapes, straight and truncated. Both bamboo sticks are cut, but distinguished by the location of the axes. The interior bamboo with the axis at the end causes the outer bamboo to be cut in half. Whereas the interior bamboo has an axis in the middle, causing the outer bamboo to remain intact. The experiment was still carried out in an open space and the frequency was measured indoors. The various models that have been found are arranged into façades for glare reduction analyses using IESVE application.

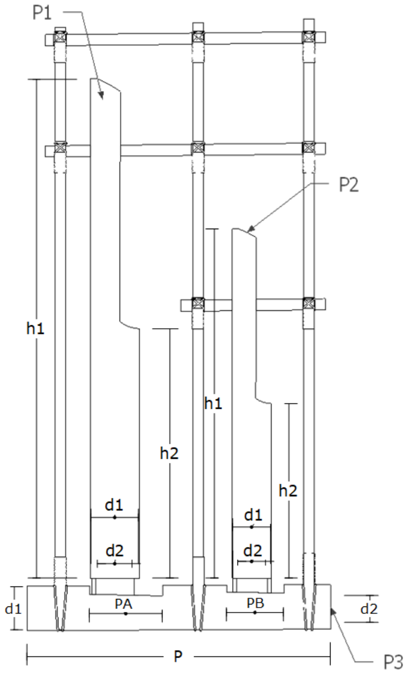
RESULTS

Baseline *Angklung*

Angklung consists of 3 truncated tubes (figure 2a), this is done to limit the weight of 1 unit of *angklung*. The sound is produced by the vibration of legs P1 and P2 hitting P3. This process requires a physical input. In this study, the frequencies were measured (figure 2b) from G4 (389Hz) to C7 (2054.95Hz). The results of the *angklung*s frequencies are more stable and easier to predict because the possible movements are limited. The tone produced is precise because it is pre-tuned according to the specified frequency and pitch. The frequency of the P2 bamboo is 1 octave above the P1 bamboo. That's why pipe 2 note A4 is the same as pipe 1 note A5.

Frequency results are also affected by the percentage of cuts. The percentage of bamboo cutting increases the frequency produced. In order to achieve a frequency close to 396Hz (G4), the ratio of clipped and uncut bamboo is 7:6 or 53.8% truncated. Then if we want to get a frequency close to 432Hz (A4) then the ratio is truncated 7:5.4 or 56.6%. Meanwhile, to approach the frequency of 528Hz (B4 and C5), the ratio of clipped to uncut bamboo is 7:4.89 or 7:4.94, if both are rounded up, it has the same ratio, namely 7:4.9. In percentage it reached 58.9% and 58.6%.

The ratio of truncated and uncut bamboo to get a frequency close to 63 Hz (D5 and E5) is 4:2.6 or 4:2.4. The percentage of cuts obtained are 60.9% and 52.5%. Meanwhile, to approach 741Hz (F5 and G5), the ratio of truncated bamboo and uncut bamboo is 4:2.55 and 4:2.46. If both are rounded, the comparison is slightly different, namely 4:2.6 and 4:2.5. As a percentage, it is found that it is 61.4% and 62.1%. Lastly is the A5 note whose frequency is close to 852Hz. Where the ratio is 5:3 or truncated by 63.1%. The thickness of the five bamboos is the same, namely 0.4 cm. Overall it can be seen in table 2.



(a)

Note	Pipe 1 (tall) d2	d1	h1	h2	thick	freq. (Hz)	standard freq.	Well-Being Freq.	Pipe 2 (short) d2	d1	h1	h2	thick	freq. (Hz)	Overall Freq.	Well-Being Freq.
G4	3,4	4.5	48.3	22.3	0,5	389	384	396	2,5	3,1	31	22	0,3	765,63	765,63	741
A4	3,4	4.2	45.4	19,7	0,5	447	432	432	2,6	3,3	29,2	10,2	0,3	906.25	906,25	852
B4	3,3	4	42.9	17,6	0,5	500	484.9	528	2,4	3,1	27,2	9	0,4	1046.9	1046.9	-
C5	3,1	4	40.6	16,8	0,4	533	513.74	528	2,2	3,1	25,2	8,8	0,3	1062.4	1062.4	-
D5	3,1	3.8	38.4	15	0,4	593	576.65	639	2,1	3	23,3	7,7	0,3	1187.5	1187.5	-
E5	2,9	3.7	35.8	13,4	0,4	625	647.27	639	2	2,5	21,3	6,7	0,3	1328.1	1328.1	-
F5	3	3.7	33.7	13	0,4	690	685.76	741	2,3	2,7	20	6,5	0,2	1468.8	1468.8	-
G5	2,9	3.5	31.2	11,8	0,4	765.63	769.74	741	2,2	2,7	18,3	6	0,2	1609.4	1609.4	-
A5	2,8	3.4	29	10,7	0,4	906.25	864	852	2	2,5	16,8	5,3	0,3	1750.1	1750.1	-
B5	2,5	3.2	27.5	9,6	0,35	1046.9	969.81	-	1,8	2,3	15	4,9	0,25	2031.3	2031.3	-
C6	2,6	3.2	25	8,5	0,25	1046.9	1027.47	-	1,8	2,1	13,5	4,9	0,25	2171.9	2171.9	-
D6	2,7	3.1	23	7,5	0,2	1187.5	1153.3	-	1,7	2,1	12,5	4	0,2	2453.1	2453.1	-
E6	2,4	2.9	21.3	7	0,25	1328.1	1294.54	-	1,5	1,9	11,1	3,8	0,2	2734.4	2734.4	-
F6	2,3	2.7	19.6	6,7	0,25	1468.8	1374.51	-	1,5	1,9	10,2	3,6	0,2	2875	2875	-
G6	2,1	2.6	18.1	6	0,25	1561	1539.47	-	1,3	1,8	9	3,4	0,25	3296.9	3296.9	-
A6	2,1	2.5	16.6	5,6	0,2	1750.1	1728	-	1,4	1,8	8,3	3	0,2	3578.1	3578.1	-
B6	1,8	2.3	15	5,1	0,25	2031.3	1939.61	-	1,2	1,6	7.4	2,9	0,2	3718.8	3718.8	-
C7	1,8	2.2	13.7	4,8	0,25	2171.9	2054.95	-	1,2	1,4	6,6	2,8	0,2	4140.6	4140.6	-

(b)

Figure 2. (a) *Angklung*'s Notation; (b) *Angklung* Measurement Results

Table 2. Frequency and Percentage of *Angklung* Tone Cutting

Note	*Angklung* P1's Freq. (Hz)	Freq. Solfeggio	Truncated	Whole	Percentage cut (%)	Comparison truncated	Comparison untruncated	Thickness
G4	389	396	26.0	48.3	53.8%	7	6	0.5
A4	447	432	45.1	45.4	56.6%	7	5.4	0.5
B4	500	528	42.9	42.9	58.9%	7	4.89	0.5
C5	533	528	40.6	40.6	58.6%	7	4.94	0.4
D5	593	639	38.4	38.4	60.9%	4	2.6	0.4
E5	625	639	35.8	35.8	62.5%	4	2.4	0.4
F5	690	741	33.7	33.7	61.4%	4	2.55	0.4
G5	765.63	741	31.2	31.2	62.1%	4	2.46	0.4
A5	906.25	852	29.0	29	63.1%	5	3	0.4

Baseline Windchimes

This experiment uses 3 types of wind chimes (table 3). The first wind chimes (WC) consisted of 5 bamboo units arranged in a circle with a coconut shell beater (figure 3a). The yellow bamboo node is placed on top. The bamboo is light but the distance between the units is far, so that in 15 seconds it gets 38 clinks with the highest frequency at 1500Hz and the lowest is 81Hz (figure 4a). The wind during the experiment was a turbulent wind with a maximum speed of 12.3 m/s and a minimum of 3.1 m/s.

Differences in bamboo cutting were also analyzed, WC 1 had a cutting percentage of around 56.29-59.42% with an average of 57.55%. While WC 2 has a percentage of deductions from 55.02-55.98% with an average of 55.59%. Not much different, the third WC has an average cut of 55.55%. There are 6 bamboos with different cuts from 53.89% to 58.44%.

Table 3. The Difference Between Three Wind Chimes

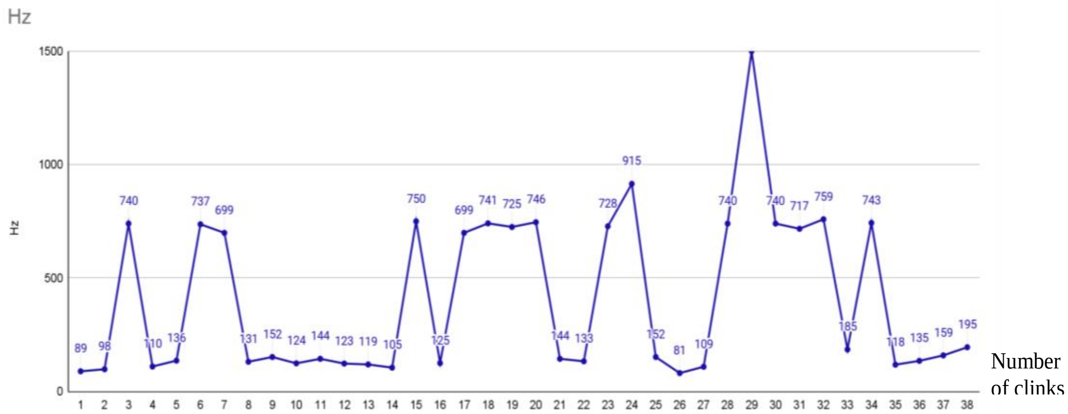
Category		Windchimes 1	Windchimes 2	Windchimes 3
Bentuk		circular, 5 vertical bamboo collided with the wooden pendulum	The 3 vertical bamboos are arranged linearly and mirror with the other side, colliding with the horizontal bamboo	circular, 6 black bamboo collided with the wooden pendulum
proximity of bamboos		1,5 - 3 cm	1 cm	0,8 - 1,5 cm
Pendulum height		18 cm	10 cm	16,5 cm
Pipe 1 (longest) (cm)	h1	34.5	36.8	40.9
	h2	15	16.2	17
	percentage	56.52%	55.98%	58.44%
	D1	3,8 cm	3 cm	4,7 cm
	Thickness	0,3 cm	0,2 cm	0,4 cm
Pipe 2 (shortest) (cm)	h1	27	28.9	30.6
	h2	11.6	13	14
	percentage	57.04%	55.02%	54.25%
	D1	3 cm	2,8 cm	3,4 cm
	Thickness	0,3 cm	0,2 cm	0,3 cm
Pipe 3 (cm)	h1	32.3	36.8	34.1
	h2	13.4	16.2	15.3
	percentage	58.51%	55.98%	55.13%
	D1	3,5 cm	3 cm	3,8 cm
	Thickness	0,3 cm	0,2 cm	0,3 cm
Pipe 4 (cm)	h1	30.8	28.9	38.6
	h2	12.5	13	17.8
	percentage	59.42%	55.02%	53.89%
	D1	3,4 cm	2,8 cm	4,2 cm
	Thickness	0,3 cm	0,2 cm	0,5 cm
Pipe 5 (cm)	h1	28.6	36.8	32.5
	h2	12.5	16.2	14.3
	percentage	56.29%	55.98%	56.00%
	D1	3,5 cm	3 cm	3,7 cm
	Thickness	0,3 cm	0,2 cm	0,3 cm
Pipe 6 (cm)	h1	–	13	36.5
	h2		13	16.2
	percentage		-	55.62%
	D1		2,6	4,1 cm
	Thickness		0,4	0,4 cm
Number of clinks		38	39	45
Wind Speed	max	12.3 m/s	11 m/s	8.7 m/s
	min	3.1 m/s	0.3 m/s	0 m/s
Freq. (Hz)	max	1500	1235	1207
	min	81	94	100

Although the second WC also uses yellow bamboo, instead of 5, there are 6 bamboos are arranged linearly and divided into 2 mirror layers (figure 3b). Vertical bamboo no longer has nodes, so foam is added at the ends of the bamboo. While the pendulum is a horizontal bamboo that has no nodes. Maximum wind speed is 11m/s and minimum 0.3 m/s. Produces a maximum frequency of 1235Hz and a minimum of 94Hz (figure 4b).

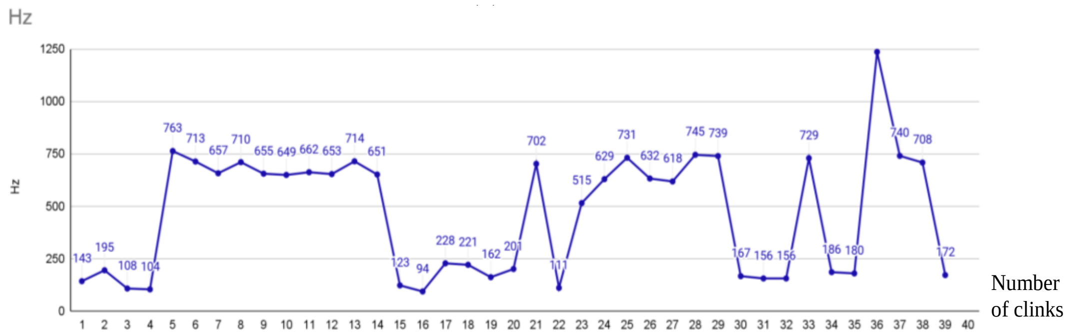
The third WC (figure 3.c) has 6 vertical bamboos with the largest bamboo dimension so that the distance between the bamboos and the distance to the pendulum is short. Because of its size, it requires more energy to move but easily collides and produces sound. As a result, 45 clinks are generated in 15 seconds, even though the wind speed is a minimum of 0 m/s and a maximum of 8.7 m/s. The type of bamboo used is black bamboo so the sound produced is also more pleasing to the ear. The maximum frequency is 1207Hz and minimum frequency is 100Hz (figure 4c).

(a) (b) (c)

Figure 3. (a) The First WC, (b) The Second WC, (c) The Third WC



(a)



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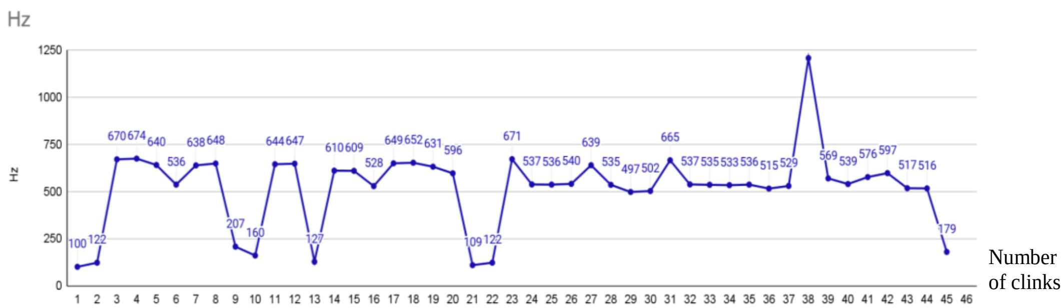


(c)

Figure 4. (a) WC 1 Frequency Chart ; (b) WC 2 Frequency Chart; (c) WC 3 Frequency Chart

Experiment

The twelve variants have a resulting frequency with a close proximity to the solfeggio frequency of 1 - 63Hz (Table 4). Of the 12 variants, the best variant for apartments are D, E, K, and L. This is because these variants produce frequencies close to the solfeggio frequencies that are appropriate for residents, such as 285Hz, 396Hz, 432Hz and 528Hz. All solfeggio frequencies have some positive impacts. So all the variants are equally valuable to be focused on. As such, the focus for the next experiment is fixing the constraints and joints, such as the weight of the bamboo and the stiff joint, in hopes of increasing the movement capacity of the bamboo when it is struck by wind.

Table 4. Analysis of the first 12 Experimental Variations

Varia-tion name	Variable				Freq. (Hz)	Solfeggio Freq. (Hz)	Further Information
	Material Joint	Bamboo's Length	Interior Modif.				
			Length	Axis			
A	Rubber	30	40	Node above	408; 742; 682	432;741; 639	Makes no sound, swings occasionally but sound occurs only once in a long time
B	Rubber	30	25	In the Middle	407; 627; 643	432; 639; 639	produces more sound because the axis is in the middle but still doesn't sound when the wind blows (joint problem)
C	Rubber	40	50	Node above	356; 111; 600	396; 174; 639	It doesn't make a sound, it's even hard to swing when the wind blows. probably due to its weight, but the rubber makes it easier to swing
D	Rubber	40	30	In the Middle	429; 499	432; 528	It doesn't produce sound, it's even hard to swing, but it's better than EF, because the joint material is rubber (more elastic), and the axis in the middle makes it easier to swing.
E	Rubber	50	60	Node above	400; 321; 895	432; 285; 852	It doesn't make a sound, it's even hard to swing when the wind blows. probably due to its weight, but the rubber makes it easier to swing
F	Rubber	50	35	In the Middle	624; 311; 348	639; 285; 396	It doesn't make a sound, it's even hard to swing when the wind blows. probably due to its weight, but the rubber makes it easier to swing
G	Rope	30	40	Node above	614; 631; 283	614;631; 283	Swing, but AB swings more easily. Also AB and OP sound more than G
H	Rope	30	25	In the Middle	650; 709; 603	650;709; 603	Swinging but it's easier to swing if the material is rubber. But H is better than MN
I	Rope	40	50	Node above	619; 715; 735	619;715; 735	It doesn't make a sound, it's even hard to swing when the wind blows. probably due to its weight.
J	Rope	40	30	In the Middle	321; 591; 957	321;591; 957	It doesn't make a sound, it's even hard to swing when the wind blows. probably due to its weight.
K	Rope	50	60	Node above	331;324; 346; 600	331;324; 346; 600	It doesn't make a sound, it's even hard to swing when the wind blows. probably due to its weight.
L	Rope	50	35	In the Middle	449; 471; 428	449;471; 428	It doesn't make a sound and it's even hard to swing when the wind blows, probably due to its weight, but the L variation is better than the UV variation

The second experiment focused on changing the joints and cutting the bamboo properly into wind chimes. Another modification is to change the bamboo interior to be cut, either in half (no. 5, 6) or using smaller dimensions (no. 1, 2). Afterwards, the joints are replaced so it does not lock up the bamboo. It was observed that the joint should be at the top center point, as this makes movement easier. Three different joint configurations were tested. First using an iron hook as a holder (no. 2,4,6), do the bamboo. Similarly, a few iron hooks were bent and tied up into one point (no. 5). Finally, using an iron plate as a holder (no.1,3). Then the joints and axes in the bamboo interior were also altered, upper axis (no. 1,2,6) and middle axis (no.3,4,5). Lastly, the length of the pendulum bamboo was also modified to represent chimes in general (no.1, 2). As a result, there are 6 variations (Table 5) of the second experiment, with the frequencies depicted in Figure 5.

As shown in table 5, models 1 and 2 are distinguished by being coated with iron plates on both sides or only one side. As a result, both were light and made a sound, but the sound was not the result of the colliding bamboos but instead of the zinc plate with iron hanger, the zinc plate with small bamboo bolts, and the meeting of iron hanger with bamboo. This causes an unpleasant sound and produces high frequencies. The frequencies of the first models were very high, as high as 5272Hz and nowhere near solfeggio frequencies. While number 2 is still highly volatile, reaching 3364Hz and only 1 is close to the solfeggio frequency (852Hz).

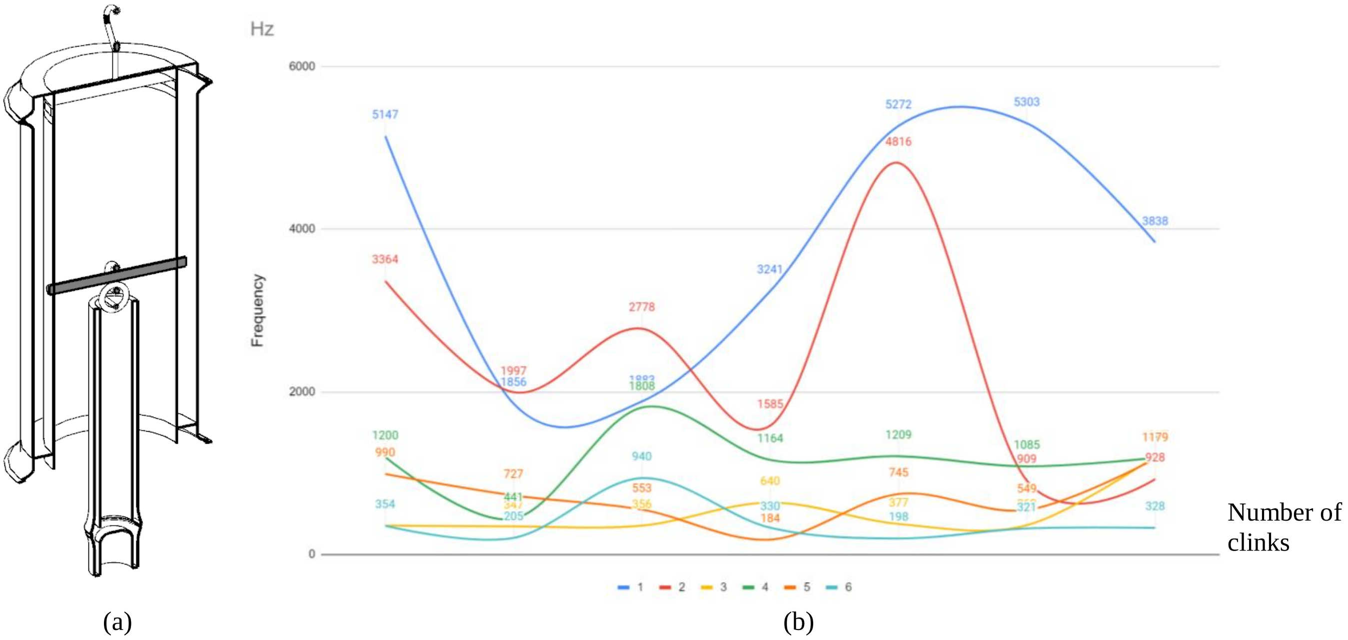


Figure 5. (a) Model Number 6 Perspective Cut (b) Second Experiment Frequency Graph

Table 5. Analysis of the Second Experiment

No	Freq. (Hz)	Freq. Solfeggio	Strength	Weakness	Variable		
					Independent	Dependent	Control
1	5147; 1856; 1883; 3241; 5272; 5303; 3838	-	produce sound, light so move easily	Because it uses a zinc plate as a support, it makes it difficult for the pendulum to move due to the circular boundaries of the zinc plate, the majority of the sound is iron meets zinc.	Shape, interior bamboo modification s interior axes, joints, joint materials, types of bamboo	Bamboo kinetic, Length (30 cm), bamboo diameter	Wind speed
2	3364; 1997; 2778; 1585; 4816; 909; 928	852	produce sound, light so move easily	The sound is not the clash of bamboo against bamboo, but the clash of zinc plates with iron hooks or the clash of bamboo iron hooks or the clash of bamboo bolts with zinc			
3	357; 347; 356; 640; 377; 362; 1207	396; 396; 396; 639; 396; 396; -	The joints are the easiest to move large bamboo units, the interior axis of the bamboo is in the middle so that the moment force to swing is not much	Because the interior bamboo is intact (not cut) it is difficult to swing and produce sound. the bamboo swings but doesn't make a sound	Shape, modification of the bamboo interior, interior axis, joints, joint materials	Bamboo kinetic, Length (40 cm), bamboo diameter	Wind speed
4	1200; 441; 1808; 1164; 1209; 1085; 1189	432	It sounds the most because once it swings it is able to glance off the interior bamboo, this is because the bamboo is truncated and the axis is in the middle so that it is lighter and easier to swing.	Using rubber material so that it is heavier to swing, it would be better if using small strings or ropes. Also better to use only one joint above like number 3			
5	990; 727; 553; 184; 745; 549; 1179	852; 741; 528; 174; 741; 528; -	the fifth variant is the second easiest to sound, this is because the interior bamboo is cut in half. the resulting sound is more pleasing to the ear	Because the interior bamboo axis from above sounds less frequently than number 3.	Shape, modification of the bamboo interior, interior axis, joints, joint materials	Bamboo kinetic, Length (40 cm), bamboo diameter	Wind speed
6	354; 205; 940; 330; 198; 321; 328	396; 174; 852; 285; 174; 396; 396	The upper joint is easy to swing the bamboo because the bamboo axis is in the middle	Rarely produces sound because the interior bamboo is not cut			

The third experiment has reduced variation and focused on the final 2 shapes. Both bamboo sticks are cut, but are differentiated by the location of the axes. The interior bamboo with the axis at the end (3B) causes the outer bamboo to be cut in half. While the interior bamboo with an axis in the middle (3A), causes the outer bamboo to remain intact. The results of the frequency are displayed in the graph in Figure 6.

Both models in experiment 3 move, and produce sound but the first model still has weaknesses. On the 3A model, the hanger beneath the interior bamboo is insignificant, even visually disproportionate. Next, the iron joint underneath sometimes collides creating an unpleasant sound in high frequencies. When compared with the solfeggio frequency, this is avoided because it is more than 1000Hz.

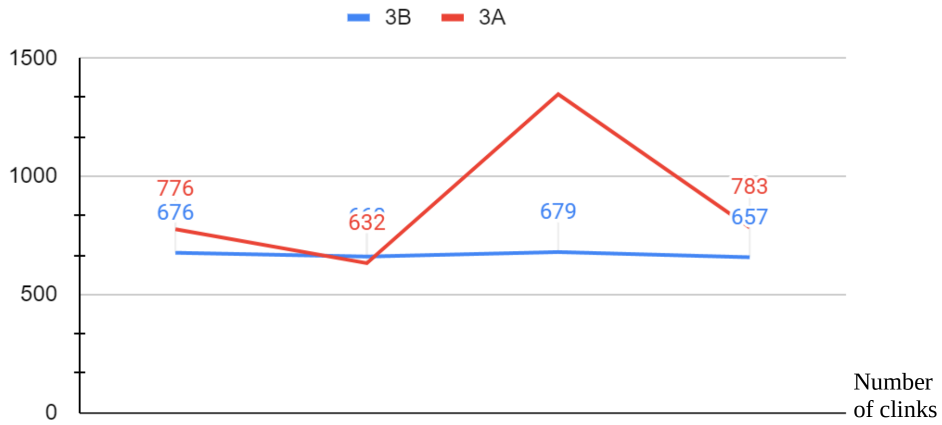
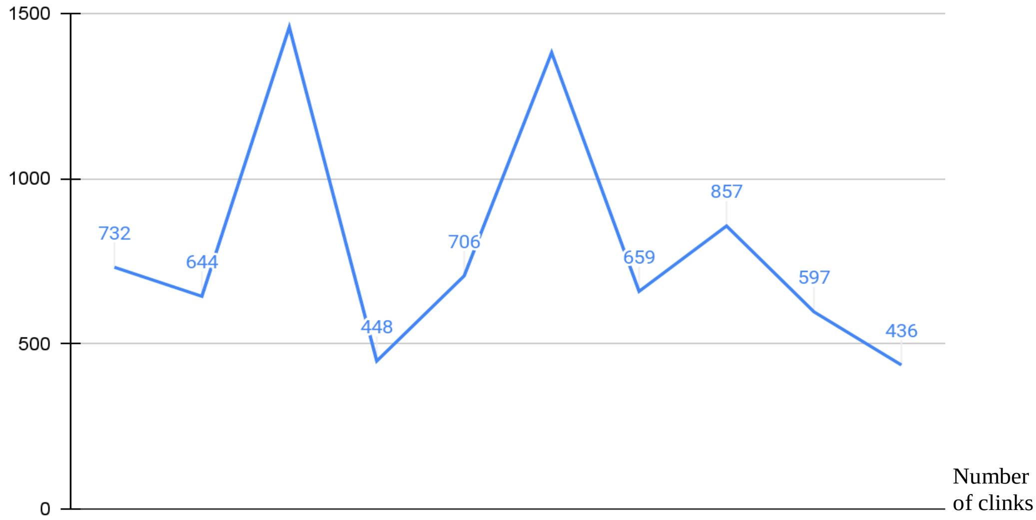


Figure 6. Third Experiment Frequency Graph

The finalization of the shape simply transforms the bamboo interior into pendulum wood. The final form promotes movement. This is achieved by a lightweight pendulum hook and hanger using thin ropes. As such, a slow wind (0,8-2,8 m/s) could move it. The hanger under the pendulum is also effective because it is able to provide a movement when the wind blows, causing clinks. The sound produced is also pleasing to the ear. This is because these frequencies are close to the solfeggio frequencies and the distance is not too far, only 4-42Hz. Also the final form also stably provides 3 variations of solfeggio repeatedly, namely 432, 639, 741, 852Hz (figure 7a, 7b).

Freq. (Hz)	Solfeggio Freq.
732	741
644	639
1459	-
448	432
706	741
1382	-
659	639
857	852
597	639
436	432

(a)



(b)

Figure 7. (a) Final Shape Frequency Analysis; (b) Final Shape Frequency Graph

Each final shape frequency obtained has a positive impact that can improve the user's well-being. Starting with a frequency of 432Hz which has a positive impact and has proven to lower heart rate, increase feelings of peace, joy and harmony. It can also improve sleep quality which is desirable for user's everyday life. Next, the frequency of 639Hz can create community, strengthen harmonious relationships and build interpersonal relationships. Moreover, it also improves communication, mood, emotion, understanding, tolerance, and love. It also has an influence on balance, health and tranquility so it is good for improving the well-being of apartment users. The next frequency is 741 which is known as the detoxification frequency, which can increase self-expression and help problem solving.

In conjunction with the 852Hz frequency, it can help relieve nervousness and anxiety, helps awaken intuition. That way it can improve the user's well-being when hearing this bamboo on the façade.

DISSCUSSION

In the *angklung* study, it was found that the shorter and smaller the dimensions of the bamboo, the higher the frequency. Conversely, the longer and larger the dimensions of the bamboo, the lower the frequency. This is due to the difference in wavelength, the longer the wavelength, the lower the frequency. That's why bamboo pipe 1 on G4 has the lowest frequency of 389Hz because it has the longest and the largest dimension. Bamboo pipe 2 on C7 or also called C8 has the highest tone of 4.1408 kHz because it is the shortest and has the smallest diameter.

The bamboo nodes on the angklung are still intact creating a resonant tube which magnifies the sound and doubles the wavelength. Therefore, even though bamboo is not long, it is still able to get low frequencies. So if we want to get frequencies within the solfeggio range, we can use the dimensions recommended according to the baseline to make the same wavelength and frequency. Starting from 3-4.5 cm in diameter and 30-50cm long. The thickness of the bamboo is between 0.4-0.5cm according to the dimensions of the bamboo. At least the proportion of cutting is half bamboo, in fact the general range is 53.8-63.1%.

In the study of wind chimes, visually the WC 2 looks effective for producing sound but in fact it is not so effective because the wind moves turbulently, so the WC rotates more often on one main axis (moment of inertia) than moving back and forth. Because of that, clashes didn't happen often, only 39 clinks in 15 seconds. While WC 1 and 3 have a circular shape that responds to turbulent winds. Balanced with the weight of the bamboo so that even though the wind speed is high (4.3-12.3 m/s) the wind chimes do not just spin around but collide with each other. Meanwhile, with low wind speeds (0.1-4.2m/s), a light pendulum in the middle still creates a moment, causing it to collide and make a sound.

In the WC research, a formula cannot be found because the concept of WC is toneless and not rigid. This is to increase the opportunities for movement and sound to be produced. The resulting frequency is also varies and fluctuated a lot. The most stable frequency is found in WC 3 with 1 peak, 3 valleys and an average of 600Hz. That's because WC3 has a small spacing between bamboos making the bamboos collide stably in certain areas. Whereas WC 1 and 2 have a rather far distance, allowing the bamboo to touch other parts of the bamboo which creates high frequencies. This distance also makes the bamboos rarely clash so there is a part of the sound with low frequencies. However, from wind chimes, the writer can learn how bamboo can move and make sounds. Bamboo moves because the joints in the main bamboo are loose so it can move in all directions. Furthermore, the shape of the truncated bamboo helps in the process of movement because the bamboo is lighter and the truncated part receives the wind's force. The circular pendulum part adapts to the circular shape of the windchimes. The thickness of the pendulum is thin so that it is not heavy and easily moved by the wind. At the bottom of the pendulum use 5x10cm bamboo strand. This strand is thin and light so it is easily moved by the wind. The movement of the bamboo strand creates a pendulum moment. The pendulum connection with bamboo strand uses a lightweight material so that it is easily moved by low wind speeds. The pendulum and bamboo strands are shaped to be light to hold on to the thin rope.

The first experiment concluded that it was necessary to use a pendulum from inside the bamboo to produce a better sound, due to resonance. The smallest dimension of black bamboo is about 3-4 cm in diameter. Therefore, the bamboo consists of 2 layers, the interior bamboo (4cm in diameter) and the main bamboo (8cm in diameter). After experimenting, it was found that bamboo with a diameter of 8 cm has a bass (low) sound so it is easy to get solfeggio frequencies. The 8 cm bamboo emits a bass sound because the larger and longer dimensions make the wavelengths longer so that the frequency is lower according the formula $f=v/\lambda$. however, the large dimensions are heavy, making it difficult to be moved by the wind even with wind speeds of more than 10m/s

From the second experiments of models 3, 4, 5, and 6, it was found that if the interior bamboo was cut in half like wind chimes, the resulting frequency would be higher than if it was not cut. This is because the rebound in the bamboo occurs more if they are not cut off, as a result the wavelengths are longer and produce lower frequencies. However, the bamboo material still allows getting low frequencies compared to using iron and zinc materials.

The best frequency in the second experiment is model number 6 because the frequencies produced were around 174Hz, 285Hz and 396Hz repeatedly. Model 5 is also comparable to this because it is also close to the given solfeggio frequency variations of 174Hz, 528Hz, 741Hz, and 852Hz. While models no. 1 and 2 were eliminated because the resulting frequency was high, and it was difficult to produce a good sound because it used yellow bamboo inside. Yellow bamboos have convex nodes and the bamboo fibers are not evenly aligned so that the sound reflection in it is not clear. That's why it's better to use black bamboo like wind chime 3.

In the second experiment, the joint is best if it is in the middle axis like No. 4, 5, and No. 6. While the movement is best when the inner bamboo is cut and the axis is in the middle. The joint material with the pendulum was replaced by using a thinner rope to reduce weight and increase movement. It would be better if the bottom of the pendulum (bamboo interior) was added with strands of bamboo similar to wind chime to increase moment of force from the wind speed. As such, the next experiment (third) focuses on the most ideal truncated shapes for movement and generate frequencies to improve well-being.

On the 3B model, the sound produced is more pleasing to the ear. This happens because the resulting frequency is more stable because it goes through a cutting process which is a bamboo stem process. Same as the process on the *angklung*. The unit is also lightweight because it is truncated making it easier to swing. The resulting frequency is close to 639Hz, which has the side effect of increasing communication, mood, emotion, understanding, tolerance and love. It also influences balance, health and calm.

The cutting of the main (outer) bamboo in experiment 3 was adjusted to the average cutting of the bamboo in the wind chime. The average truncated part of wind chimes bamboo is 56.16%, while the cut part of bamboo 3B is 56.25%. In angklung, if the bamboo is cut around 56% it will get a frequency close to the solfeggio frequency of 432Hz (A5). This is in accordance with the results of the final bamboo frequency where there are 2 frequencies close to 432Hz. This cutting process not only helps with movement but also helps reach the solfeggio frequency range. However, the percentage of cutting does not guarantee a consistent frequency like the tone of the angklung. The finalized form is an improvement over the 3b model, but the bamboo interior is modified using a thin wooden circular pendulum to adjust the wind chime to make it easier to move.

CONCLUSION

The experiment results show that the bamboo model from experiments 1 to 4 mostly approached the solfeggio frequency. This is because bamboo is a material capable of producing sound with low frequencies (bass). Influenced by the large dimensions of the bamboo, which is 8 cm in diameter, the sound waves become longer resulting in a lower frequency. This lower frequency approaches the solfeggio frequency. However, when the bamboo is cut, the resulting frequency is higher (reduced wavelength). That's why the final form of bamboo gets a rather higher frequency of 432, 639, 747 and 852Hz. The final form of bamboo is easily moved by the wind at low wind speeds because it is light and the bamboo system creates moment. The final form stably produces a frequency close to the solfeggio frequency with the least difference compared to other models. Factors supporting the results of the frequency are the cutting of bamboo, intact bamboo nodes, pendulum material, and the type of bamboo. The effects given are also able to improve the welfare of apartment users such as improving sleep quality, providing a feeling of peace, improving mood, reducing anxiety and affecting calm and balance. For future research, it is suggested that variables such as tone, rhythm, sound intensity, thermal, and how users feel in it is highlighted.

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