Marimba Instrument Construction from Kayu Malam Wood (*Diospyros maingayi*)

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This work investigated the possibility of using a local wood Kayu malam (*Diospyros maingayi*) to construct a marimba, a musical instrument. The marimba was constructed as similar as possible to the commercial rosewood marimba. The sound and established frequencies were compared with a commercial rosewood marimba. The findings showed that although the peak value of the spectrum from the prototype marimba differs from pitch to pitch, it is useful to note that the prototype marimba was tuned according to piano standard. The commercial marimba only has peaks at the lower end of the spectrum whereas the prototype marimba contained peaks up until the higher end of its spectrum. The marimba made of Kayu malam (*D. maingayi*) produced the same pitch as the marimba made of rosewood.

Keywords: Kayu malam (Diospyros maingayi); Marimba; Frequency and pitch

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INTRODUCTION

A marimba is a wooden musical instrument that has a number of bars with different lengths that correspond to a different pitch with a different frequency spectrum. The instrument is commercially made from rosewood because the wood is a dense hardwood, although it is very expensive and difficult to cut (Suits 2001). Rosewood's resonant qualities (*i.e.*, low damping factor) cause it to ring much longer when struck. A clean, knot-free portion of a large board must be selected because all of the bars should be made from the same board so that the tone quality and appearance will be uniform (Flynt 2009). Kayu malam with density of 605 kg/m^3 is chosen based on its physical and mechanical aspects, such as decay resistance (the wood is resistant to decay and no pretreatments are involved), dimensional stability, ease of processing, and appearance, which consists of texture, grain pattern, and color. The sound absorption coefficients at 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz octave frequencies are 0.06, 0.17, 0.41, 0.72, 0.87, and 0.92, respectively (Mohammad *et al*. 2010). Kayu malam is advantageous in its comparative abundance and is relatively easy to shape with simple tools. The unique and desirable spectrum of the physical and mechanical properties of kayu malam makes it the choice for musical instruments that matches the manmade materials such as plastic or metal. Kayu malam is scientifically known as *Diospyros maingayi* from the Ebenaceae family found in Borneo, Peninsular Malaysia and Sumatra. The tree is named after the British botanist A. C. Maingay.

In the construction of musical scales, the scale is built upon the plan of having as many pairs of tones as possible, which is pleasing to hear when sounded together. The standard keyboard consists of a white, seven note diatonic scale, C-D-E-F-G-A-B-(C), repeated over seven octaves, into which 5 black-note pentatonic scale, C#-D#-F#-G#-A#-(C#), is subverted. The technique of solfege involves assigning the notes of a scale to a particular syllable. The seven syllables commonly used for this practice are *do, re, mi, fa, sol, la,* and *ti*. A scale is best defined as a sequence of notes. The scale translates the pitch location into a spatial location on a graph. Each note corresponds to an audible division of the octave space (Olson 1967). The notes are separated by intervals, with some larger than others. The ear perceives certain intervals as regulatory consonances, but these tend to be the larger intervals: octave, fifth, and fourth, with the smaller intervals being ambiguous. Because the smaller intervals of semitone, tone, and thirds are less easy to quantify by ear, the question arises whether pitches should be considered as precise frequency locations. In everyday music making, a written note is regarded as not corresponding to a fixed point in the pitch spectrum, but to a region of acceptable pitch variation.

The definition of middle C, for example, is what the ear accepts as lower than C sharp and higher than B natural, and so on. It could be possible that modes and scales are simply octave divisions of convenience, determined by a mixture of guesswork and musical function. The octave is subdivided into five for a pentatonic scale, or seven for a diatonic scale or mode. A small correction is applied by tuning individual notes, playing and listening until the resulting progression of pitches is pleasing to hear, and expresses a well-defined character. The frequency of a pure sound determined the pitch. An F sharp is slightly higher than an F whereas an E flat is slightly lower than an E.

The stiffness of the wood is a factor that determines the pitch. Although wood has a series of overtones, these overtones are not harmonics. The pitches produced from these overtones are not an integral multiple of their fundamental pitch. This non-harmonicity in wood yields a distinctive tone. For a uniform cross-section middle C bar without undercut, the pitch of the overtone corresponds approximately to F sharp (Flynt 2009). A bar with a uniform cross-section will vibrate with frequency directly proportional to its thickness but inversely to the square of its length. Therefore a bar with half its original thickness will produce half the original pitch whereas a bar with half its original length will produce quadruple the original pitch.

To sharpen or flatten the pitch, a bar can be tuned by grinding on its end or in its thickness. By removing approximately 3% from its length, a pitch can be raised by one semitone. The first overtone of a uniform bar will naturally occur at about 18 semitones (or about 1.5 octaves) above the fundamental pitch. This particular interval happens to be somewhat dissonant when played in chords with other instruments, but it gives the marimba its characteristic type of sound, and is usually satisfactory. The objective of this work is to produce a prototype marimba from kayu malam as similar as possible to the commercial rosewood marimba.

EXPERIMENTAL

In constructing this instrument, a technique discussed by Flynt (2009), was adapted as a guide. The technique remains the same even though a different material was used in constructing the marimba. A local wood *D. maingayi* or locally known as kayu malam, was used for constructing the marimba musical instrument. The acoustic properties such as specific dynamic Young's modulus (E_d/γ), internal friction (Q^{-1}), and acoustic conversion efficiency (ACE) were examined using free-free flexural vibration. The sapwood portions of tree were cut into 120 cm length and 4 cm thickness. Then they were conditioned to air-dry condition in a room with relative humidity of 60% and ambient temperature of 25 °C for 3 months prior to testing. The clear, defect-free planks were machined into dimensions of 340 mm (L) x 20 mm (T) x 10 mm (R) for free-free vibration test.

The experimental setup for free-free flexural test is shown in Fig. 1. The specimen was held with a thread according to the first mode of vibration. An iron plate bonded at one end of the specimen is set facing the electromagnetic driver, and a microphone was placed at the centre below the specimen. The frequency was varied from 1 Hz to 1000 Hz in order to achieve a resonant or natural frequency. The dynamic Young's Modulus (E_d) was calculated from the resonant frequency using Eq. 1,

$$Ed=4\pi^2 f^2 l^4 A\rho / I(m_n)^4 \quad (1)$$

where, $I=bd^3/12$, d is beam depth, b is beam width, l is beam length, f is natural frequency of the specimen, n is mode of vibration, ρ is density, A is cross sectional area, and m_1 = 4.73.

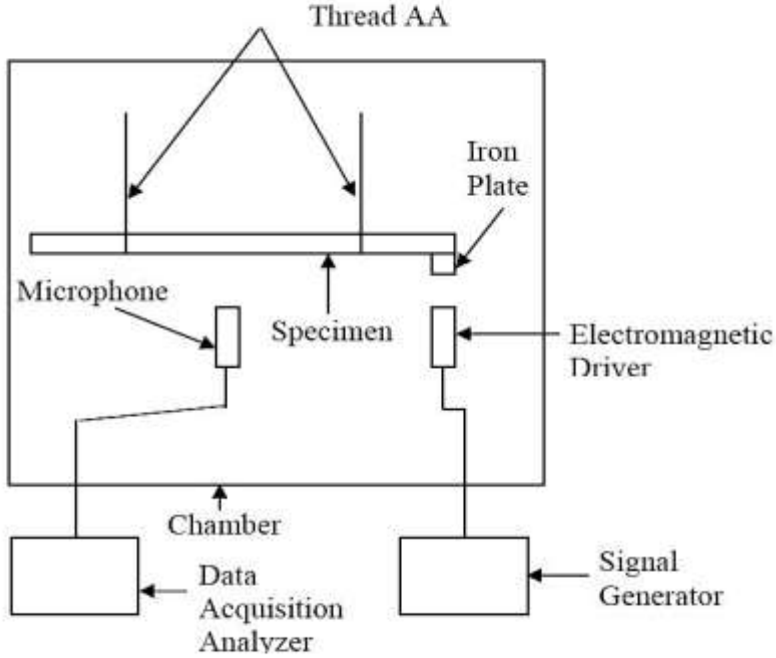

Fig. 1. Schematic diagram of free-free flexural system

The Q^{-1}, was calculated from the resonant, lower, and upper frequencies (Eq. 2). The upper frequency f_2 and lower frequency f_1 were obtained by reducing the amplitude to 0.5 (6.02 dB) below the amplitude of the resonant frequency f_0,

$$Q^{-1} = \tan(\delta) \quad (2)$$

where, $\delta = \pi\Delta f/f_0\sqrt{3}$ & $\Delta f = f_2 - f_1$

The ACE was evaluated by using Eq. 3,

$$ACE=\sqrt{Ed/\gamma}/\ \gamma\tan\delta \quad (3)$$

where, specific gravity (γ) in the air dry state was determined using Eq. 4,

$$\text{Specific gravity } (\gamma) = m/m_w \quad (4)$$

where, m is the oven dry mass of sample (mass of sample at air dry state) and m_w is the mass of displaced water.

A comparative study was made with a set of commercial and readily available marimba made from rosewood (Kawai, Japan). The wood was cut according to the exact specifications of the commercial marimba in terms of its length (24.5 to 37.5 cm), width (4.5 cm), and thickness (2.25 cm). Different lengths and thicknesses produce different pitches; as the length becomes shorter, it will produce a higher pitch and *vice versa*.

Once the wood was cut into bars the next phase of constructing the instrument was to tune it according to the standard tuning as practiced in common notation. The initial process required the crafter to rasp the bars throughout the process; a chromatic tuner CA-30 (Korg, Japan) was used as a reference to the pitch for standard tuning until the desired frequency was achieved. The rasping process was focused on the underside of the bar, which resulted in a form of an arc (Fig. 2). It should be noted here that the rasping process on the underside of the bar was done merely on an experimental basis. It is also noted that the moisture content also has a noticeable effect on the wood bars. The known solution for this is to apply a lacquer or varnish once tuning to its desired frequency is achieved. The marimba was designed with two octaves in diatonic key. Measurement of the frequency spectrum was done at times until the desired frequency value was obtained. The marimba consists of two seven note diatonic keys, and two pentatonic keys. A ‘C’ key is present at the end of the two keys. The pentatonic keys were raised above the diatonic keys.

The fundamental and overtone rise in pitch by removing material from the ends of the bar (Flynt 2009). The fundamental will flatten when material is removed from the center (Fig. 2). The overtone will flatten only when material is removed near the nodes only (approximately 25% inward from each end). The fundamental and overtone are tunable separately. This is important when tuning to remove the material from the proper areas to obtain the desired result.

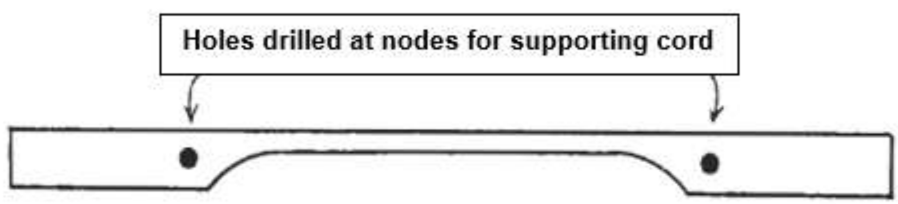

Fig. 2. Cross-section of a typical marimba bar (Flynt 2009)

The fundamental vibrating mode has two points called nodes along the length of the bar where there is no motion (the bar must be physically supported at these points). The bars were supported on a cord that runs along the length of the instrument. Each bar was drilled horizontally at its two nodes to accommodate the supporting cord. The hole was drilled at the node to avoid the musical tone from dampening or fading away quickly. The hole was drilled before final trimming to pitch. During the tuning to the final pitch an electronic tuner was used to tune to the pitch of a piano. The fundamental is excited by carefully striking the bar in its center. Table 1 shows the bar length of the prototype marimba. The octave for this prototype is C2 and C3 only (ends at C4). Note that the number represents the octave of the prototype marimba. The commercial marimba has four octaves (C1, C2, C3, C4, and C5), which end at C5.

The Pico Scope computer software (Pico Technology, 3000 series, Eaton Socon, UK) was used to view and analyze the time signals from Pico Scope oscilloscopes (Pico Technology, 3000 series, Eaton Socon, UK)) and data loggers for real time signal acquisition. Pico Scope software enables analysis using Fast Fourier transform (FFT), a spectrum analyzer, voltage-based triggers, and the ability to save/load waveforms to a disk. Figure 3 shows the schematic diagram of the experimental setup. The marimba was placed to where the sound could be captured with minimum interference. The amplifier (Behringer Powerplay Pro XL, Behringer, China) ensured the sound captured was loud enough to be detected by the signal converter. Figure 4 shows the rasping, testing, and the completed prototype marimba.

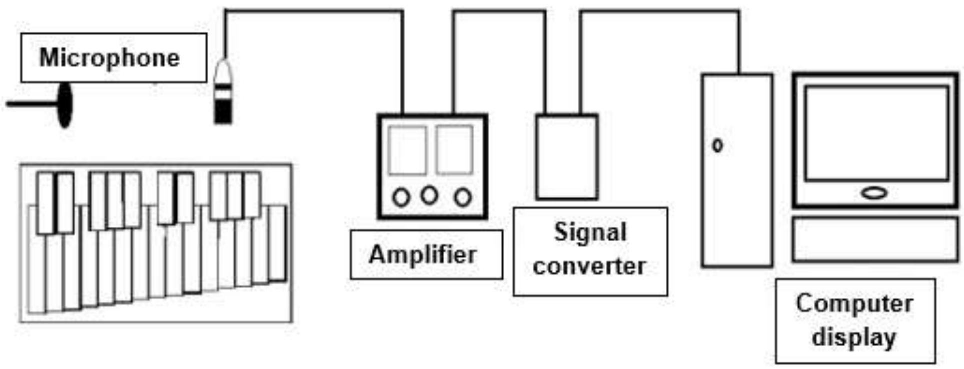

Fig. 3. Schematic diagram of the experimental setup

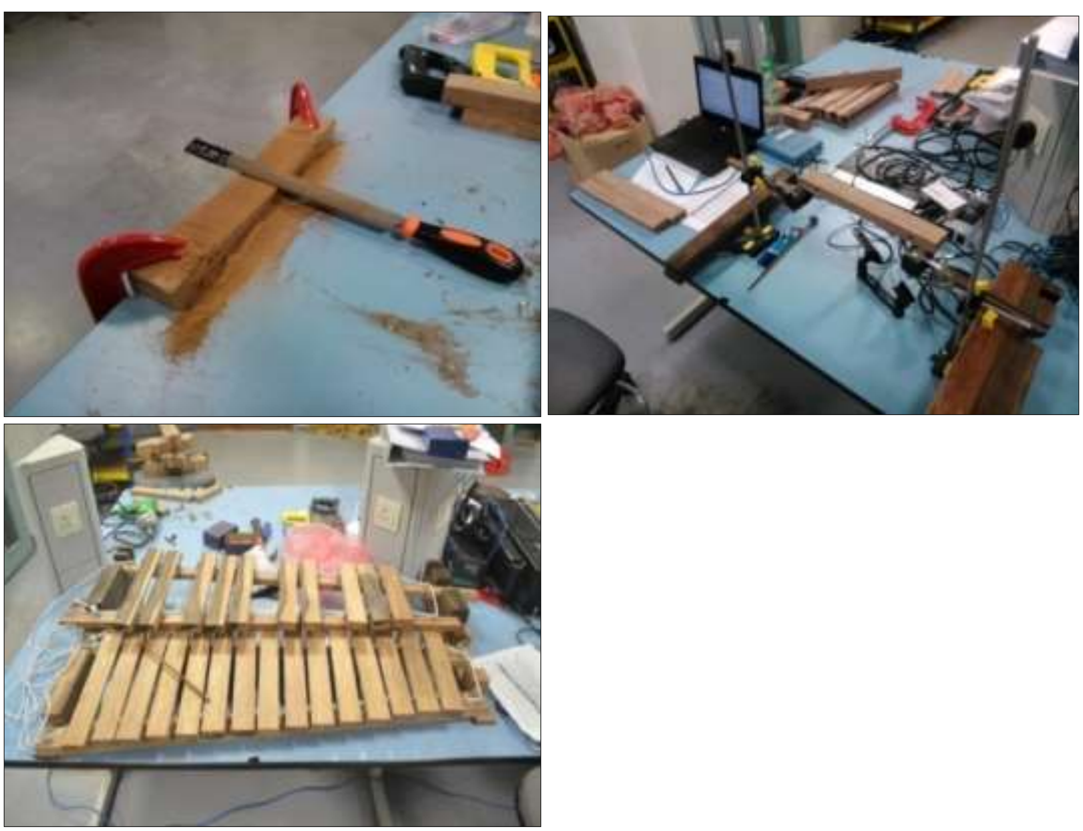

Fig. 4. Rasping, testing process, and the completed prototype marimba

Table 1. Bar Length of Prototype Marimba

Note	C2	C2#	D2	D2#	E2	F2	F2#	G2	G2#
Length (cm)	37.2	36.5	36.0	35.4	35.1	34.2	33.7	33.3	32.8
Note	A2	A2#	B2	C3	C3#	D3	D3#	E3	F3
Length (cm)	32.5	31.9	31.6	30.7	30.1	29.8	29.2	28.8	27.9
Note	F3#	G3	G3#	A3	A3#	B3	C4		
Length (cm)	27.4	27.1	26.5	26.2	25.7	25.3	24.5		

Because both the prototype marimba and commercial marimba have different frequencies assigned to their respective pitch, the standard piano is chosen for comparison.

RESULTS AND DISCUSSION

The acoustic properties of wood can be expressed in terms of three major properties: the specific dynamic Young's modulus (E_d/γ), internal friction (Q^{-1}), and acoustic converting efficiency (ACE). The first mode of vibration was considered to evaluate the acoustic properties using free-free flexural vibration technique (Ono and Norimoto 1984; Yano *et al*. 1993). The E_d/γ and Q^{-1} or $\tan\delta$ are related to sound velocity and sound absorption or damping within the wood, respectively. The ACE is related to the ratio of acoustic energy radiated from the musical instrument to the energy given by the string (Akitsu *et al*. 1993). In this study, specific dynamic Young's modulus (E_d/γ), internal friction (Q^{-1}), and acoustic converting efficiency (ACE) of kayu malam wood were 18 GPa, 0.0045, and $5x10^7$. This result is consistent with earlier finding on *Syzygium*, *Dialium*, *Gymnostoma*, and *Sindora* wood (Hamdan *et al*. 2016).

The note position (C2, C2#, C3, C3#, C4) of the prototype marimba was determined based on the note position of the commercial marimba. Due to the different pitch range of both marimbas, the pitch from the standard piano was chosen for comparison.

This explains why C2 of both prototype and commercial marimba in Table 2 is at the same frequency as C4 of the piano. Table 2 summarizes the frequencies from the prototype marimba, commercial marimba, and standard piano.

The spectrum between the commercial and prototype marimba was compared. Although the peak value of the spectrum differed from pitch to pitch, it was useful to note that the prototype marimba was tuned according to a piano standard. The difference between the commercial marimba and the prototype marimba spatial frequency gives the impression that every musical instrument manufacturer defines their own right pitch. The construction and experiment confirmed the variables that determine how a marimba bar sounds. Marimba bars are impulsively excited instruments.

Table 2. Note and Frequency Relationship Between Prototype Marimba, Commercial Marimba, and Standard Piano (Note: middle C = C4)

Note	Prototype Kayu Malam (kHz)	Commercial Rosewood (kHz)	Standard Piano (kHz)
C2	0.261	0.254	0.262 - C4
C2#	0.277	0.284	0.277
D2	0.301	0.314	0.294
D2#	0.312	0.314	0.311
E2	0.331	0.324	0.330
F2	0.359	0.354	0.349
F2#	0.370	0.384	0.370
G2	0.382	0.394	0.392
G2#	0.417	0.424	0.415
A2	0.436	0.424	0.440
A2#	0.456	0.454	0.466
B2	0.494	0.494	0.494
C3	0.508	0.524	0.523 - C5
C3#	0.551	0.565	0.554
D3	0.590	0.605	0.587
D3#	0.611	0.637	0.622
E3	0.649	0.675	0.659
F3	0.709	0.715	0.698
F3#	0.710	0.745	0.740
G3	0.780	0.775	0.784
G3#	0.828	0.815	0.831
A3	0.860	0.885	0.880
A3#	0.930	0.925	0.932
B3	0.988	0.996	0.988
C4	1.039	1.056	1.047 - C6

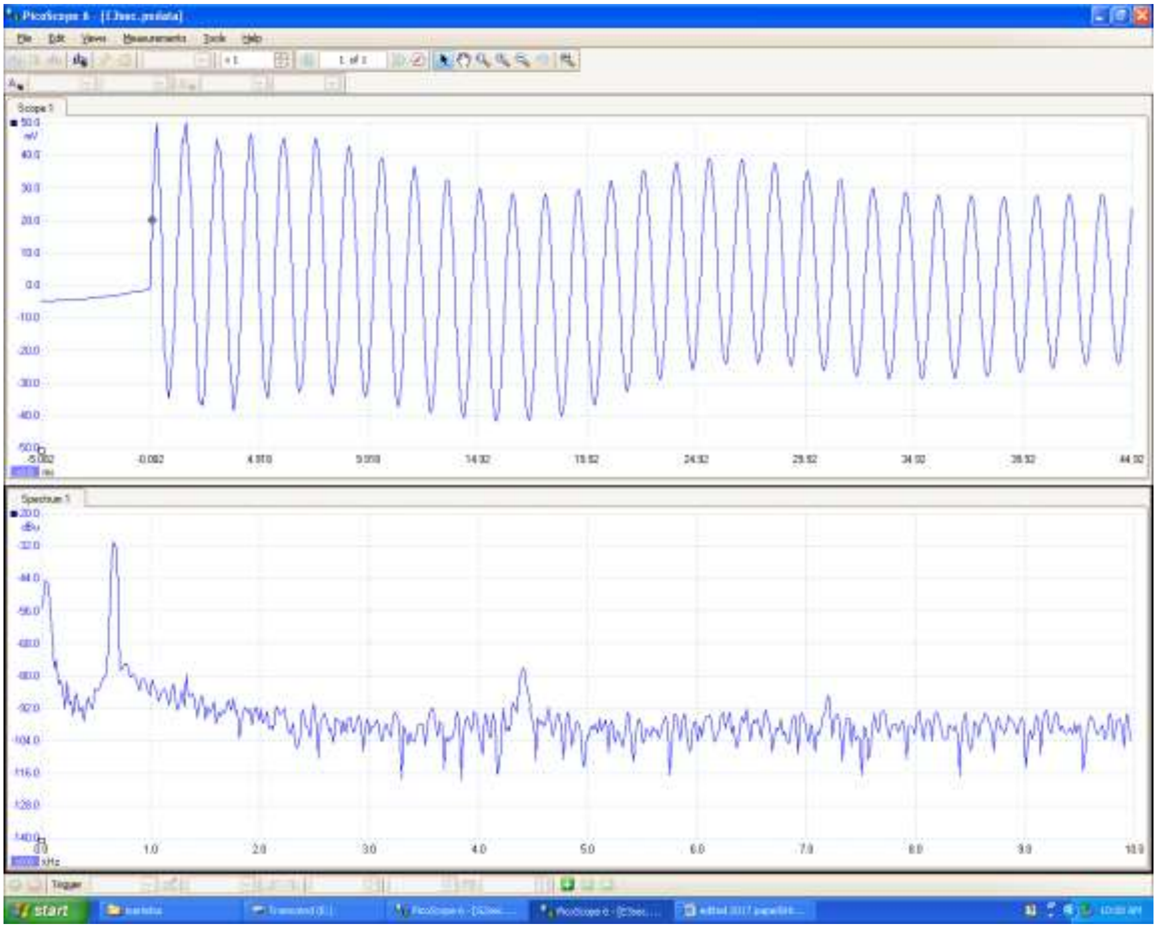

Fig. 5. Sound spectrum of the E_3 bar struck at the center

The energy that causes the bar to vibrate is transferred to it in a very short time in comparison to the damping time of the bar's vibration. According to Wegst (2006), this effect is due to the frequencies excited upon impact. This explains the differences in the spectrum pattern seen between the commercial marimba and prototype marimba. The commercial marimba only has peaks at the lower end of the spectrum, whereas the prototype contains peaks up until the higher end of its spectrum. The sound spectrum of the E_3 bar struck at the center is shown in Fig. 5. Table 3 shows the peak frequency from the sound spectrum of the E_3 bar struck at the center, along with the data from the E_3 marimba bar from Rossing (2000).

Table 3. Peak Frequency from Sound Spectrum of the E_3 Bar Struck at the Center

Fundamental and Overtone	E_3 Bar (Current Study) (Hz)	E_3 Marimba Bar From Rossing (2000) (Hz)
f1	-	169
f2	660	663
f3	-	1561
f4	-	2749
f5	4399	4093
f6	-	5669
f7	7202	7262

CONCLUSIONS

1. A music instrument is a precision instrument where sound is produced through vibration. Even though a solid material (like wood) seems to be rigid, it displays an elastic behavior at a minute level, where it can vibrate. Each sound has its own frequency, which is why different materials make different sounds.
2. In the case of sound engineering, even if there are guidelines on the frequency value needed to produce a certain pitch, it is still up to one's ear to determine whether the sound is right or not. The marimba made of kayu malam (*D. maingayi*) can produce the same pitch as the marimba made of rosewood. Therefore, *D. maingayi* was a viable material for constructing the musical instrument.
3. From the experience through this investigation, extra care needs to be taken at the manufacturing stage. The commercial value of this marimba is possible. Getting the source from a cheaper alternative would largely help to reduce the cost. Therefore, because *D. maingayi* is a local wood grown in the Malaysia-Sumatra region, it can be termed unique and become a selling point should the marimba production at a commercial level be initiated in this region.
4. Sound can be engineered through the alteration of frequency, and *D. maingayi* is a local wood that can be used for musical instrument (marimba) manufacturing.

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