Utilizing Deformable Origamic Geometries in Varying Room Acoustics Characteristics

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***Abstract*—The preliminary study proposes a different technique to provide adjustable reverberation time and sound absorption coefficient for room acoustics applications by utilizing deformable origamic geometries. Two deformable origamic geometries were used in this study. They were triangle geometry and zig-zag geometry. Measurement of sound absorption coefficients in a reverberation room was conducted according to ISO 354: 2003 in order to investigate the feasibility of the proposed technique. The results of the findings were divided into two, namely reverberation times and sound absorption coefficients. As a preliminary result, the two deformable origamic geometries showed that they have the capability to provide adjustable reverberation times and sound absorption coefficients especially at the frequency range of 2000 Hz and above.**

***Index Terms*—Origami; reverberation time; room acoustics; sound absorption coefficient.**

I. Introduction

In multi-purpose halls, various strategies have usually been implemented in an effort to provide an optimum reverberation time required suitable for different type of events. Such strategies commonly focusing on varying the absorption properties, hall volume and implementation of diffusers [1]. These strategies are used to control the reverberation time as the reverberation time has always been the major acoustics parameter to determine the sound quality of an enclosure [2]. According to the Sabine equation, reverberation time is dependent on the volume and total absorption of the enclosure [3]. Thus, to provide an adjustable reverberation times, one should be able to control the parameters that affect the measured reverberation time.

In addition, a parametric survey conducted on the wooden rectangular periodic groove structure (Figure 1) has shown that the groove structures with porous material filled inside the grooves were able to provide adjustable absorption properties by varying the parameters of the structures such as height of the groove, length of the period surface and depth of the porous material [4].

Therefore, if the sound absorption of the wooden structures could be adjusted by varying its parameters, it would be very beneficial especially if the structure is deformable, so that it can accommodate various acoustics requirements inside a multi-purpose hall. Since the wooden structures in Figure 1 are rigid, this paper proposes another technique to provide adjustable reverberation times and sound absorption coefficients by utilizing deformable origami geometries.

It is known that origami term is originated from Japanese word and the concept of origami is basically folding a flat sheet to form a 2D or 3D shape [5]. However, according to Heimbs (2013), the origami concept has been used in the aerospace and automotive industry in term of reducing noise in the aircraft cabin as well as improving vehicle structures and they are called 'foldcore' structure [5]–[7]. Figure 2 shows that the foldcores structures also come from various geometries and materials and widely used in engineering applications. The advantage of the origami structure is that it can be deformed which means that the origami can varies its geometrical conditions dynamically, whereas the wooden rectangular periodic groove structure is rigid. Therefore, this paper investigates whether the deformable origamic geometries are capable to provide adjustable reverberation times and sound absorption coefficients by varying its geometrical configurations.

Figure 1: Wooden rectangular periodic groove structure with porous material [4]

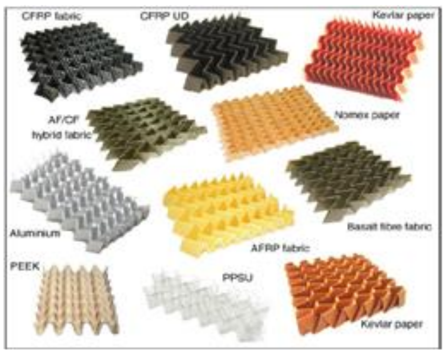

Figure 2: Types of foldcore geometries and materials [5]

II. ORIGAMI SPECIFICATION

Two different types of deformable origamic geometries have been used in the research works as shown in Figure 3 and Figure 4. They are of triangle and zig-zag geometries. The two origamic geometries were folded by using 1200 gsm chip boards. Each of them has different configuration due to different type of geometry. In order to form a large specimen, they were joined by using white glue. Practically, origami is deformable where they can be pulled or compressed which means that their geometrical conditions (i.e. length, width, height and surface area) will vary according to the applied force given to them. For example, when the triangle geometry (see Figure 3) is pulled, the parameters of x, h, z and surface area of the triangle geometry will change their conditions. Similarly, when the zig-zag geometry is pulled (see Figure 4), the parameters of x, h, y, z and surface area also will also change their conditions. However, dimension z of the triangle geometry remains the same. Dimension y and z of the zig-zag geometry also remain the same whenever the origami changes its geometrical conditions.

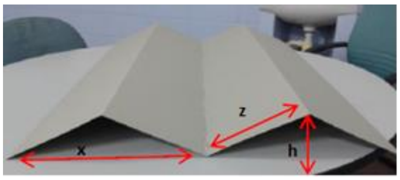

Figure 3: Types of foldcore geometries and materials [5]

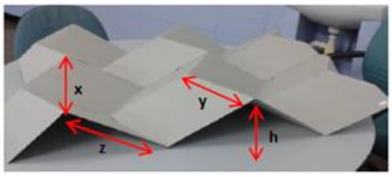

Figure 4: Types of foldcore geometries and materials [5]

III. MEASUREMENT METHOD

The purpose of the study is to investigate whether the deformable origamic geometries are capable to provide adjustable reverberation time and sound absorption coefficient by varying its geometrical configurations. Therefore, measurement of sound absorption coefficient had been conducted in the reverberation room at Faculty of Mechanical Engineering, UTM. The reverberation room has a volume of 54.65 m^3 and a Schroeder frequency of 500 Hz; which means that there is no absorption takes place below 500 Hz [8]. Although the room volume did not meet the ISO 354 requirements, the measurement procedures employed are in accordance to ISO 354:2003 [9].

A. *Measurement Procedures*

Following the ISO 354:2003 Measurement of Sound Absorption Coefficients in Reverberation Room, the two deformable origamic geometries were used as the specimen for the experimental works. Initially, the reverberation time of the room which contain no specimen were measured by exciting the room with balloon bursts. The excitation of the balloon bursts were recorded by a Solo 01dB Sound Level Meter from two different microphone positions. The two positions of microphone was 1.5 m apart and the distance of the specimen to the microphone was 1 m. Then, the specimen was introduced in the reverberation room by placing it on the floor of the room and reverberation times were measured with the present of the specimen. The measurements were then repeated with several geometrical configurations of both triangle and zig-zag geometry as depicted in Table 1 and Table 2 respectively. Each measurement was repeated four times and the reverberation times were then averaged for two microphones positions. The temperature and relative humidity of the measurement were maintained approximately at 26°C and 78% respectively throughout the whole measurements.

Table 1
Dimension of triangle geometric origami with several configurations

Test Configurations	h (cm)	x (cm)	z (cm)	Surface Area (m^2)
Configuration 1	22	37	28	3.34
Configuration 2	18	42	28	3.34
Configuration 3	14	47	28	3.34
Configuration 4	10	52	28	3.34

Table 2
Dimension of zig-zag geometric origami with several configurations

Test Configurations	h (cm)	x (cm)	y (cm)	z (cm)	Surface Area (m^2)
Configuration 1	23	31	21.5	28	3.34
Configuration 2	21	33	21.5	28	3.34
Configuration 3	17	36	21.5	28	3.34
Configuration 4	15	38	21.5	28	3.34
Configuration 5	13	40	21.5	28	3.34

B. *Test Specimen Configurations*

In this research work, the surface area covered by the specimen in a reverberation room was maintained the same as it is already known that the variation of surface area of the specimen has influence on the measured reverberation times. This is because the surface area and sound absorption coefficient are inversely proportional to each other [3]. Therefore, to maintain the surface area covered by the specimen, fractions of the specimen were removed from one configuration to another in order to maintain constant surface area covered by the specimen of triangle geometry and zig-zag geometry. This is clearly presented in Table 1 and Table 2; as the surface area were constant for each configuration. Figure 5 and Figure 6 illustrate the geometrical conditions of triangle geometry and zig-zag geometry respectively.

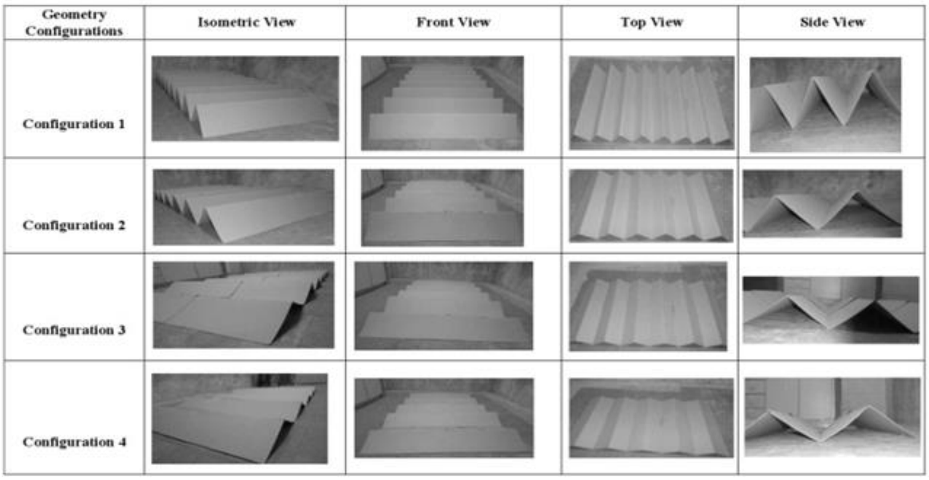

Figure 5: Geometrical configurations of triangle geometry

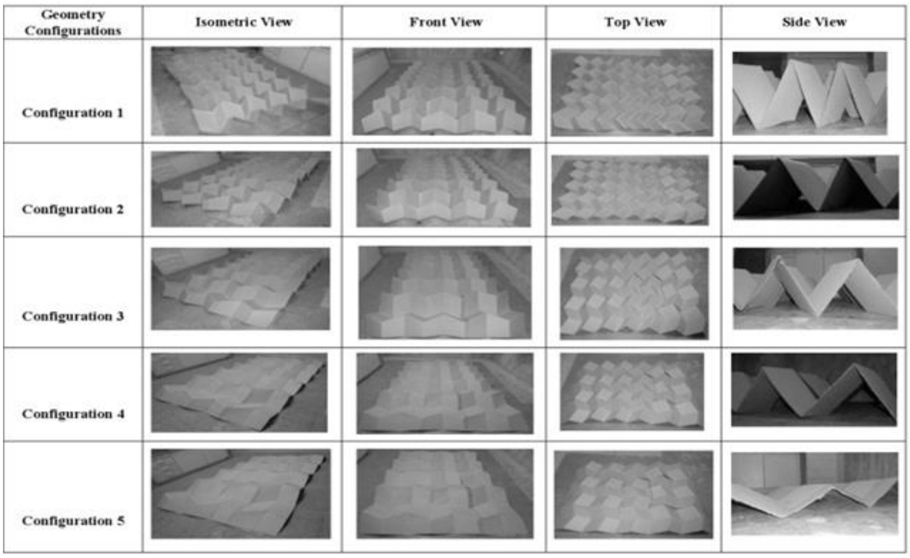

Figure 6: Geometrical configurations of zig-zag geometry

C. Method of Calculations

Sound absorption coefficients were calculated based on the measured reverberation time in the reverberation room with and without the specimen in accordance to ISO 354:2003 [8]. The equations used to calculate the reverberation time for both conditions are given in Equation (1) and Equation (2).

$$A_1 = \frac{55.3V}{cT_1} - 4Vm_1 \quad (1)$$

where A_1 is the equivalent sound absorption area for empty reverberation room (m^2), V is the volume of reverberation room (m^3), c is speed of sound in air (m/s), T_1 is the reverberation time of the empty reverberation room (s), m_1 is the power attenuation coefficient (m^{-1}) at the temperature of empty reverberation room according to ISO 9613-1 [10]

$$A_2 = \frac{55.3V}{cT_2} - 4Vm_2 \quad (2)$$

A_2 is the equivalent sound absorption area for reverberation room when the specimen has been introduced (m^2), V is the volume of the reverberation room (m^3), c is speed of sound in air (m/s), T_2 is the reverberation time of the empty reverberation room (s), m_2 is the power attenuation coefficient (m^{-1}) at temperature of the reverberation room when specimen has been introduced.

Finally, the absorption coefficients were calculated by dividing the total equivalent sound absorption area, A_T, with the surface area covered by the test specimen. Total equivalent sound absorption area, A_T; is the difference between equivalent sound absorption area of reverberation room with and without the specimen, A_2 - A_1.

$$\alpha_S = \frac{A_T}{S} \quad (3)$$

IV. Results And Discussion

The results were presented in 1/3 octave band frequency as specified in ISO 354:2003. Two parameters that were investigated are reverberation time and sound absorption coefficient. The evaluation decay range of reverberation time was T60 and evaluated by 01dB Solo Sound Level Meter. However, the results only show good trends at high frequency range which is from 2000 Hz to 5000 Hz although the Schroeder frequency of the reverberation room is 500 Hz. Therefore, as preliminary investigations, the discussions are focusing only on the frequencies above 2000 Hz.

A. *The Effect of Triangle Geometric Variations on Reverberation Time and Sound Absorption Coefficient*

Figure 7 shows the effect of geometrical configurations on the reverberation time of triangle origami geometry. Huge difference is observed between the reverberation time of empty reverberation room and the reverberation time at configuration 1 where the specimen is first introduced. It can be further observed that as the geometrical configurations are varied from configuration 1 to configuration 4, the reverberation time at high frequencies are slightly increased and shifted toward the reverberation time of empty room. The trends of the results provide some insight that as the triangle geometry varied from configuration 1 to configuration 4 (h decreased, x increased) the reverberation time increases.

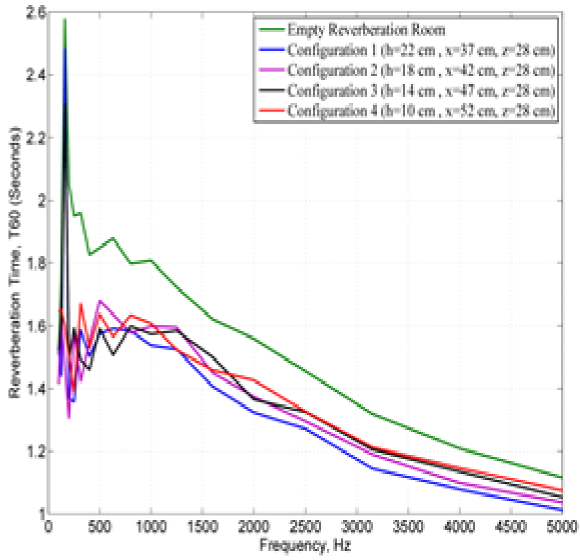

Figure 7: The measured reverberation times of triangle origami geometry at 1/3 octave band frequencies

In addition, Figure 8 shows the changes observed on the calculated sound absorption coefficient.

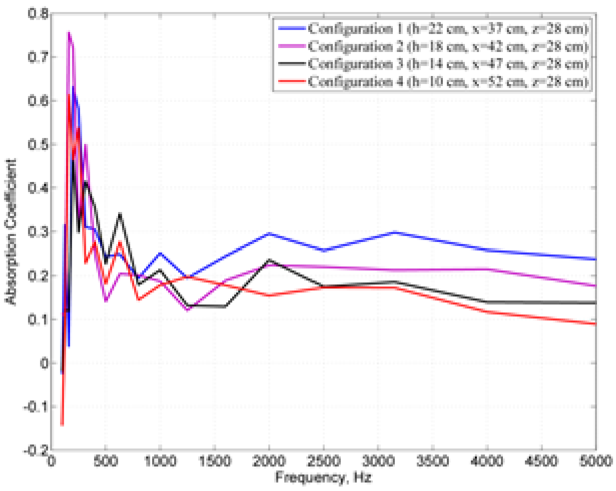

Figure 8: The calculated sound absorption coefficients of triangle geometry at 1/3 octave band frequencies

Based on the graph, the sound absorption coefficient decreases as the triangle geometry change its configuration from 1 to 4 (h decreased, x increased). Overall, at higher frequencies of above 2000 Hz, the sound absorption coefficients seem able to be varies from 0.1 to 0.3.

B. *The Effect of Zig-Zag Geometric Variations on Reverberation Time and Sound Absorption Coefficient*

Figure 9 illustrates the reverberation times of five zig-zag origami geometrical configurations. The results show similar trends as triangle geometry as observed in Figure 7. At frequencies above 2000 Hz, the reverberation time is slightly increased as the geometrical configurations varies from configuration 1 to 4 (h decreased, x increased). Meanwhile, Figure 10 depicts the changes of sound absorption coefficient of zig-zag origami. The results show that sound absorption coefficient decreases as the zig-zag origami geometry change its configuration (h decreased, x increased). The sound absorption coefficients can be varied between 0.2 and 0.35 for frequencies above 2000 Hz.

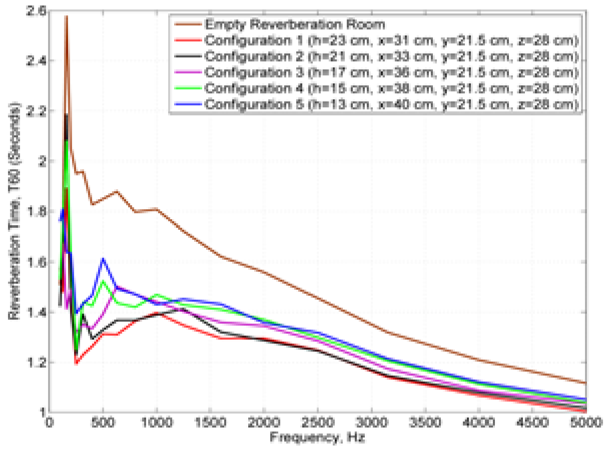

Figure 9: The measured reverberation times of zig-zag origami geometry at 1/3 octave band frequencies

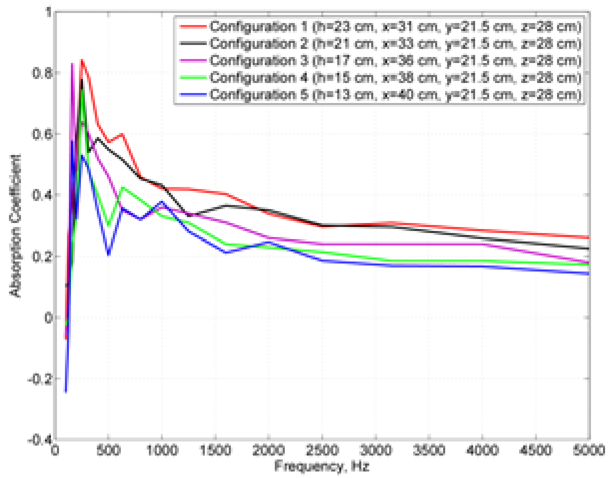

Figure 10: The calculated sound absorption coefficients of zig-zag geometry at 1/3 octave band frequencies

C. Discussions of Triangle Geometry and Zig-Zag Origami Geometry Results

The calculated sound absorption coefficient of triangle and zig-zag origami are shown in Figure 8 and Figure 10. The results show inconclusive trends for frequencies below 2000 Hz. These are probably due to the small volume of the reverberation room (54.65 m3) and a Schroeder frequency of 500 Hz; which means that the reverberation room unable to produce absorptions below 500 Hz. It is also inappropriate conduct analyse for those frequencies due to the inaccuracy [8]. Besides that, for an effective absorption to take places, the thickness or depth of the material should be at least one-quarter of the wavelengths [11]. This is because each particular frequency has its own wavelength and the higher the frequency, the shorter the wavelength as tabulated in Table 3. However, at the frequency of above 2000 Hz, the results show good trends. This is because the depth of the origamic material is sufficient to absorb sound at that particular frequency range.

Table 3
The Wavelengths of the Frequencies in 1/3 Octave Band

Frequency	Wavelength (cm)	¼ of the Frequency Wavelength (cm)
100	348	87
125	278	70
160	218	54
200	174	44
250	139	35
315	110	28
400	87	22
500	70	17
630	55	14
800	44	11
1000	35	9
1250	28	7
1600	22	5
2000	17	4
2500	14	4
3150	11	3
4000	9	2
5000	7	2

V. CONCLUSION

Two types of deformable origamic geometries have been tested in the reverberation room to provide a better understanding of the relationship between the variation of origamic geometries with the reverberation characteristics as well as sound absorption coefficients. The present preliminary work provides good trends especially at frequency of 2000 Hz and above. Hence, from the results of the two deformable origamic shapes, it can be concluded that deformable origami are capable to provide adjustable reverberation time and sound absorption coefficient by varying their geometrical configurations. However, it should be noted that the measurements in this study is carried out in a reverberation room that does not meet the ISO 354 requirements. Future measurements will include extensive experiment conducted in scaled model of reverberation chamber to enhance the findings of this preliminary investigation.

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