The Design of MPP and its Application to Enhance the Acoustics of a Real Auditorium

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ABSTRACT

Micro Perforated Panels (MPP) backed by air cavity is an acoustic absorber based on the Helmholtz resonance mechanism. MPP is potential to be an alternative acoustic absorber amid the carcinogenic issues of porous material. It is however, MPP has several limitations in its application. One of them is its narrow absorption bandwidth. One way to overcome this problem is by arranging some MPPs with particular parameters working on different absorption peaks to deal with wideband absorption as commonly required in room acoustic cases. In this paper the MPP were designed by simulation using Dah – You Maa model. There are four parameters that can be adjusted to get the right sound absorption coefficient from the MPP; those are panel thickness, pore diameter, cavity depth, and perforation area. Validations on the simulation results are carried out through Impedance Tube Measurements using transfer function method based on ISO 10534-2 standard. The paper also discusses the application of the MPP into a real auditorium by modeling and simulation. The aim is to overcome the acoustics problem for speech, classical music, and Indonesian traditional music performance in the auditorium. The influence of MPP's configurations on the acoustics of the auditorium are presented and discussed.

Keywords: Micro Perforated Panels (MPP), Room Acoustic
I-INCE Classification of Subjects Number(s): 51.1.2

1. INTRODUCTION

Aula Barat ITB is one of the historical Buildings located inside the Bandung Institute of Technology (ITB). It was designed by Dutch architect, Henry Maclaine Pont (1). It was built in 1918 and finished in 1919. Its function was to accommodate ceremonial activities such as graduation ceremony, professor appointment, etc.

In 2013, the restoration process for Aula Barat ITB was finished. The main difference between Aula Barat before and after restoration processes is the removal of curtain. Meanwhile, the function of Aula Barat ITB is increased. At the time being, the Aula Barat ITB is usually used for auditorium (class room, seminars, and workshop), classical concert hall, and Indonesian traditional music festival. From acoustic point of view, this is a challenge because acoustic condition in one room usually specific for certain activities.

In the concept of acoustic, if one room has good acoustic condition for speech, it doesn't ensure good acoustic condition for concert hall (2). The Indonesian traditional music festival discussed in this paper is only Gamelan Bali.

Measurement of acoustic parameters in the Aula Barat shows that the reverberation time in Aula Barat ITB is about 2 seconds, C_{80} -4 – 2 dB, D_{50} 30 – 50%. The ideal reverberation time in a building which has a volume of around 3000 m^3 for classical concert hall is 1.4 – 1.8 seconds and C_{80} -1 – 4 dB (2), for speech in auditorium is 1.2 seconds, D_{50} 40 – 70% (2), and for Gamelan Bali is 1.41 seconds, C_{80} 1- 6 dB (3). Because of the difference on the ideal acoustic parameters, the concept of adjustable concert hall can be implemented in Aula Barat ITB to accommodate all the activities discussed in this paper.

In this paper, this concept was implemented by modifying the sound absorption characteristics of

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the material in Aula Barat ITB. The sound absorber used for this research is MPP (Micro Perforated Panel). MPP is a new acoustic absorber based on Helmholtz Resonator. It has pore's diameter from 0.1 – 0.9 mm and cavity depth to adjust the resonant frequency. The utilization of MPP based on the advantages of MPP. MPP doesn't change the interior and architecture condition of Aula Barat ITB as it can be constructed with transparent material e.g. acrylic while it is more environmentally friendly. It is however, MPP also has several disadvantages such as narrow bandwidth frequency. One way to overcome this problem is by designing an MPP according to the needs of the room acoustic. The configuration of MPP placement is also important for achieving optimum acoustical performance.

2. ROOM ACOUSTIC PARAMETERS

2.1 Reverberation Time (T_{60})

Reverberation time is a time need for sound to drop by 60 dB and it is a frequency dependent parameters. In room acoustics, T_{60} is calculated with 1/1 octave filter. This parameters can be defined as (2)

$$T_{60} = \frac{0.161V}{A} \quad (1)$$

with V is room volume and A is total area surface of absorption in a room. A can be defined as

$$A = \Sigma S_i \alpha \quad (2)$$

with S is surface area of absorption and α is sound absorption coefficient.

In this paper, T_{30} is used in measurement and simulation. The main different between T_{30} and T_{60} is a time need to gather data. In T_{60}, it need 60 dB to calculate the reverberation time, in T_{30} in only need 30 dB, but the results is linearized to 60 dB drop.

2.2 Clarity (C_{80})

Clarity is an acoustic parameter that calculate ratio of sound energy between first 80 milliseconds of impulse response with energy after 80 milliseconds. This parameter can be defined as (4)

$$C_{80} = 10\log\left(\frac{\int_{0}^{80ms} h^2(t)\,dt}{\int_{80ms}^{\infty} h^2(t)\,dt}\right) \quad (3)$$

with h is sound energy at any given moment. C_{80} is usually used to determine the clarity of music. Higher the value of C_{80} means more direct sound than its reverberation.

2.3 Definition (D_{50})

Definition is an acoustic parameter that calculate ratio of sound energy. It is almost identical with C_{80}. The main different between D_{50} and C_{80} is time calculation. In D_{50} the sound energy is calculated in first 50 milliseconds of impulse response with energy after 50 milliseconds. This parameter can be defined as (4)

$$C_{50} = \left(\frac{\int_{0}^{50ms} (g(t))^2\,dt}{\int_{50ms}^{\infty} (g(t))^2\,dt}\right).100\% \quad (4)$$

with $g(t)$ is sound energy at any given moment. D_{50} is usually used to determine the definition of speech. Higher the value of D_{50} means more direct sound than its reverberation.

3. MPP (MICRO PERFORATED PANEL)

Micro Perforated Panels (MPP) is a sound absorber based on viscous-thermal and Helmholtz resonance with very small pores diameter sound absorber. The diameter of pore is in the range of 0.1 mm – 0.9 mm with some cavity depth behind the panel. The cavity depth is arranged to the need of the expected room acoustic conditions.

The inventor of this absorber is Professor Dah You Maa, and he proposed the mathematical model to predict the characteristic of sound absorption of MPP. According to Maa equation, the acoustic impedance of MPP can be defined as (5)

$$z = \frac{Z_1}{\left(\sigma \rho_0 c d^2\right)} = r + j\chi_m = r + j\omega m \tag{5}$$

where

$$r = \frac{32\mu}{\sigma c}\frac{t}{d^2}\left(\sqrt{1+\frac{x^2}{32}} + \frac{\sqrt{2}}{8}x\frac{d}{t}\right) \tag{6}$$

$$\omega m = \frac{\omega t}{\sigma c}\left(1 + \frac{1}{\sqrt{9+\frac{x^2}{2}}} + 0.85\frac{d}{t}\right) \tag{7}$$

and

$$x = 316 d\sqrt{f} \tag{8}$$

where d is the pores diameter, b is the centre-to-centre distance between holes, f is the frequency, t is the panel thickness, and x is the perforation constant, μ is kinematic viscosity, and c is the speed of sound in the air. r represent acoustic resistance and ωm represent acoustic reactance. The perforation area ratio is defined as

$$\sigma = \frac{\pi}{4}\left(\frac{d}{b}\right)^2 \tag{9}$$

The sound absorption coefficient is found from

$$\alpha = \frac{4r}{(1+r)^2 + \left(\omega m - \cot\left(\omega D / c\right)\right)^2} \tag{10}$$

where D is the cavity depth of MPP. For wideband MPP where there are two or more acoustic impedance in one panel, the sound absorption coefficient was calculated by equation 2 and the diffraction effect is negligible.

4. EXPERIMENTS

This experiment is aimed to validate Ma model before being implemented to predict the absorption behavior of MPP with particular specification.

4.1 Impedance-tube Test

A schematic diagram for impedance tube test is shown in figure 1.

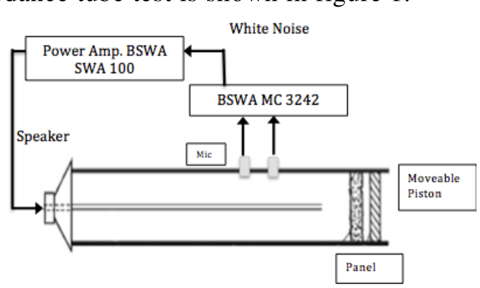


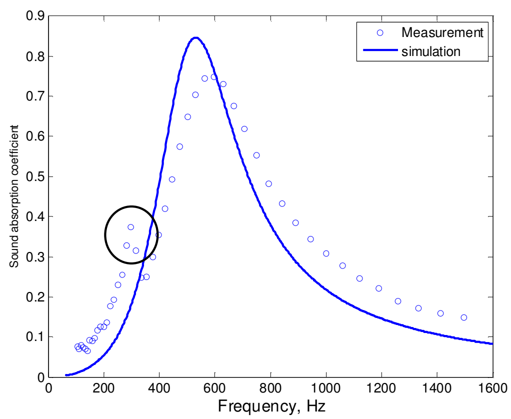
Figure 1 – Schematic diagram of impedance tube test

In this test the white noise was generated from 64 Hz up to 1600 Hz using frequency analyzer (BSWA MC 3242 system) and amplified by power amplifier (BSWA SWA 100). The measurements were carried out using two microphones (BSWA MPA 416). The sound absorption coefficient of MPP was obtained by two microphones with transfer function method based on ISO 10543-2(6).

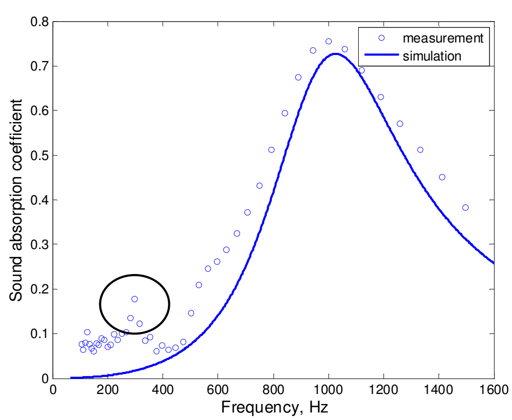
Figure 2 (a)-(b) presents the measurement result of impedance tube test from sample A and B. The specification of the two samples can be seen in Table 1. It can be seen that the maximum absorption is pronounced at 528 Hz and 1026 Hz for sample A and B respectively. Compared with the peak predicted by Ma model, the measurement results are similarly reasonable. Moreover, another considerable peak is also seen at lower frequency as indicated by the blue circle for each sample. This peak commonly corresponds with fundamental mode of the panel rather than caused by the Helmholtz resonance. This is occurred as the panel vibration cannot be totally omitted from specimen, while such vibration is neglected in Ma model by assuming the panel is rigid instead of elastic one. Bravo et al.[7] discussed panel and Helmholtz resonance based on vibro-acoustics point of view. Considering the comparison results, Dah you Ma model (5) can be employed to predict the absorption behavior of MPP required for particular functions of Aula barat ITB.

Table 1 – Specification of MPP sample

Perforation Parameters	Sample	
	A	B
d, mm	0.8	0.8
b, mm	7.8	5.8
t, mm	1.5	1.5
D, mm	50	25



(a)



(b)

Figure 2 – Comparison between measurement result and simulation: (a) sample A; (b) Sample B

4.2 Design of sample MPP

The applications of MPP in the Aula Barat ITB were done by simulation. The simulations were carried out using CATT Acoustic V.9 with ray tracing method and used 1/1 octave filter. Based on simulation needs, the MPP samples were designed to accommodate the problem in several frequencies (125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz). There were 7 samples of MPP, 3 samples are single MPP (one acoustics impedance in one panel) and 4 samples are wideband MPP (two acoustics impedances in one panel).

Their specifications are shown in Table 2 and Table 3. The specification is determined based on the required absorption frequency. Meanwhile, their sound absorption coefficients are obtained using Eq. (10) and listed in Table 4 and Table 5.

Table 2 – Specification of single MPP

Sample	Specification (mm)				
	Pores Diameter (*d*)	Cavity Depth (*D*)	Porosity (*b*)	Panel Thickness (*t*)	Perforation Area (%)
1	0.8	150	14	1.5	0.25
2	0.8	50	13	1.5	0.29
Sample	Specification (mm)				
	Pores Diameter (*d*)	Cavity Depth (*D*)	Porosity (*b*)	Panel Thickness (*t*)	Perforation Area (%)
3	0.8	2	4.5	1.5	2.5

Table 3 – Specification of wideband MPP

<table>
<tr><th rowspan="2">Sample</th><th colspan="5">Specification 1 (mm) | Specification 2 (mm)</th></tr>
<tr><th>Pores Diameter (d)</th><th>Cavity Depth (D)</th><th>Porosity (b)</th><th>Panel Thickness (t)</th><th>Perforation Area (%)</th></tr>
<tr><td>4</td><td>0.8</td><td>25|17</td><td>9.5|6</td><td>1.5</td><td>0.55|1.39</td></tr>
<tr><td>5</td><td>0.8</td><td>25|25</td><td>8.7|6.5</td><td>1.5</td><td>0.66|1.12</td></tr>
<tr><td>6</td><td>0.8</td><td>15|15</td><td>12.5|6.5</td><td>1.5</td><td>0.32|1.18</td></tr>
<tr><td>7</td><td>0.8</td><td>5|5</td><td>11|5.5</td><td>1.5</td><td>0.42|1.66</td></tr>
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Table 4 – Sound absorption coefficient of single MPP

Sample	Sound Absorption Coefficient %					
	125	250	500	1000	2000	4000
1	81.53	36.1	9.73	4.11	1.34	0.47
2	16.01	71.31	19.1	4.32	1.35	0.63
3	0	0	0.04	0.21	2.24	34.82

Table 5 – Sound absorption coefficient of wideband MP

Sample	Sound Absorption Coefficient 1 (%) I Sound Absorption Coefficient 2 (%)					
	125	250	500	1000	2000	4000
4	1.38I0.22	10.78I1.15	66.46I9.88	13.22I57.64	2.85I10.76	0.89I2.42
5	1.12I0.58	7.93I3.37	66.85I37.54	17.74I43.65	3.46I6.78	1.06I1.86
6	0.86I0.21	7.3I1.1	54.38I9.53	8.14I57.02	1.7I9.36	0.54I2.1
7	0.06I0.02	0.34I0.07	3.15I0.4	41.34I3.73	3.95I45.16	0.79I5.46

In table 5, there are two sound absorption coefficients in each frequency, the two sound absorption coefficient were distributed by averaging the two coefficients in each frequency. The reflection effect due to the differences of impedance was neglected.

4.3 Room Simulation

4.3.1 Aula Barat ITB in Existing Condition

The simulation of Aula Barat at existing condition was carried out with the purpose to compare the reverberation time in simulation with the measurement results. The average error of the comparison is not exceeding 10 %. The validation and geometric result are shown in Figure 3 and Figure 4.

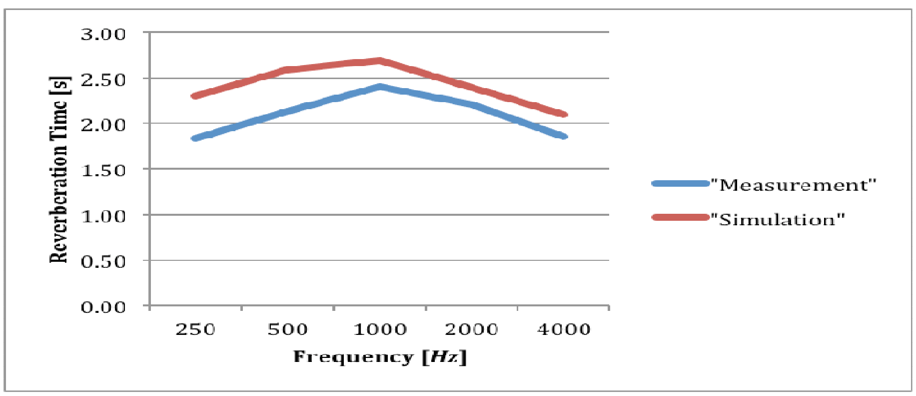

Figure 3 – Comparison of simulation and measurement results for reverberation time of Aula Barat at existing condition

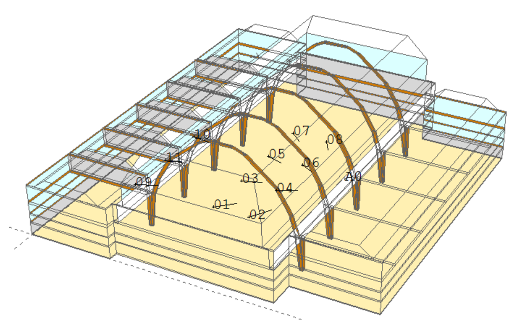

Figure 4– Schematic diagram of Aula Barat ITB in existing condition

Figure 3 showed the different between simulation results and measurement results. The maximum error is 10%. Table 6 showed the result from room measurement and ideal reverberation time for classical concert hall, auditorium for speech, and concert of Gamelan Bali (2)(3).

Table 6 – Comparison of simulation result with ideal reverberation time

Reverberation Time						
Frequency [Hz]	125	250	500	1000	2000	4000
Simulation [s]	1.40	2.3	2.59	2.69	2.39	2.09
Classical Music(s)	-	-	-	1.4 – 1.8	-	-
Speech (s)	-	-	-	1.2	-	-
Gamelan Bali (s)	-	-	1.41	1.41	1.6	-

The total surface area in Aula Barat ITB is 4344.9 m^2 and the total volume is 3731 m^3.

4.3.2 Aula Barat ITB for Classical Concert Hall

Table 6 showed that for classical music the ideal reverberation time is in the range of 1.4 – 1.8 seconds, with the existing reverberation time condition of 2.69 seconds. To reduce the reverberation time, the sound absorber must be added to the room. Therefore, for this condition MPP sample 4 and MPP sample 5 were used. The configuration and results is shown in figure 5 where MPP positions are indicated with different colour corresponding with frequency absorption of 125 Hz to 4 Khz.

Sample 4 (500 Hz) is used about 1.2 % of the total absorption surface area, sample 4 (1000 Hz) is used about 2.3 % of their total absorption surface area and sample 5 (2000 Hz) is used about 1.3 % of the total absorption surface area.

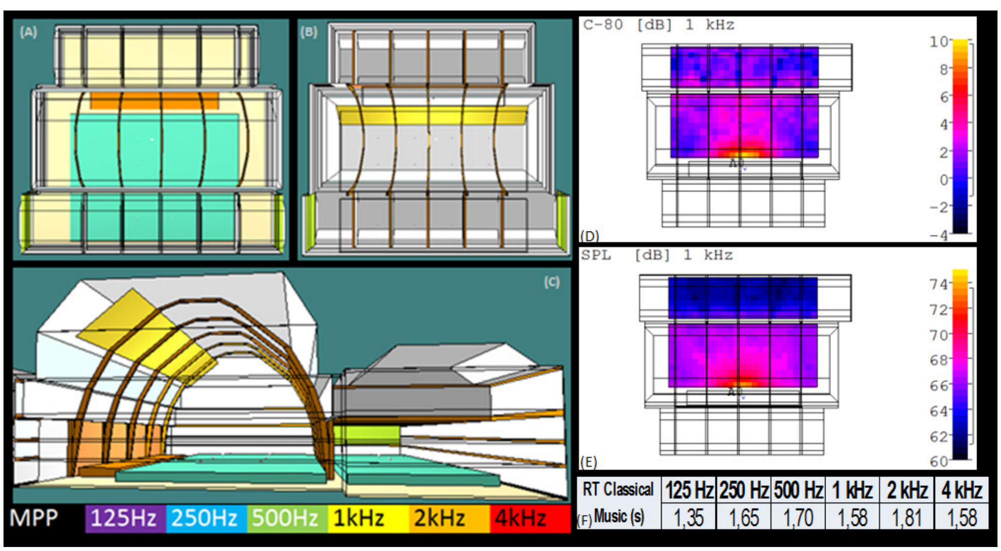

Figure 5 - (A) Top down perspective, (B) Bottom up perspective, and (C) Side view of Aula Barat ITB (D) C_{80}, (E) SPL, and (F) reverberation time for Classical Concert Hall

4.3.3 Aula Barat ITB for Speech Auditorium

Table 6 showed that for speech in auditorium the ideal reverberation time is 1.2 seconds, with the existing reverberation time of 2.69 seconds, at 1000 Hz. To reduce the reverberation time, the sound absorber must be added to the room. For this condition, MPP sample 4 and MPP sample 5 were also used. The configuration and results are shown in Figure 6.

Sample 4 (500 Hz), sample 4 (1000 Hz) and sample 5 (2000 Hz) area is covered about 4.5 %, 4 %, and 2.8 % of the total absorption surface area, respectively.

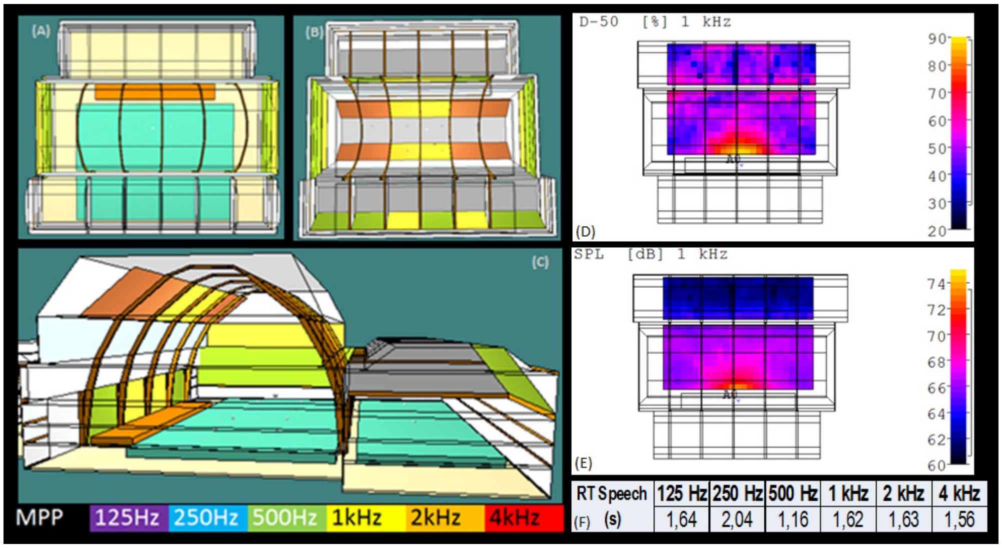

Figure 6 - (A) Top down perspective, (B) Bottom up perspective, and (C) Side view of Aula Barat ITB (D) C_{80}, (E) SPL, and (F) reverberation time for speech auditorium

4.3.4 Aula Barat ITB for Gamelan Bali Concert Hall

Table 6 showed that for Gamelan Bali the ideal reverberation time is 1.41 seconds for 500 Hz and 1000 Hz, and 1.61 for 2000 Hz with 10% of range. It is also shown that the existing condition has a reverberation time of 2.69 seconds. To reduce the reverberation time, the sound absorber must be added to the auditorium. MPP sample 2 and MPP sample 5 were used. The configuration and results is shown in Figure 7.

Sample 2 (250 Hz), sample 5 (500 Hz), and sample 5 (1000 Hz) is covered about 2.2 %, 6.9 %, and 2.2 % of the total absorption surface area.

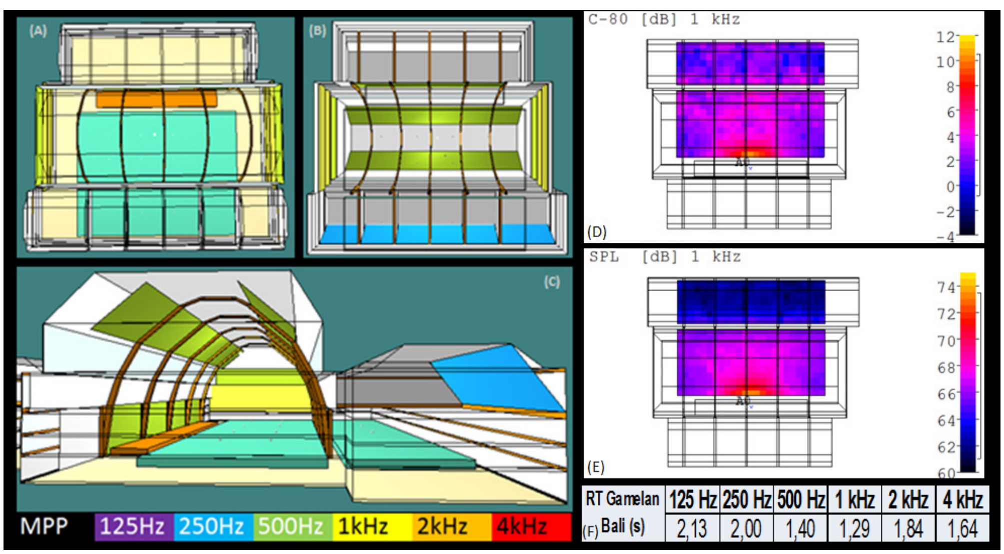

Figure 7 - (A) Top down perspective, (B) Bottom up perspective, and (C) Side view of Aula Barat ITB (D) C_{80}, (E) SPL, and (F) reverberation time for Gamelan Bali concert hall

5. RESULTS AND DISCUSSION

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In Figure 5F, the ideal reverberation time for classical concert hall was achieved by the configuration of MPP in Aula Barat ITB. It is showed in Figure 5 that the ideal reverberation time achieved in all range of frequencies (125 Hz – 4000 Hz). The clarity produced by the configuration of MPP was -1 to 4 dB, which is the preferred value for classical music performance. The SPL difference between the audiences in the front (near source) with audience in the back was 6 dB. In the front, the audiences were perceived 62 dB, while in the rear areas the audience perceived 68 dB. Six dB differences can be tolerated for human perception to listen to musical performance.

This achievement was due to the proper placement of MPP. Sample 4 (500 Hz) were placed only on the wall at the back of Aula Barat to reduce reverberation time for 500 Hz. The sample not placed on all over the wall since applying sample 4 (500 Hz) placed all over the wall, would make Aula Barat produce very small reverberation time, less than the ideal reverberation time for classical music. Sample 5 (1000 Hz) were placed on the top between the building foundations. Sample 5 (2000 Hz) were placed on the back of stage. These made a very effective partition for Aula Barat.

In Figure 6F, the ideal reverberation time for speech in auditorium was achieved only at 500 Hz. This is occurred due to the limitation of Aula Barat itself, and the bandwidth frequency of MPP was very narrow. If the building is large enough, there are some possibilities to apply more MPP in the room and makes MPP to achieve the ideal reverberation time in all range of frequency. The frequency band of 500 Hz was chosen since it is the dominant range of frequency where human usually use for speech. It is showed in figure 6 the definition affected by the placement of MPP in Aula Barat was 40 – 70%. This was shown that MPP made the acoustics of Aula Barat ITB better than the existing condition. Again, those achievements were related to the MPP configuration. Sample 4 and 5 were chosen since they have high absorption coefficient and wideband of frequency. These samples were placed on the top part of buildings wooden pillars and curves.

In figure 7F, the ideal reverberation for Gamelan Bali was achieved also only at 500 Hz. This is also occurred due to the limitation of Aula Barat it self and the bandwidth frequency of MPP. The application of MPP in Aula Barat was also increasing the clarity in Aula Barat to 1 – 6 dB, which is good for Gamelan Bali. The SPL difference produced was about 6 dB between the audiences in the front with the audiences at the back. This can be achieved because the right placement of MPP. Sample 2 (250 Hz) were placed at the back, sample 5 (500 Hz) placed at the back of the stage, and sample 5 (1000 Hz) placed on the side of building.

6. CONCLUSIONS

The concept of adjustable acoustics can be implemented in the Aula Barat ITB using configurations of MPP. The implementations effect of MPP in the Aula Barat was determined by simulation using ray tracing method. It was shown that MPP can solve some acoustical problems in the Aula Barat. When Aula Barat is used for classical concert hall, MPP can reduce the reverberation times and improve the clarity. The samples used for treatment were sample 4 and sample 5. For this treatment, sample 4 (500 Hz) were used about 1.2 %, sample 4 (1000 Hz) used about 2.3%, and sample 5 (2000 Hz) used 1.3 %, of the total surface area inside the Aula Barat.

When Aula Barat ITB used for speech, MPPs sample 4 (500 Hz), sample 4 (1000 Hz), and sample 5 (2000 Hz) can solve the acoustic problem at 500 Hz and improve the definition in Aula Barat.

For Gamelan Bali performance in Aula Barat, MPPs configuration were also solved the reverberation problem at 500 Hz and improve the clarity.

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