Objective and subjective acoustics measurement of audience seating areas in a medium size auditorium

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Abstract. Several consideration of the acoustical quality of a multi-purpose hall should be taken into account and therefore, the audiences must be fully aware of the acoustical consequences in deciding their seating positions. In this paper, objective measurement and subjective assessment in the medium capacity, Driyarkara multi-purpose hall, has been investigated. Room impulse responses (RIR) were taken for several monaural parameter distribution including G, EDT, and C80 at 16 positions referring to ISO 3382-1:2009. The signals were convolved with anechoic sound of musical instruments to reproduce acoustic stimuli for subjects to listen. Stimuli data is reduced to 8 measurement' positions, which indicated the noticeable difference. These were generated to reproduce binaural sounds for further subjective assessment. The distribution of binaural parameters were observed in 250 Hz, 1 kHz, and 4 kHz to obtain JND (Just Noticeable Difference). The result reveal that this hall contains 3 different acoustic zones with the range of acoustics parameters of G: -8.91 dB – 1.07 dB, EDT: 1.12 s – 1.52 s, C50: -0.11 dB – 5.05 dB, C80: -3.70 dB – 2.03 dB, D50: 31.00 – 60.71, Ts: 62.75 ms – 106.50 ms, IACC: 0.43 s – 0.82 s, Treble Ratio: 0.67 – 0.96 and Bass Ratio: 0.81 – 2.80. Furthermore, this result correlates with the JND value for G: 2.26 dB, Ts: 17.5 ms, Treble ratio: 0.2, Bass Ratio: 0.03 and D50: 16.67.

1. Introduction
Auditorium have many functions, some of the most familiar functions are for meeting room and for having performances. Auditorium as a performing space should have a capacity of volume per seat minimum 6.2 m³ and maximum 10.8 m³ [1]. Music performance space or concert hall emphasizes on distribution of sound in the entire hall. Commonly closed performance space produce low background noise. Suyatno et al [2] studied the acoustic parameters for gamelan performances in Pendopo Mangkunegaran Surakarta. The result of background noise shows in the main hall, pendopo terrace and outside area pendopo are 54 dB, 62 dB and 71 dB, respectively. The pavilion that has a roof with pyramid shape, greatly affects the sound distribution inside the main hall. The largest reverberation time inside the pendopo at the center of the main hall is 2.2 s. This is influenced by the distribution of reflected sounds from the geometry of the roof and its material.

The same phenomenon occurs in an atrium that has a large capacity with solid material used for the roof. These architectural elements created acoustic discomfort. The results of computer simulations show that micro-perforated panels can improve the noise level and reverberation time [3] where the reverberation time decreased around 1 to 2 s. A research done by Marc Aretz and Raf Orlovski[4] reported that changes in the area of absorption not only change the value of the reverberation time but
also the value of G. Concert hall will produce a good sound distribution when reverberation time is between 1.6 s to 2 s [5]. Reverberation time also affects the conductor and the orchestra player in their ability to hear the clarity of the tone of each phrase from musical composition [5].

Measurement technics and just noticeable difference (JND) value is provided in ISO 3382-1:2009 [6]. A study reported a JND value for reverberation time that is larger than the value in ISO 3382-1, which is 24.5 with 6.9% in standard deviation [7]. Distribution of acoustic parameters can be presented with area mapping using data at points that are suitable enough to see the differences. Taeko Akama et al [8] suggested that it is not about the larger amount of measurement points that will give one the mapping discrepancies but by enough measurement points. This is to insure a best visualization in presenting the acoustics parameters distribution. To get enough measurement points, Taeko Akama also suggested to do some measurements with different amount of points. Other study reported by Mike Barron [9], found that the value of G (strength) is not constant. As the distance between sound source and receiver increases, the G value will decrease. As the distance gets farther away from the sound source, the G value will decrease more.

To evaluate the quality of a performance space, subjective evaluation is also needed besides of acoustics parameter measurements. Acoustic stimuli helps respondents to identify their favorite seats rather than using visual stimuli only [10]. The combination of these two stimuli shall produce a more suitable assessment. Angelo Farina reported the index for subjective evaluation to assess concert hall and opera houses [11]. The indices are obtained by the regression value more than 0.3 in every experiment of the comparison between objective parameters and subjective index. Case studied in this research is the Driyarkara Auditorium in Yogyakarta, Indonesia. Driyarkara Auditorium was designed specifically for speech and music purposes without electrical sound system. With capacity more than 1000 audiences, this auditorium is required to fulfill the acoustic needs for the entire audience seats.

2. Research Methodology
Auditorium Driyarkara, Yogyakarta as a multipurpose-hall is functionalized as a graduation ceremony building and also rent as a concert hall. It is a medium size auditorium with a capacity of 974 seats at the first floor and 126 seats at the second floor. Design of the wall is covered by diffusor panels and absorber material. Structure of the wall is arranged with a zig-zag pattern. In front of the stage, a huge diffuser panel is installed to scatter the sound. This condition affects the audience seating area by providing sound reflections that are coming from many surfaces.

Equipment of this research is balloon with 30 cm diameters as the sound source, omnidirectional microphone BSWA MPA416 as the receiver, soundcard, laptop and headphone. Preliminary research was done to obtain positions of measurement that represent the acoustics profile of the auditorium. Objective measurement was done by recording at 16 seats (A1, A8, B15, B22, G1, G9 G18, M26, S1, S8, S18, and S26; see Figure 1 and 2). The recorded Room impulse response (RIR) was then convolved with a dry sound from guitar instrument following the steps of auralization. The auralization signals are then used as the acoustic stimuli for the subjective evaluation. In the subjective evaluation, a comparison of 2 sounds at three directions (vertical, horizontal and diagonal) was performed. Every comparison consist of three questions; (1) Which sound is louder?; (2) Which sound is clearer?; (3) Which sound is more reverb?. The answer options are (a) sound 1; (B) sound 2; (C) No differences perceived. The result of the objective measurement is the percentage difference of three parameters (G, RT, and C80). The result of the subjective evaluation is compared with the parameters obtained from the objective measurements for positions with significant differences.
2.1. Objective Measurement

Binaural recording was done at 8 seats (C5, C16, H7, H18, M8, M22, R9, and R22) based on the previous preliminary result. Audacity was used as the software for recording the RIR with each 7 seconds. The height of the source (balloon) and microphone receiver are 1.5 m and 1.2 m respectively. Microphone mounted on a person’s head was used to obtain a binaural recording. Data of the recording file was save in .wav format. Before generating the acoustics parameters, the recording file had to be trimmed to delete the early portions of the in order to minimalize error in the energy decay curve. In addition, “trimming” was done to reduce the discrepancies between the reverberation time values obtained from measurement using dodecahedron loudspeaker and balloon as the sound sources. Acoustic parameters analyzed are the G (strength), EDT (Early Decay Time), C80, D50, C50, Ts, IACC, Treble Ratio and Bass Ratio. Room Impulse Response (RIR) in 8 eats convolved with dry sound from guitar instrument by GratisVoolver from CATTacoustics. The result of convolution become acoustics stimuli on subjective evaluation.

2.2. Subjective Evaluation

Subjective evaluation was done using questionnaire with semantic scale rating from -3 to +3 with zero as neutral value. Respondents were listening to 8 acoustics stimuli through headphones and were giving the assessment based on the subjective parameters, which represents acoustic parameters in the objective measurement. Subjective parameters are pleasant-unpleasant, round-sharp, soft-hard, diffuse-localizable, detached-enveloping, dry-reverberant, treble booster-treble reduced, bass boosted-bass reduced, and quiet-loud. Respondents were selected based on several criteria which are students that have taken acoustics courses, or musicians or those that have experienced attending an indoor live concert.

3. Results and discussion

Result of the objective measurement is shown in Table 1. Many positions are having values there are under the recommended JND in ISO 3382-1:2009. The result should be validated with the respondent’s perception in order to observe their listening quality of the sound happening in the auditorium.

3.1. Subjective Evaluation

Subjective evaluation was done with 81 people (17 until 27 years old), contain of 50 males and 31 females also 32 musicians and 48 non-musicians. Respondents should closed at least one of the requirements; 1. Have been attending acoustics class in university, 2. Musicians, or 3. Have been watching indoor live concert. Result of the subjective evaluation is shown in Figure 3, with the axes are (1) pleasant-unpleasant, (2) round-sharp, (3) soft-hard, (4) diffuse-localizable, (5) detached-enveloping, (6) dry-reverberant, (7) treble booster-treble reduced, (8) bass boosted-bass reduced, and (9) quiet-loud. The result of rating scale shows that respondents have a tendency to give the assessment at -2 till +2. It is shown that we can actually reduce the rating scale to 5 scale only from -2 to +2.
### Table 1. Objective measurement result

| Frek (Hz) | C5   | C16  | H7   | H18  | M8   | M22  | R9   | R22  |
|-----------|------|------|------|------|------|------|------|------|
| G (dB)    |      |      |      |      |      |      |      |      |
| 250       | -3.17| -0.45| -5.45| 0.73 | -5.11| 1.13 | -5.29| -7.82|
| 1000      | -5.39| -5.69| -6.23| -4.25| -5.80| -3.76| -6.20| -8.61|
| 4000      | 1.83 | 0.66 | 4.07 | 6.53 | 2.37 | 3.48 | 2.15 | -2.07|
| EDT (s)   |      |      |      |      |      |      |      |      |
| 250       | 1.81 | 1.32 | 1.89 | 0.88 | 1.81 | 1.16 | 1.73 | 1.77 |
| 1000      | 1.50 | 1.30 | 1.33 | 1.36 | 1.35 | 1.35 | 1.40 | 1.31 |
| 4000      | 1.00 | 1.17 | 0.99 | 1.08 | 1.14 | 1.10 | 0.83 | 1.11 |
| C80       |      |      |      |      |      |      |      |      |
| 1000      | 2.06 | 2.12 | 3.57 | 1.75 | 4.63 | -0.49| 2.57 | 4.54 |
| 4000      | 5.10 | 5.75 | 8.20 | 5.70 | 5.77 | 3.13 | 6.76 | 5.89 |
| Ts        |      |      |      |      |      |      |      |      |
| 250       | 158.00| 91.00| 165.33| 85.67| 153.33| 75.67| 152.00| 136.33|
| 1000      | 78.67| 91.00| 72.00| 88.67| 61.33| 105.00| 92.67| 68.33|
| 4000      | 57.67| 48.67| 40.67| 45.00| 47.33| 69.33| 57.67| 55.67|
| D50       |      |      |      |      |      |      |      |      |
| 1000      | 53.23| 46.54| 52.43| 49.79| 56.42| 34.63| 39.94| 59.47|
| 4000      | 61.13| 71.10| 64.32| 69.77| 63.80| 52.26| 65.69| 66.16|
| IACC      |      |      |      |      |      |      |      |      |
| 1000      | 0.84 | 0.42 | 0.74 | 0.55 | 0.69 | 0.39 | 0.42 | 0.40 |
| 4000      | 0.56 | 0.59 | 0.53 | 0.49 | 0.69 | 0.29 | 0.50 | 0.41 |
| TR        |      |      |      |      |      |      |      |      |
| BR        |      |      |      |      |      |      |      |      |

**SUBJECTIVE EVALUATION**

![Subjective Evaluation Diagram](image)

#### 3.2. Just Noticeable Difference

Objective measurement result in Table 1 converts to subjective scale and compares with the subjective evaluation. This comparison obtained the percentage value of respondents who gave the same perception with the objective measurement rating. The Yellow color represents the maximum percentage of the rating from respondents in subjective evaluation. The blue color is the result of converting the objective measurement result. Meanwhile, the green color shows the same result between objective measurement.
and subjective evaluation. From the 9 comparison, we can obtained the value of JND for G, D50, Ts, Bass Ratio and Treble Ratio as 2.26 dB, 16.68 %, 17.5 ms, 0.03 and 0.2 respectively.

| Points/ Scale | -3 | -2 | -1 | 0  | 1  | 2  | 3  |
|---------------|----|----|----|----|----|----|----|
| H7            | 4% | 26%| 17%| 12%| 26%| 14%| 1% |
| C5            | 0% | 12%| 17%| 23%| 31%| 14%| 2% |
| R22           | 1% | 21%| 27%| 23%| 15%| 12%| 0% |
| M22           | 7% | 27%| 22%| 16%| 15%| 9% | 4% |
| H18           | 7% | 30%| 27%| 17%| 14%| 5% | 0% |
| M8            | 1% | 14%| 27%| 16%| 28%| 14%| 0% |
| C16           | 16%| 33%| 14%| 10%| 14%| 10%| 4% |
| R9            | 5% | 15%| 27%| 14%| 25%| 14%| 1% |

### 3.3. Acoustic Zoning

Regression analysis was used to obtain parameters which has the highest correlation. The distribution of the parameters is to predict the location of the most convenient seat, acoustically speaking. The regression analysis shows that G, EDT, Ts, C80, D50, C50, IACC, Treble Ratio, Bass Ratio and IACC are 0.42, 0.32, 0.24, 0.06, 0.08, 0.26, 0.23, 0.06 and 0.18 respectively. From this result only G and EDT which have regression value above 0.30. The distribution of G and EDT at low (250 Hz), mid (1000 Hz), and high (4000 Hz) were analyzed and obtained the acoustic zoning (see Figure 4). The result indicated that middle seats have the highest listening quality. Hypothetically, these middle seats are receiving the most sound reflections from all surfaces that enable to support the listening quality. Meanwhile, the fair listening quality are seats at the front rows. Seats that are far away from stage have the poor listening quality.

![Figure 4. Acoustics zoning.](image)

### 4. Conclusion

Using the objective measurement, we obtained range of values of acoustics parameter of G, EDT, C80, C50, D50, Ts, IACC, Treble Ratio, and Bass Ratio are (-8.91 to 1.07 dB), (1.12 to 1.52 s), (-0.11 to 5.05 dB), (-3.70 to 2.30 dB), (31.00 to 60.71), (62.75 to 106.50 ms), (0.42 to 0.82 s), (0.67 to 0.96), and (0.81 to 2.80). Comparison between the results from objective measurement and subjective evaluation give JND values for G, D50, Ts, Bass Ratio and Treble Ratio of 2.26 dB, 16.68 %, 17.5 ms, 0.03 and 0.2
respectively. In addition, based on the regression result of G (0.42) and EDT (0.32), we obtained three acoustics 3 zones (see Figure 4) of different listening quality where middle seats are the best, front seats are the intermediate class and the worst listening quality are seats that are further away from the stage.

5. References

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