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Acoustical Evaluation of Café in Heritage Building at Jonker Walk, Melaka

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Abstract: All the time, café is an essential part of our daily life - a node where people socialize, work, or even where they got their inspiration of idea. Lately, there been booming of adaptive reuse of heritage buildings to become café along the Jonker Street Malacca; each café is various in size and theme. All these projects mainly to restore historical visual traits and focus on restoration through function change. Somehow, designers and planners always neglect the role of sound, which is very crucial element of our environment and daily lives when making place making. Thus, this research is aimed to investigate and evaluate the level of the acoustical performance of adaptive reuse buildings at Jonker Street Malacca. Analytical method on a computational modelling of cafe will be used for this research which involved acoustical evaluation (noise level, reverberation time, Speech Transmission Index) simulation. Few cafe types were modeled in a room acoustic simulation application with a manipulated variable of volume, sizes and ceiling height. Basic sound field properties of typical cafe types are highlighted based on the finding of the study. The generated index from variables hopefully could be used to design and evaluate café specific acoustic environments in the future.

Keywords: Adaptive reuse, café, Odeon simulation, reverberation time, sound transmission index

1. Introduction

The bustle of heritage tourism rises the number of dilapidated buildings that were rejuvenated and being transformed into chic establishments that draw tourists and trendy urbanites. With redevelopment finally obtain traction, these derelict structures are reborn through adaptive reuse (Said et al., 2013). Adaptive reuse defines the process of repurposing dilapidated buildings or ineffective old buildings for new purposes by not abolish their historical features (Abdullah et al., 2020). It is considered as a constructive way to reduce urban sprawl, retain existing resources and, most importantly, preserve unique and authentic built heritage (Teng, 2017). These rescued buildings continue to excite people by restoration through function change – a café.

All the time, cafes are an essential part of our daily life (Grafe and Bollerey, 2007). It becomes a node where people eat, socialize, work, reading or any celebrations (Hodgson et al., 2009). Somehow, designers and planners always neglect the role of sound, which is a very crucial element of our environment and daily lives when making place-making. There is noise leakage from the cafe into adjacent areas that are not recognized and addressed until there are concerns

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(Ramakrishnan and Dumoulin, 2016). There are many sound sources in restaurants and cafés, including songs, refrigerant and coffee machines, and people speaking (Caniato et al., 2013). In the absence of sound-absorbing materials, noise is reflected on concrete, rubber, and steel equipment, which is categorized as weak sound absorbent and is reflected back to the customer as noise (Yun et al., 2020).

In the literature, customer's dining selection is no longer limited to food factors; the dining atmosphere, especially the sound environment, has a significant impact on diners' evaluations of their satisfaction and the overall dining experience (Meng et al., 2017). A restaurant's ambiance is always what keeps people coming back, regardless of the restaurant's decent food or service quality (Mistar et al., 2020). The dining environment has a direct impact on customers' intentions to spread positive comments and willingness to spend more (Heung and Gu, 2012). With the industry of food and beverage keep growing, it is important to identify the influencing components of noise sensitivity as regards acoustic comfort within multiple sorts of eatery locations (Mistar et al., 2020). Conventional approaches to sound are strictly limited to noise management (Carles et al., 1999). Schafer had developed a positive approach towards the acoustic environment stating the divider line between the sounds we tend to preserve and eliminate is required for the improvements of soundscapes (Bartle, 1977). Indeed, minimize sound levels doesn't always improve acoustic comfort (Raimbault and Dubois, 2005).

The Café and Restaurant Acoustics Index (CRAI) is an acknowledged system of acoustic comfort categorizations for eatery locations in New Zealand ("Cafe & Restaurant Acoustic Index,"). These classifications, however, were created solely rest on diners' expected input and subjective reactions, with the use of statistical metrics (Mistar et al., 2020). Despite a large number of studies on the effects of dining atmosphere on consumer behaviour (Bottalico, 2018; Ryu and Han, 2010), there is limited empirical research exploring acoustic rate and acoustic comfort of the dining area, particularly in the café business(Culling et al., 2020). Nonetheless, a similar stream of study in Malaysia shows that dining restaurant atmospheric elements play an important role in customer satisfaction (Ariffin et al., 2017; Jalil et al., 2016; Kong and Jamil, 2014; Mohi, 2012). In contrast, Aini (Mistar et al., 2020) provides a conceptual framework for acoustic comfort sorting of café and restaurants, which might be used as a guideline for future acoustic design and practice in Malaysia.

Lately, there has been a booming of transformation projects of heritage buildings to become café in Melaka Heritage areas (Said, 2016). Those transformed cafés are located at different spots along Jonker Street (Said et al., 2016); each café is various in size and theme. Hence, this work is aimed to examine the acoustical performance in these cafes, bars, or restaurants for their occupants in adaptive reuse buildings. The generated index from variables hopefully could be used to design and evaluate café specific acoustic environments in the future, in terms of requirements and ratings (i.e., background noise level and speech transmission index) to create satisfactory target acoustic conditions.

2. Research Methodology

For this study, three (3) cafes from different locations of the same street as well as the design were selected for purpose of this research. These cafes are classified into 3 different locations of the street: intermediate lot, corner lot, and end lot. Figure 1 showing the location map of each selected cafe along Jonker Street at Melaka.

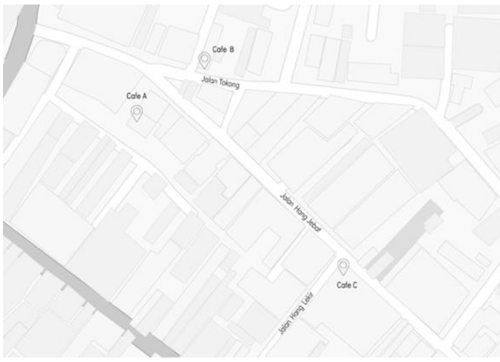


Fig. 1 - Location map showing selected cafes along Jonker Street, Malacca

Plans and sections of three cafes are obtained based on the measurement on-site to generate three-dimensional models by using Sketch Up for acoustical simulation later (Waxman, 2006). All architectural details as well as knick-knack and framing were excluded throughout the 3D modelling process due to these particulars make no remarkable differences on early reflections to the receivers. Yet, notable specular reflection at the receiver would be only produced by furniture that is adjacent to a source or receiver point (Culling et al., 2020).

Next, a completed model is export to the par file format by using SU2ODEON plugin. The par file can be opened directly in ODEON Room Acoustic Software Version 16.07 (Odeon, 2020) which was used for the computer simulation (Yun et al., 2020). Odeon software provides a calculation of room acoustic parameters by using a hybrid approach (Naylor, 1993): the early reflections were computed by using two methods, which are ray tracing and image source, followed by generated diffuse secondary sources. Subsequently, the water tightness assessment is to secure the model is completely sealed to improve the accuracy of the results.

In order to run simulation, materials to be chosen from its library and apply to each model's surface. For this research, materials are chosen to be similar to the actual material on-site as feasible, followed by the sound source and receivers to be applied to it. Three single point sources, which represent normal conversation, coffee grinding noise, and children noise that are commonly found in a café are being defined and placed 1.2 meters (sitting position above ground and 1 meter away from the wall to provide accurate simulation. Moreover, 6 receiver points where simulated in each cafe according to the seating position of the customer and chair arrangements in the café.

Finally, after all, the necessary information was entered, the simulation will be run to achieve the data required for comparison of the study by using four parameters (Pangestu et al., 2018; Wright et al., 2016): Reverberation Time (RT), Speech Transmission Index (STI), Early Decay Time (EDT) and Sound Pressure Level (SPL).

3. Results and Discussions

For this study, 3 cafes were selected to assess the Acoustical performance by using ODEON Software. Four parameters were used to codify and compare the findings: (1) Reverberation Time (RT), (2) Speech Transmission Index (STI), (3) Early Decay Time (EDT), and (4) Sound Pressure Level (SPL). The materials, sound source, and receivers' positions, and background noise level used for the simulation were explained in previous chapters. All results of the simulation for all acoustical parameters will be presented in the form figure.

3.1 Reverberation Time (RT)

The comparison of the reverberation time of every room model is shown in Figure 2. Based on the results, the RT for each cafe dropping as the frequency rises from 250Hz to 2000Hz. This phenomenon happens due to low frequency is not effectively absorbed in most materials, hence resulting in shorter reverberation at a higher frequency and longer reverberation in lower frequency (Zannin and Zwirtes, 2009). As refer to Figure 2, when reaching 250Hz, Café A showed the maximum T (30) value, which is 1.18, whereas Café C has the minimal value which is 0.58.

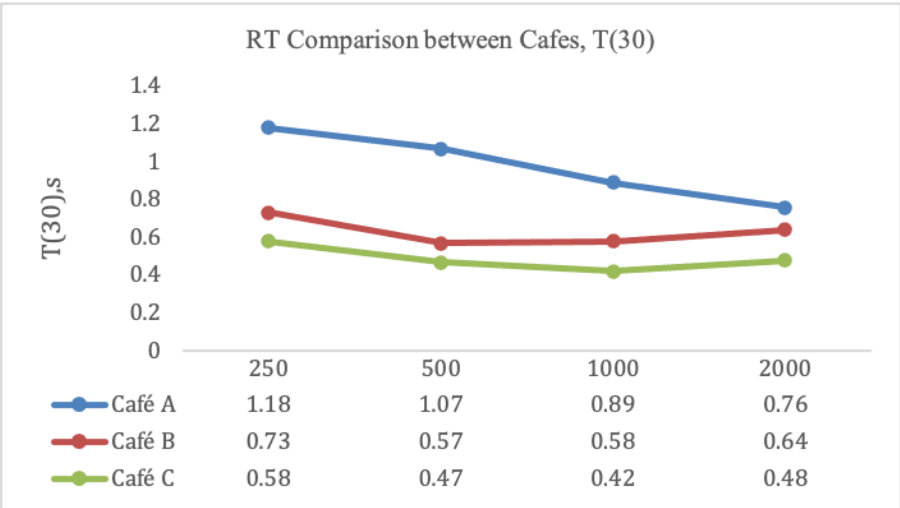


Fig. 2 - Reverberation Time, T (30) for room model

In the previous explanation in Section 2, a good acoustical café has an RT value between 0.7s to 0.8s, subject to the standards from various countries. Nonetheless, only café B takes a place in a good acoustical café. RT is influenced by two different variables, the volume of room and area of absorption. As stated by Sabine, reverberation time, T = 0.161 (V/A), where V is the room volume and A is the total sound absorption area(Long, 2014). Thus, the minimal RT may stimulate by the small ratio of the total area of absorption to the room volume.

Based on figure 2, Café A has generally higher RT value followed by Café B and then Café C. This is due to their difference in total absorption area where Café A is enclosed with wall and fixed glass, while Café B and Café C have more windows and openings. This proves that the RT value is directly proportional to the total absorption area, with an increase in absorption area resulting in a lower RT value.

3.2 Sound Pressure Level (SPL)

The results of SPL for each receiver in each room model have been presented in Figure 3. By referring to the bar chart shown in Figure 3, Café B has the highest average SPL which is 84.5dB after that Café A which is 84.3dB, followed by Café C which is 70.3dB. As suggested in ODEON, a normal conversation between a customer in a normal voice tone with a 63.0dB. The contrast between the sound produced by the normal conversation and the average customer position for Café B is 21.5dB, Café A is 21.3dB while for Café C is 7.3dB. This shows that the sound energy loss in all cafes is generally high.

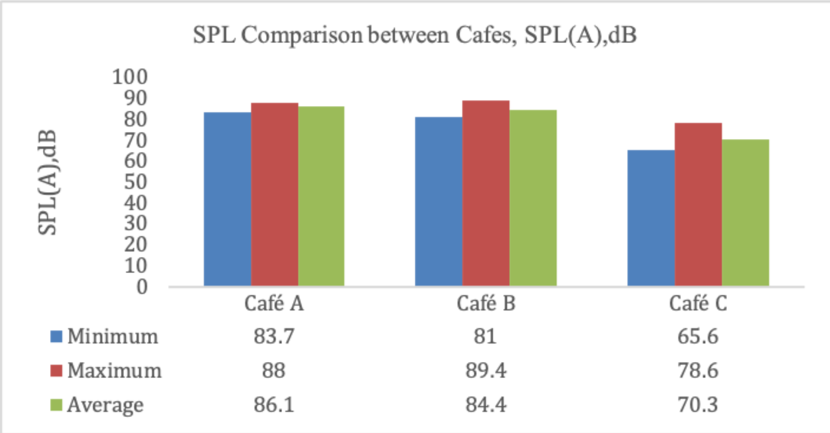


Fig. 3 - Sound Pressure Level for each receiver in room model

In comparison, Café C is the lowest average SPL value as it has the highest ceiling of 3.83m followed by Café B which is 3.33m, and lastly, Café A which is 3.25m. On the other hand, Café B has the highest SPL due to its shortest distance between the customer and the furthest customer with the length of cafe of 10.8m where Café A and Café A has the length of cafe of 23.2m and 26.2m.

Consequently, it can be concluded that the further the sound source away from receiver pressure, the lower the SPL level(Hansen, 2001). In addition, SPL level might be affected by the height of the café as well. In Culling's study, high ceilings are more conducive to dialogue than low ceilings (Culling et al., 2020). Any increase in room volume, as indicated in the Sabine equation, will increase the reverberation time, because volume always increases faster than surface area, even if only one dimension is modified.

3.3 Early Decay Time (EDT)

Early Decay Time is the measure of time of perceived reverberance energy to fall by 10dB (Jordan, 1970). Figure 4 shows a comparison of the EDT of each room model. While the frequency rises from 250Hz to 2000Hz, the EDT will be started to fall. This phenomenon happened due to sound waves lose energy and being damped when traveling through the medium. Hence, sound wave able to travel certain distance only before it loses its energy as heat. Due to less energy transmitted to the medium, low-frequency sound waves may travel a longer distance than high-frequency waves(Pierce, 2019). In a conclusion, the higher frequency sound wave disperses energy quicker to the air, resulting in a shorter period for reverberant energy in cafes to fall by 10db, EDT.

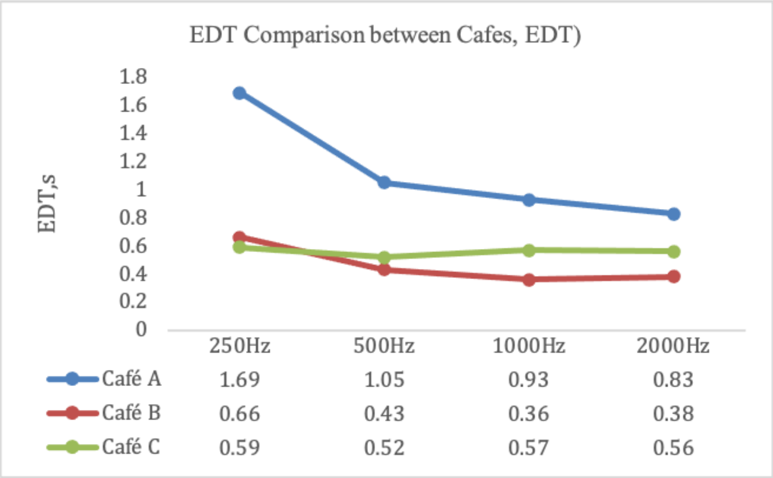


Fig. 4 - Early decay time, EDT (s) for each room model

According to the table shown in Figure 4, the highest EDT value happens in Café A, which is 0.69 whereas the lowest EDT value is Café C, 0.59 when reaching 250Hz. It can be perceived that RT and EDT results having a similar pattern but the RT value, 0.77 is greater than the EDT value, 1.69 at the frequencies of 250Hz, 500Hz, 1000Hz, and 2000Hz. This is due to the fact of lower frequency sound waves are more difficult to absorb than higher frequency sound waves. In general, EDT and RT have a similar curvature graph, with a lower value when reaching higher frequency as the sound absorption by the air.

3.4 Speech Transmission Index (STI)

The result of the STI of each room model has been presented in Figure 5. The highest average value of STI is Café B which is 0.79, where the lowest STI value is Café A, which is 0.74. Both café A and café C falls under the "Good" STI rating which is between 0.6 to 0.75. Café B is categorized under an "Excellent" STI rating. In order to accomplish "Excellent" speech intelligibility, the cafes have to achieve a minimum STI value of 0.75 or above.

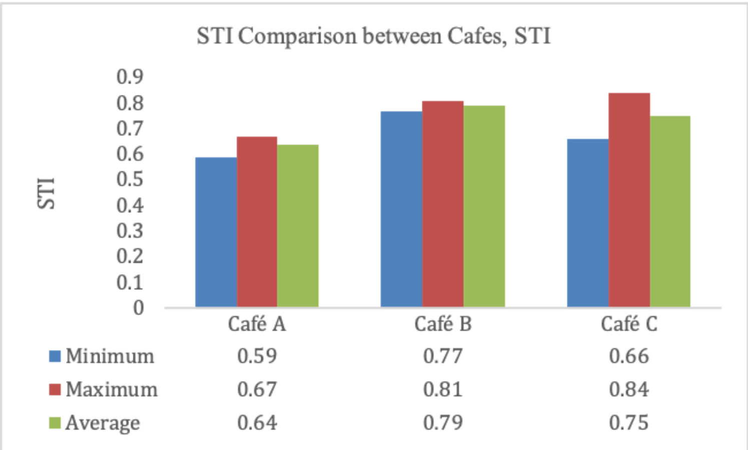


Fig. 5 - Speech transmission index, STI for each room model

In comparison, it is obvious that there is a direct relationship between STI value and room volume. As the room volume increases, the STI value decreases. Café C has the highest STI value compare to the other two cafes as it has the biggest volume which is 804.2m^3. The produced sound waves have to travel farther to reach the receiver. In short, the volume of café is required to minimize in order to improve the STI value and this minimization can be achieved by lowering the café height.

Hongisto's study showed that a café with a lower ceiling would produce stronger early sound energy reflections that come up with higher speech intelligibility (Hongisto et al., 2004). Nevertheless, the ceiling should limit to a minimal level which does not affect the distribution of sound reflections to the rear part of the room, which can diminish the speech intelligibility.

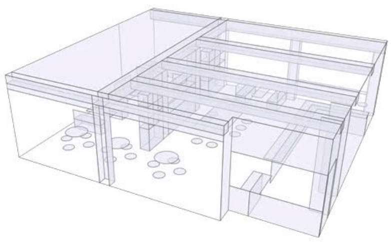
According to Figure 5, Café B complied most of the acoustical benchmark with an STI value of 0.76 and a uniformly distributed SPL to the whole café. Moreover, in terms of RT, all cafes are in the range of 0.6s to 1.0s. Consequently, two experiments will be conducted to upgrade the RT value and STI value of the cafe.

i. To examine various ceiling forms that will manipulate the RT and STI.
ii. To examine various materials used that will manipulate the RT and STI.

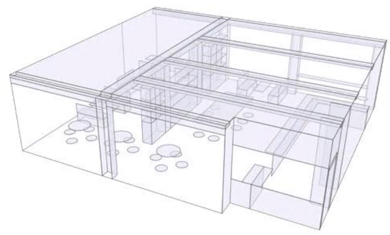
3.5 Experiment 1: Ceiling Profile Vs Reverberation Time and STI

Café A is used as the based study model in this experiment. There would be 4 different ceiling shapes were designed for the cafe to study the effect of the ceiling profile on the acoustical performance of the cafe. The cafes are all constant by using similar plan and area as it is based on the base model of Café A but the volume may be different due to the different profile and height of the ceiling. All modified café with different scenarios have shown in Figure 6 below.

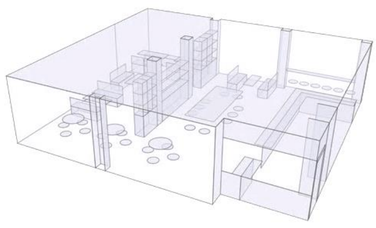
O: Original Cafe Model with no ceiling



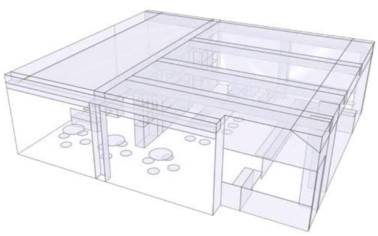
MO1: With ceiling and drop to 3000mm floor to ceiling height



MO2: Ceiling camouflage with beam soffit and drop to 2900mm ceiling height



MO3: Single Slope Ceiling 30° on both sides of café



MO4: Single Slope Ceiling 30° on all sides of café

Fig. 6 - Ceiling profile and height of each modified café

3.5.1 Reverberation Time (RT), T (30)

Table 1 below showed the comparison of RT results for the modified café. The result showing RT drop once ceiling materials were introduced in the café. When the ceiling level is lowered from 3200mm to 2900mm ceiling height, the RT value falls dramatically from 1.18s to 0.81s at the frequency of 250Hz. This shows a fall of 31% in the RT value which provides a more intimate environment for café. On the other hand, alteration in the ceiling of the café can improve the RT in a significant manner too instead of lower down ceiling height of the café. The significant changes in RT for MO3 and MO4 are due to the changes in volume due to the chamfering of the ceiling.

Table 1 - Comparison of T30 results for the modified café

Room Model	Reverberation Time, T(30), s Frequency, Hz 250	500	1000	2000
O	1.18	1.07	0.89	0.76
MO1	1.01	0.68	0.57	0.50
MO2	0.81	0.78	0.89	0.95
MO3	0.84	0.66	0.59	0.52
MO4	0.80	0.70	0.67	0.69

Original café model result

RT improved result

Nonetheless, lower RT does not mean better. For instance, the preferable reverb time for spaces like restaurants or café falls on 0.7--1.1 seconds, relying on the desired liveliness of the space. A fine dine restaurant usually required 0.7-second reverberation, whereas a lively bar or up--tempo venue may desire nearly 1.1 seconds. Hence, a low reverb time may have the undesirable "dead" sound (Oniku and Bello, 2011).

3.5.2 Speech Transmission Index, STI

Based on the ODEON simulation, the uses of ceiling and decrease in ceiling height have a significant improvement on the Speech Transmission Index of the café. Moreover, chamfering of the ceiling can help improve Speech Transmission Index if the option of lower down the ceiling is not preferable by cafes owner. However, the average STI of the café increased from 0.64 to 0.75, it is still within the "Fair" range, yet reaching the "Excellent" range.

Table 2: Comparison of STI results for the modified café

Room Model	Speech Transmission Index, STI Minimum	Maximum	Average
O	0.59	0.67	0.64
MO1	0.71	0.79	0.75
MO2	0.75	0.79	0.76
MO3	0.72	0.77	0.74
MO4	0.73	0.79	0.75

Original café model result

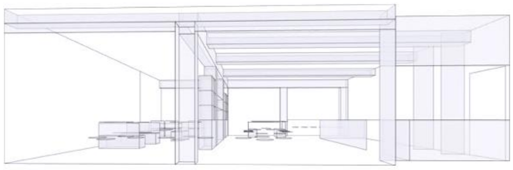
RT improved result

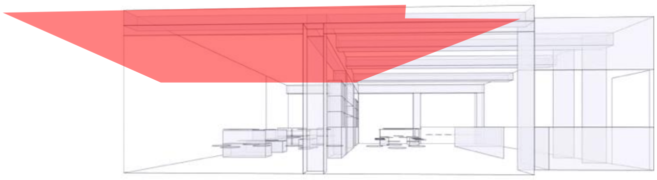
Moreover, the results derived from table 2 show the option of chamfering of the ceiling can help enhance STI if the option of lower down the ceiling is not preferable by cafes owner. However, the average STI of the café increased from 0.64 to 0.75, it is still within the "Fair" range, yet reaching the "Excellent" range. An "excellent" STI value can help to increase of enjoyment of customers, as for returning customers (Wright et al., 2016).

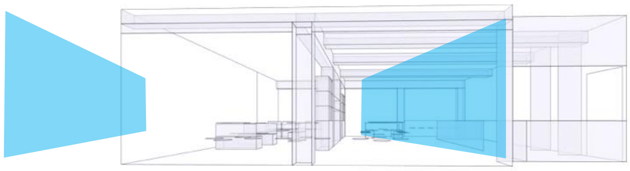
3.6 Experiment 2: Materials Used Vs RT and STI

As a reference to the previous experiment, by lowering the ceiling height or using chamfered edge ceiling, the RT decreases significantly but the value is still can be improved for the café to fall in "Excellent Rating". All RT values for MO1, MO2, MO3, and MO4 fall between recommended range 0.7s-0.11s, but Speech Transmission Index just fall on "Good Rating", yet reaching "Excellent". Thus, modification of material is keen to enhance the acoustical performances of the cafe.

In order to achieve notable changes in RT and STI, larger surfaces are selected for the replacement of the material. There are two surfaces targeted to enhance the RT value, which is the acoustic panel on the wall and ceiling.

O	**Material alteration for ceiling**			
Material	(RED) Concrete block, painted (Harris, 1991)			
Room Model				
Frequency, Hz	250	500	1000	2000
Absorption Coefficient	0.05	0.06	0.07	0.09

MO5	**Material alteration for ceiling**			
Material	(RED) Flex acoustics AqFix Panel system, dept. construction 70mm (www.flexac.com)			
Room Model				
Frequency, Hz	250	500	1000	2000
Absorption Coefficient	0.14	0.08	0.08	0.08

MO6	**Material alteration for wall**			
Material	(RED) Flex acoustics AqFix Panel system, dept. construction 70mm (www.flexac.com)			
Room Model				
Frequency, Hz	250	500	1000	2000
Absorption Coefficient	0.14	0.08	0.08	0.08

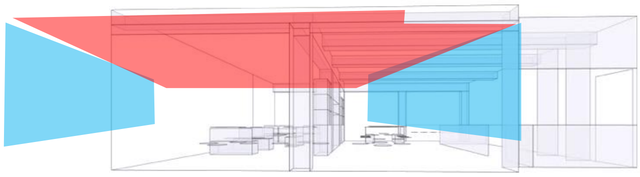
MO7	**Material alteration for ceiling and wall**			
Material	(RED) Flex acoustics AqFix Panel system, dept. construction 70mm (www.flexac.com)			
Room Model				
Frequency, Hz	250	500	1000	2000
Absorption Coefficient	0.14	0.08	0.08	0.08

Fig. 7 - Comparison of STI results for the modified café across four-octave bands (250Hz-2000Hz)

3.6.1 Reverberation Time, T (30)

As a result, derived in Table 3, among other experiments, MO7 has the best RT range of 1.13s to 0.74s when the frequency of 250Hz increases to 2000HZ. This shows an acceptable RT for cafe activities, no matter intimate environment or more lively event was carried out (Knauf, 2019). Table 3 below indicates the comparison of STI results for the modified café.

Table 3: Comparison of Speech Transmission Index, STI results for the modified café

Room Model	Reverberation Time, T(30), s Frequency, Hz			
	250	500	1000	2000
O	1.18	1.07	0.89	0.76
MO1	1.01	0.68	0.57	0.50
MO2	0.81	0.78	0.89	0.95
MO3	0.84	0.66	0.59	0.52
MO4	0.80	0.70	0.67	0.69
MO5	1.41	1.10	0.94	0.79
MO6	1.37	1.02	0.87	0.73
MO7	1.13	0.99	0.86	0.74

Original café model result

RT improved result

RT optimized result

On the other hand, Culling's study shows that material of ceiling and wall replace to the materials with better absorption coefficient was more effective which able to reduce the RT in the café (Culling et al., 2020). Instead, the most effective control of reverberation for speech intelligibility is to install an absorbers panel or acoustic materials vertically, perhaps on the wall and close to dinners.

3.6.2 Speech Transmission Index, STI

The comparison of STI results derived from experiments was indicated in table 4. Based on table 4, the substitution in materials for ceiling and wall in experiments of MO5, MO6, and MO7 was slightly improved compared to the original model. However, the rating does not have an impact compare to the MO2, which increased the STI rating to 0.76.

Table 4: Comparison of Speech Transmission Index, STI results for the modified café

Room Model	Speech Transmission Index, STI		
	Minimum	**Maximum**	**Average**
O	0.59	0.67	0.64
MO1	0.71	0.79	0.75
MO2	0.75	0.79	0.76
MO3	0.72	0.77	0.74
MO4	0.73	0.78	0.75
MO5	0.61	0.69	0.65
MO6	0.63	0.70	0.67
MO7	0.65	0.72	0.69

Original café model result

RT improved result

RT optimized result

In experiments MO5, MO6, and MO7, absorptive materials were introduced at the ceiling, wall, and combination of both areas. Using absorptive materials to increase absorption of the room surface provided a better STI rating, but the improvement was not significantly impact compared to lowering the ceiling (Nahid and Hodgson, 2008). However, the STI rating of MO5, MO6, and MO7 is still considered to be in the "Good" range. An STI that near to 1.0 was rated as excellent intelligibility, whereas lower and near to 0.0 was rated as weak speech intelligibility conditions(Christie, 2004).

4. Conclusion

In this study, three cafes were chosen from different locations of a similar street to determine the acoustic performance on how to achieve balance in acoustic and quality of cafe. The outcome showed that speech intelligibility and reverberation time of a cafe is influenced by the volume and the material absorption. Camouflage flat ceiling and improvement on absorptive materials are some recommendations to make café accommodate various activities, from intimate to lively events. The generated index from resulted variables hopefully could be used to assist the early design stage and could help on evaluation of café in specific acoustic environments in the future. Further investigations are pursuing intensively.

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