EFFECT OF VARIOUS PLAN TYPES ON ACOUSTICAL CHARACTERISTICS OF RESTAURANTS

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ABSTRACT

EFFECT OF VARIOUS PLAN TYPES ON ACOUSTICAL CHARACTERISTICS OF RESTAURANTS

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The acoustic performance of the interior environment is part of the interior environment's quality factors that determine the comfort, satisfaction and wellbeing of the users. Furthermore, the physical environment of the restaurant plays a major role in the comfort and dining experience of the visitors. Therefore, it is essential to study the parameters that need to be controlled during the interior design of the space. As per the literature review, factors affecting the acoustic performance of the interior space are physical, architectural, psychoacoustic and social. This research main aim is to investigate the effects of interior design architectural factors on the acoustic performance of restaurants through studying different plan types and material types combinations. Six models were designed using three geometric plan types; square, rectangular and rhombus. Nine material combinations were derived from three material types; reflective, absorptive and diffusive. Using software simulation, ODEON, three acoustic performance parameters were taken at corners and walls; reverberation time (RT), sound pressure level (SPL) and speech transmission index (STI). The acoustic parameters that were entered into the software are based on the common restaurant acoustic environments. The results of the research show that there are significant differences between different plan types and material types combinations in terms of the three acoustic parameters. Moreover, the compliance analysis shows that three geometric and material variations yielded the most ideal scenarios for the restaurant physical environment.

Keywords: acoustic performance, restaurant, physical environment

ÖZ

ÇEŞİTLİ PLAN TİPLERİNİN RESTORANLARIN AKUSTİK ÖZELLİKLERİNE ETKİSİ

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Temmuz 2019, 55 Sayfa

İç ortamın akustik performansı, iç ortamdaki kullanıcıların rahatlığını, memnuniyetini ve mutluluğunu belirleyen kalite faktörlerinin bir parçasıdır. Ayrıca, restoranın fiziki çevresi, ziyaretçilerin rahatı ve yemek deneyiminde büyük rol oynamaktadır. Bu nedenle, mekanın iç tasarımı sırasında kontrol edilmesi gereken parametreleri çalışmak önemlidir. Literatür taramasına göre, iç mekanın akustik performansını etkileyen faktörler fiziksel, mimari, psikoakustik ve sosyaldir. Bu araştırmanın temel amacı, farklı plan tipleri ve malzeme türleri kombinasyonları inceleyerek iç mekan tasarım mimari faktörlerinin restoranların akustik performansı üzerindeki etkilerini araştırmaktır. Altı model üç geometrik plan tipi kullanılarak tasarlanmıştır; kare, dikdörtgen ve eşkenar dörtgen. Dokuz malzeme kombinasyonu üç malzeme türünden elde edildi; yansıtıcı, emici ve yaygın. Yazılım simülasyonu kullanılarak, ODEON, köşelerde ve duvarlarda üç akustik performans parametresi alındı; yankılanma süresi (RT), ses basıncı seviyesi (SPL) ve konuşma iletim endeksi (STI). Yazılıma girilen akustik parametreler, genel restoran akustik ortamlarına dayanmaktadır. Araştırmanın sonuçları, farklı akustik parametreler açısından farklı plan tipleri ve malzeme türleri kombinasyonları arasında önemli farklılıklar olduğunu göstermektedir. Ayrıca, uyumluluk analizi, restoranın fiziksel ortamı için en ideal senaryoları üç geometrik ve malzeme varyasyonunun verdiğini göstermektedir.

Anahtar kelimler:akustik performans, restoran, fiziksel çevre

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1. INTRODUCTION

Comfort in restaurant is one of the most important factors that are essential to attract customers. Therefore, it is important to understand the factors that contribute into increasing the attractiveness of the restaurant environment. Acoustic factor is part of several factors that affect the interior environment quality. Thus, it is considered essential to know the sound factors, indices and indicators that contribute into the enhancing it. Reverberation time is one of the most important physical factors, which is affected by the frequency of the sound and the dimensions of the environment (Mijic and Masovic, 2010). Speech intelligibility is a perceptual acoustic quality that enables the space user to carry out a conversation comfortably (Shinn-Cunningham, 2003). Other factors affect the sound environment, including background noise, sound pressure level and psychoacoustical factors (Long, 2014).

Due to the many factors and sounds that affect the acoustic environment, the study of interior soundscape was founded to hear the full auditory picture summing all the sounds and understanding the perception of its users (Miller, 2013). The closed nature of the interior environment allows several factors to influence its acoustical performance. Architectural factors, such as geometry, plan types and finishing material, were suggested in the literature to affect the sound environment (Dokmeci Yorukoglu and Kang, 2016). Furthermore, social factors such as occupancy, function and usage can contribute into a calm or noisy interior (Herranz-Pascual, et al., 2017).

The sound environment of restaurants is unique as there are sound sources that can only be found in it, including nearby conversations, kitchen noise and tableware clinking (Lindborg, 2016). The recent studies just got into the classification of restaurant sound environment, while the literature remain lacking further investigations on physical environment factors that can enhance the acoustic performance in them. This research studies the sound and acoustics of restaurants through an investigation of the plan types and material types that can influence its sound environment. The study adopts an investigative approach in order to understand the differences between using different variations of the two factors using an advanced acoustic software.

1.1Aim of the Study

The main aim of the study is to investigate the variations in plan types and material types that affect the acoustic performance in the restaurant context. Significant acoustic performance indices are included in the research, such as reverberation time (RT), sound pressure level (SPL) and speech transmission index (STI). It is also important to construct a methodology to enable the researcher to achieve the main aim of the study. Therefore, the objectives of the research are as the following:

- Study and select the acoustic performance factors that are important for the restaurant environment.
- understand the physical, psychoacoustic and social factors that contribute into creating the interior soundscape in restaurants.
- Survey the literature for studies that addressed the restaurant sound environment in order to build on their results and discuss them along with the findings of the current research.
- Design plan type model and use them to simulate the sound environment of a restaurant.
- Calculate the key acoustic performance indicators for the research: RT, SPL and STI.
- Compare the results with each other in order to understand differences in acoustic performance based on plan type and material type.
- Find the most compliant models with the restaurant acoustic performance criteria.

1.2Thesis Structure

As the thesis commenced by providing an overview of the subject and introducing the main aim and objective in this chapter, the second chapter focuses on surveying the literature to understand the key sound and acoustic environment concepts, review studies that addressed the restaurant sound environment and other contexts, and study the factors that affect enhancing or worsening acoustics in restaurants. The third chapter provides the design of the research and the methodology used for the assessment. Additionally, the models that are tested in this research are presented and the standards are provided for comparison and compliance. The third chapter includes also the results of the study for the effect of the plan types and material types on the acoustic performance of restaurants. Moreover, the most compliant model variation is presented, and the results are discussed in line with the literature. The fourth chapter provides the conclusions of the study, as well as answering the research questions, testing the hypothesis and providing the necessary recommendations.

2. LITERATURE REVIEW

2.1 Introduction

The chapter addresses the acoustic design and performance as reviewed by the many studies in the literature. Several main research points are included in order to form an understanding of the main concepts needed for the subject and the case study. Firstly, the room acoustic is reviewed based on several contributing factors; physical andpsychoacoustic. The physical factors of the sound are defined and relations between the different variables are established. Reverberation time, as one of the most important parameters for acoustic design, is connected with other factors and parameters. Key considerations for the physical factors, such as background noise and speech intelligibility are also addressed. The psychoacoustic factors are mainly related to the individuals' perceptions of the sound properties. Factors like pitch, sharpness, roughness and loudness are included in the study.

Furthermore, soundscape is reviewed as an important concept that studies the sound environment collectively and provides measures for its enhancement, which takes into consideration the perception of the space users, in addition to the sound sources that are forming the overall sound of the environment. Architectural factors that are related to the case study are studied through the literature, including geometry and plan type, volume and finishing material. Social factors are briefly reviewed to understand their impact on the acoustic environment. Additionally, studies that performed acoustic studied within restaurant contexts are included under a separate section in this research to understand any specific considerations for the case study. Finally, previous studies of room acoustics, soundscape, architecture and social factors are reviewed for discussion purposes in alignment with the results of the research.

2.2 Room Acoustics

Designing a room or an interior space to yield a specific acoustic performance is a problem that is continuously addressed by specialists. Based on the type of the room and the importance of the acoustic performance that is expected from the design, several methods are used to calculate approximate and exact indicators. For instance, the acoustic performance in theatres and cinemas is considered vital to the functionality of the space, while it might be less important in office and residential spaces (Branski, Kocan-Krawczyk, & Predka, 2017). One of the first steps that are used to understand the acoustic performance of a space is performing acoustic modelling for it. Geometrical acoustic simulation tools are used for this purpose to collect and analyze information and parameters that describes the acoustic properties of the surfaces; absorption, scattering, transmission.

There are two main parts that are required to perform an acoustic simulation for an interior space, which are modelling the geometry of the space and modelling the material properties. It can be understood that in studying the acoustic performance or designing room acoustic is lengthy and complex; however, Alonso and Martellotta (2015) divided studying room acoustics' steps into the geometrical and material properties parts. In the geometrical study the authors stated that it is important to consider the relevant details regardless of its apparent magnitude, as ignoring small details may result into inaccurate designs or assessment. Furthermore, material selection has the most impact on the accuracy of the final results (Alonso & Martellotta, 2015).

2.2.1 Physical Factors

The main physical factor that affects room acoustics is the distance between the sound source, surfaces and receiver. The distance that is measured is called the reverberation radius, which is defined as the radius surrounding the sound source where the direct sound level is equal to the reflected sound level. In order to for a listener to receive a good sound quality, he or she need to be within the reverberation radius, which is also called critical distance. The reverberation radius r_c can be calculated using equation (1), which is valid on the source axis with maximum intensity (Mijic & Masovic, 2010).

$$r_c = 0.057 \sqrt{\frac{\gamma V}{T}} \qquad (1)$$

Where, V is the space volume in m^3, T is the reverberation time and γ is a sound source property called directivity factor.

Mijic and Masovic (2010) used four different rooms to calculate the reverberation radius theoretically and measure it through the frequency of the sound and the reverberation time. As understood from the equation, the physical environment's dimensions and distances are also influential in determining the reverberationradius. The results of the study show that equation was able to calculate the parameter with an acceptable accuracy in most of the cases (Mijic & Masovic, 2010). Moreover, the human factor affects the perceived distance from the sound source, as shown in review that compiled twenty-one studies with the total of 659 participants (Zahorik, Brungart, & Bronkhorst, 2005). The reverberation of the sound is another physical factor that affects the physical perception of the sound for the hearer. A study stated that reverberation affects all acoustical attributes, including the spectral content, intensity, temporal structure and interaural differences(Shinn-Cunningham, 2003). Further details on reverberation and the way it is measured for acoustic design are provided in the next section.

2.2.1.1 Reverberation Time

Reverberation is a phenomenon that describes the travel of the sound from its source, reflection on surrounding surfaces and absorption by air and other material. The desirability of reverberation depends mainly on the functionality of the space. A lower reverberation is required in social areas, while spaces with audience may require a higher or a specific reverberation. Due to its importance in acoustic design, an essential design parameter was established describing the time a sound would take from the source to reflect on a surface, which is the reverberation time. The reverberation time is defined as the decay time needed for a sound energy to decrease 60 dB to one-millionth of its original intensity (Cavanaugh & Wilkes, 1999). Reverberation time is considered critical in some contexts, especially the ones where the acoustics are fundamental for its functionality, such as opera houses and theatre (Rossing, 2014). Therefore, a preferred reverberation time (T) is assigned to different sound types, as shown in Figure 1.

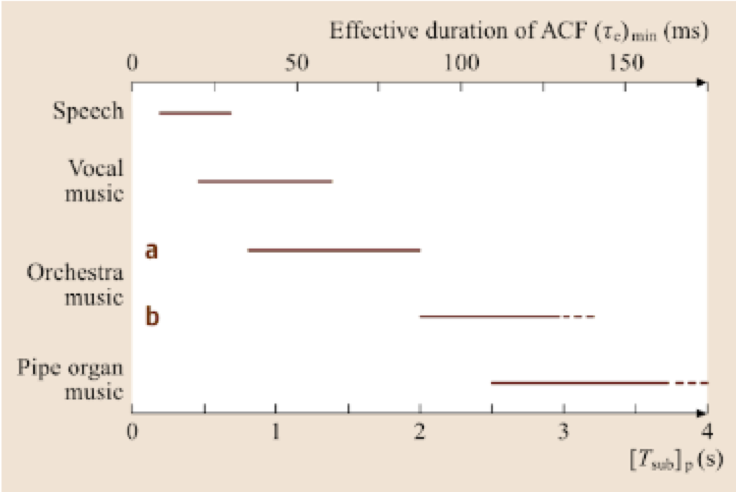


Figure 1: Recommended/ Preferred reverberation time for different sound sources (Rossing, 2014)

2.2.1.2 Speech Intelligibility

Speech intelligibility is an auditory perception quality that is studied along with the spatial hearing factor. Both factors depend mainly on the hearing sensitivity of the hearer. As speaking is one of essential activities for social interaction, achieving a good level of speech intelligibility is one of the important goals in certain environments. Studies show that the increase in sound reverberation decreases speech intelligibility (Shinn-Cunningham, 2003). By definition, speech intelligibility is the measure of the comprehensibility of the speech in the environment as affected by internal or external sound reverberations. The measurement of speech intelligibility is performed by calculating the ratio between the speech and reverberation of speech sounds to the noise level (Subramaniam & Ramachandraiah, 2006).

Since noise was found to mask speech and the ability to understand it by people in the environment, the parameter is measured through the signal-to-Noise Ratio (SNR) (Latham, 1979). Speech intelligibility is based on factors that measure the clarity and the ability for speech definition by the listener. The lower the reverberation of the sound, the higher is the sound reflection, the higher the speech transmission from the source to the listener and higher the early energy fraction, the better is the speech intelligibility (McNeer, Bennett, Horn, & Dudaryk, 2017).

2.2.1.3 Background Noise

Background noise describes the sound signals that are produced by all sources, except for the main sound source that is meant to exist in a certain environment (Al Zubi, 2018). As shown in the previous section, the noise level has a direct adverse impact on speech intelligibility by masking 90% of the speech. Nonetheless, it is mentioned that a low-level background noise enhances speech intelligibility (Subramaniam & Ramachandraiah, 2006). Studies also found that fluctuation in ambient noise has effects on speech intelligibility(McNeer, Bennett, Horn, & Dudaryk, 2017).

A study on classroom settings confirmed the impact of excessive background noise on the academic achievement of the students. Therefore, the intended usage and functionality of the interior space can be affected by the background noise if it exceeds certain limits (Knecht, Nelson, & Feth, 2002). As an acoustic parameter, the functionality of the interior space plays a major role in determining the background noise limit, as it affects the comfort and attention of the occupants, as well as providing speech privacy. A study in an open plan office environment measured speech privacy through the background noise level, where the higher the background noise the higher the speech privacy in an office environment (Vervoort & Vercammen, 2015).

2.2.1.4 Sound Pressure Level and Sound Power Level

Sound pressure and power are two parameters that measures the emitted sound from a source, while each one of them describes the sound measurement based on the place of the reading. The sound power level measures the sound power from the source in Watt (W), which is emitted in all directions, while the sound pressure level measure the effect of the sound source in dB with reference pressure of 0 dB or in another unit $2x10^{-5}$ Pascal, which is the threshold of human hearing (Al Zubi, 2018). Figure 2 shows the sound pressure levels for typical sound sources measured in decibels (dB).Sound pressure is often used to calculate the sound power level, and vice versa, through a complex mathematical model. Therefore, obtaining one of the two measurements allows for finding the other one in order to estimate the impacts of the noise (Peterson, 1980).

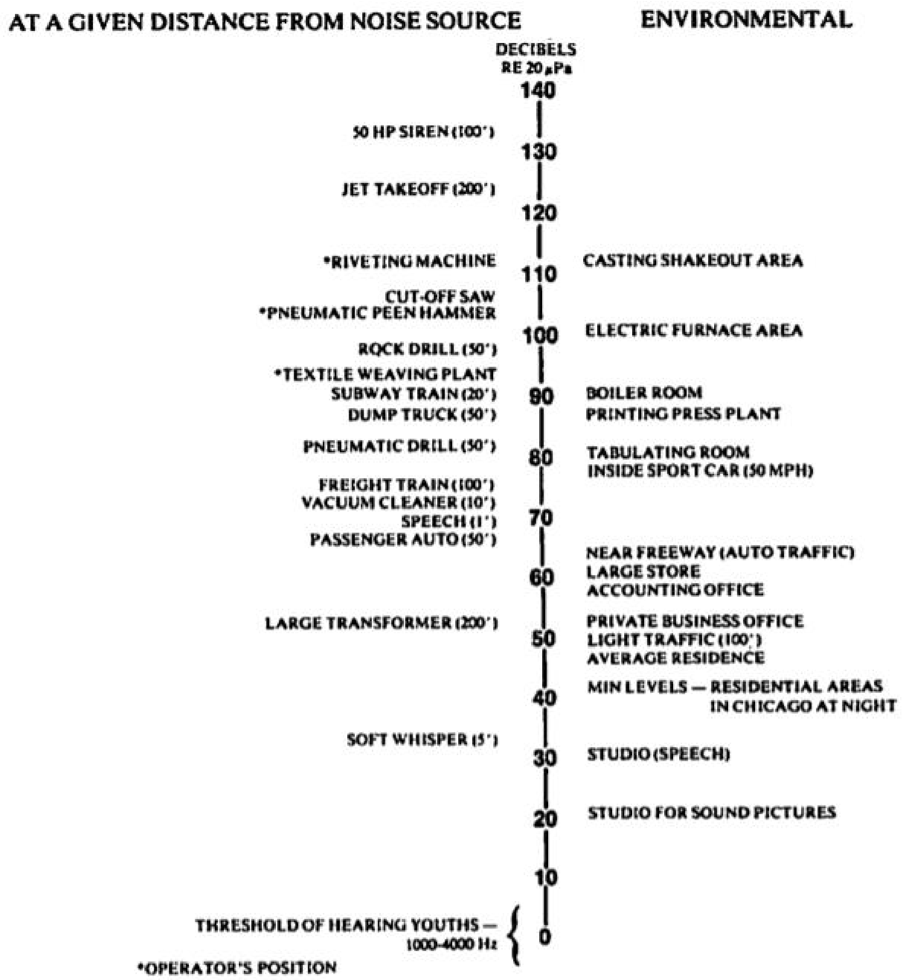


Figure 2: Sound pressure levels for typical sound sources(Peterson, 1980)

Sound pressure level and sound power level are measured as acoustic design parameters.It is important to obtain these values in any settings as they are related to the psychological status and hearing safety of the space occupants. The effects of excessive sound pressure can cause strain, anger and increase of blood pressure (Picu, 2009).Other studies have also confirmed the psychological effects of sound pressure levels on space occupants through the change of mood and behavior(Novak, La Lopa, & Novak, 2010).

2.2.2 Psychoacoustical Factors

These factors are directly related to the sound frequency level, which is different than the sound intensity properties described by the sound pressure and power levels.

Sounds with the same intensities can have different frequencies through different time of occurrence and durations, which subsequently have different psychological and emotional effects (Long, 2014). The psychoacoustical factors describe the perception of the sound through human differences, while several ones can be used solely or combined, such as pitch, loudness, sharpness and roughness (Yost, 2015).

2.2.2.1 Pitch

Pitch is the perception of the periodicity of the sound, where a certain harmonic spectrum of a certain frequency is repeated (McDermott & Oxenham, 2008). According to the American National Standards Institute, pitch is "the attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from high to low" (Houtsma, 1997). In speech, prosody and in tone languages are defined through their pitch rising and falling, while in music melody is defined by the pitch sequence and harmony is formed through combinations of pitches. The periodic repetition of spectrum is defined as the fundamental frequency (F0) and the amplitudes of the waves define the sound quality, with sounds between 30 to 4000 Hz simulating the pitch sensation (Oxenham, 2012).

2.2.2.2 Loudness

The loudness of the sound is referenced to the sound pressure measurement. Figure 3 describes the relationship between the two parameters, where the sound pressure increases, the sound loudness increases. It was first described by Fletcher and Munson in the 1930s to describe a 1000 Hz tone. Hence, the loudness level is used to describe a 1000 Hz sound in dB, which is expressed in "sone". The one sone describes the sound above the listeners threshold, which is 1000 Hz and 40 dB(Mendonca, 2012). The specific definition of loudness as per the American National Standards Institute is: "the intensive attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud" (Houtsma, 1997).

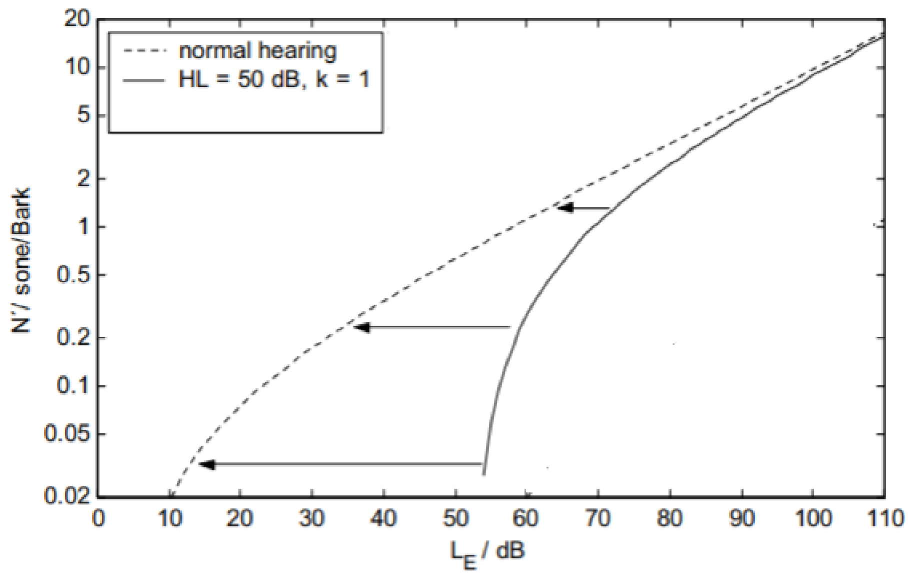


Figure 3: Relationship between sound pressure and loudness for normal hearing and impaired hearing persons (Fastl, Psychoacoustics and Sound Quality, 2005)

2.2.2.3 Sharpness

Sharpness is a sound quality that is sensed through frequency. The higher the frequency of the sound, the higher its sharpness (Mendonca, 2012). Sharpness is considered as the color for the tone, where its addition gives the sound powerfulness and excess sharpness gives an aggressive perception to the sound. The sharpness of the sound is correlated to its loudness. Therefore, it is possible to estimate the sharpness. As shown in Figure 4, through the integration of the loudness function (g). The dashed and the dotted arrows shows the change in sharpness when a low frequency sound is added. Through studying the relation between loudness and sharpness, it was found that adding low frequency sounds reduce sharpness, while low loudness sounds can be increased by decreasing the sharpness to enhance the sound quality.

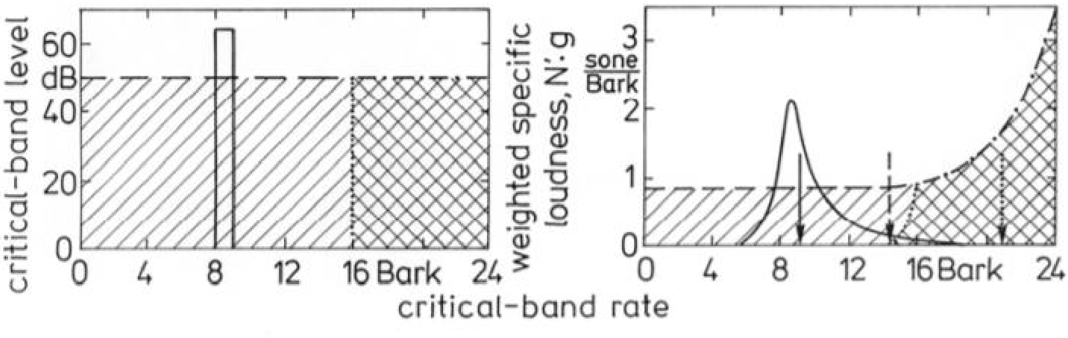


Figure 4: Sharpness model and relationship with loudness (Fastl, 2006)

2.2.2.4 Roughness

The temporal variation of the sound is described as roughness, where the faster the variations, the sound is described as rougher. Roughness masks the pattern of the sound with a maximum modulation frequency of 70 Hz (Fastl, 2006). Roughness can also be described as the added frequency to the band of signals producing a total roughness value (Park, Park, Seo, & Lee, 2012). As shown in Figure 5, the roughness of the sound increases with the increase of the modulation frequency and the sound frequency; however, with the continuation to increase the modulation frequency, the roughness starts to decrease after reaching a peak (Eddins, Kopf, & Shrivastav, 2015).

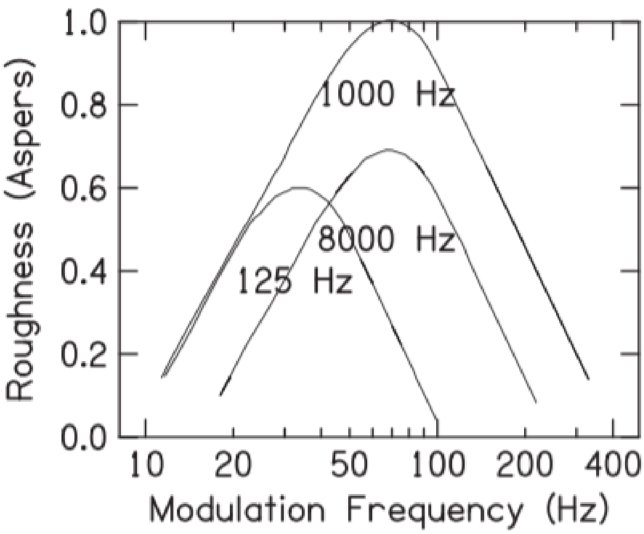


Figure 5: Change in roughness with the increase of modulation frequency at different carrier frequencies(Eddins, Kopf, & Shrivastav, 2015)

2.3 Interior Soundscape

Soundscape is defined as the sum of all sounds within an environment as perceived by the environment users or groups. Understanding the way users perceive the sound in an environment is a key factor in studying and analyzing its soundscape. Therefore, there are several factors to consider when studying soundscape, including the location and appearance of the environment, the functionality and activities performed in the space, the history and expectations of the users, and the users' socio-cultural background (Miller, 2013). The concepts of noise management and soundscape are distinct in their approaches. While noise management treats sound as waste and focuses on the sounds that are causing discomfort, soundscape perceive sounds as a resource and focuses on the preferred sounds in the environment. Moreover, noise management treats all sounds as an integrated unit and a receiving point and works to reduce sound levels, while soundscape distinguishes between the sound sources and the perception of the individuals towards these sounds and works on not allowing wanted sounds to be masked by unwanted sounds (Brown, 2010; Brown, 2012).

There are several methodologies that can be used to study the soundscape of the interior environments depending on the desired outcome of the study. In a post occupancy research of soundscape relationship with spatial experience, Aburawis and Dokmeci Yorukoglu (2018) reviewed three stages of the soundscape assessment. The first stage is indicative, where the usage factor is evaluated through observation of the users' behavior and the physical environment evaluation is performed through sonic measurements. The second stage is the investigative stage, where the users and social contexts are evaluated through interviews and the architectural design is evaluated through a spatial architectural survey. The third stage of research is the diagnostic stage, where the overall soundscape perception and spatial experience are assessed through a sound walk and a questionnaire for the interior space users (Aburawis & Dokmeci Yorukoglu, 2018).

Unlike the exterior environment, the interior spaces are mostly characterized with a passive soundscape, where the sources of the sound are mainly coming from the exterior. Some of the interior spaces have dull soundscapes due to the isolations added in the surface material to eliminate sounds from the outside. The Australian architect Abdrew Czink suggest a technique to color the sound of the interior space through understanding the properties of the sounds in a manner that allows the space owner to amplify the wanted sounds and attenuate the unwanted sounds. Moreover, new sounds can be introduced into the environment that are compatible with the space's resonant frequencies. The tools include a microphone and an amplifier that allows for recording the sound of the space and editing it in a way that facilitates the idea. The architect stated that he tried the method into his own space and emphasized the importance of soundscape in the interior environment. Furthermore, the author stressed that aural architecture is not less important that aesthetical elements, as it allows space users to create intimacy with the space and reinforces comfort (Czink, 2010).

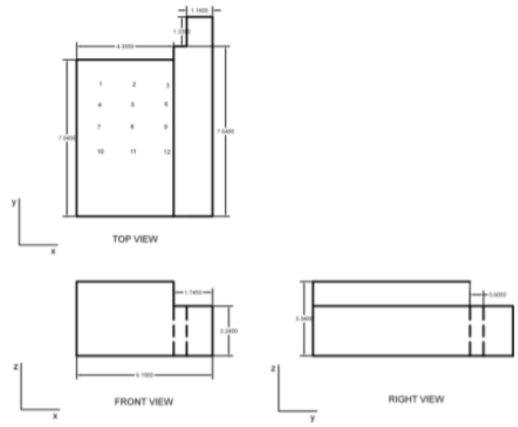
2.4 Architectural Factors

There is no doubt that the architectural design of an interior space affects its acoustic performance. Factors including the geometry of the space, its dimensions and the materials that are used for its elements all have impact on the way sound is reflected and reverberated within the environment (Subramaniam & Ramachandraiah, 2006). Through the mathematical model presented in equation (1) earlier, it can be seen that the volume of the room affects directly the reverberation time (Mijic & Masovic, 2010). Moreover, the geometry is addressed in many researches, which shows that the angel of the surfaces plays a role in the acoustic performance of the room. These factors, in addition to plan types and finishing material effects are reviewed within this section.

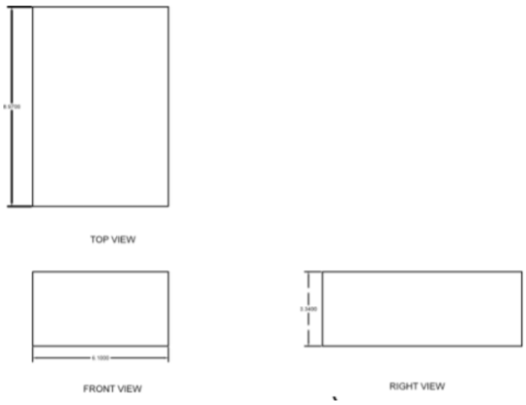
2.4.1 Geometry and Volume

The effect of geometry on the acoustic performance of the room is studied through minor modifications in the geometric shapes or comparison of several geometric shapes with great differences.Research showed that changes in the angels of the surfaces and the number of surfaces yields different results when testing acoustic parameters (Kuster, et al., 2004; Siltanen, Lokki, & Savioja, 2008). Reverberation time is considered one of the most significant parameters in acoustic design, as it affects the frequencies and the sound pressure level within the space. It was shown earlier that geometry has an impact on the acoustic performance. Nonetheless, even the same geometric shapes can produce different results based on their volumes. A study has shown that cylindrical ducts with different diameters and lengths has different acoustic performances. Due to its absorptive properties, the increase in the volume of the shape by increasing its diameter or length increases the absorption surface, which leads into less transmission. Moreover, the used ducts for the models have also reflective properties, where sonic wave are reflected more if the volume of the duct increased. The overall absorption and reflection are correlated to the balance in volume created to achieve the desired acoustic performance (Masmoudi, Makni, Taktak, & Haddar, 2017).

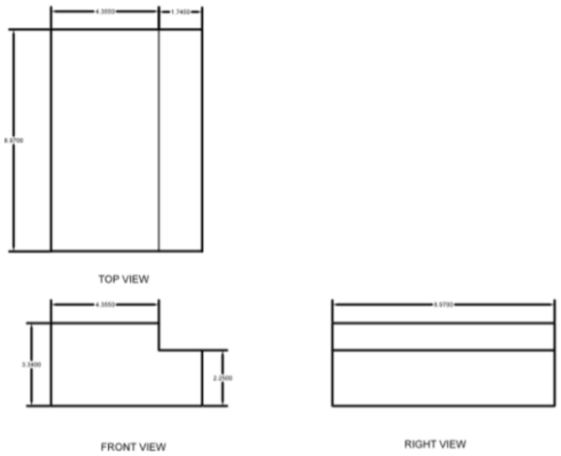
In a study that targeted the change in energy, reverberation time and sound strength based on the time required for each setup to decay different decibels, three models were examined, as shown in Figure 6. The volumes and surface areas are presented with each model. The examined parameters are the energy reflected within the 50 ms (D_{50}), which is considered useful for speech, the reverberation time of 30 dB (T_{30}) and the sound strength (G). Through testing twelve comparable points in each model, the authors were able to compare the three points based on the change percentage of each of the three parameters. The results show that there are no changes in sound strength measurements (G) or the decay in energy for the 50 dB signals (D50) between the three models, while reverberation time decaying 30 dB showed significant difference between the three models. The research also included a subjective assessment by twenty-five participants, who were asked if they can spot the difference between the three models through a test speech. The majority of the participants (more than 85%) could not spot the difference between the three models (Prawirasasra, Sampurna, & Suwandi, 2016).



Model 1
Volume: 143.31 m^3
Surface area: 183.65 m^2



Model 2
Volume: 212.41 m^3
Surface area: 210.1 m^2



Model 3
Volume: 165.69 m^3
Surface area: 196.52 m^2

Figure 6: Models and their geometry for the study of Prawirasasra, et al. (2016)

2.4.2 Plan Types

The attribute of plan types is closely related to geometry and volume, as shown in the study of Prawirasasra, et al. (2016), slightly different plan types showed different results for sound energy, sound strength and reverberation time. However, the most significant difference was found in reverberation time. Nonetheless, these differences were detected through sonic machines and were hardly detected by few participants through listening to speech recordings. A more apparent plan type impact differences were found by Dokmeci Yorukoglu and Kang (2016), where one grid L-shape and two linear rectangular library floor plans were examined in terms of sound pressure level and loudness. No specific comparison was performed for the plan type effect; however, the three libraries had different acoustic performances for the testing parameters, which can be emerging from the plan type change. This conclusion is supported by other research which suggested that changes an angles and surfaces, which are changes imposed by the plan type change, have significant impact on the acoustic parameters of the space (Kuster, et al., 2004; Siltanen, Lokki, & Savioja, 2008). Furthermore, different plan types are compared in the current study, which adds to the literature in strengthening this argument.

2.4.3 Finishing Material

The materials used to form the interior spaces has significant impact on the acoustic performance of the environment. Such an influence is proven through many studies in the literature under different material type usages and contexts, as reviewed in this section and upcoming sections with references. The sound absorption coefficient is the main parameter that describes the ability of the material to absorb sound waves at different frequencies. Nevertheless, there are several factors that affect the absorption of these material, including thickness, density and porosity (Amares, et al., 2017). Other factors have also influence on the absorption of the finishing material, such as compression, surface impedance and placement within the environment (Seddeq, 2009). In some interior environments, porous materials have to be added due to the space functionality and other performance criteria. Arenas and Crocker (2010) presented several material fabrics containing pores, which are made of Kenal, cotton, polyester and hemp. Figure 7 shows the absorption coefficient of hemp fibers at different frequencies as demonstrated by the authors. However, the porous property of these fibers was enhanced with increasing the density of the material and balancing the two parameters to achieve the required performance (Arenas & Crocker, 2010).

Acoustic absorbent materials are often added in special construction, such as theatres, cinemas and opera houses. However, in general construction acoustic false ceilings can be used, otherwise finished with paint, wood or glass. Walls have the same type of finishing variety, while flooring is tiled with ceramic or marble or covered with rubber or carpet. Each of these materials have their absorption coefficients, as shown in Table 1 for different material types. Martellotta, Crociata and D'Alba (2011) performed site measurement and theoretical calculation of the absorption coefficients of six churches for different frequencies. Windows and wooden doors had the highest absorption coefficients amongst other interior elements, where the highest values were at 125 Hz and 250 Hz. Itontei and Alibaba (2016) categorized acoustic material based on their function into four categories; absorbers (textile, wall coverings, wood, foam and building bricks and blocks), diffusers (irregular wall bricks), barriers (high density materials made from trees and stones) and reflectors (tiles, metals and glass).

Table 1: Acoustic absorption coefficients for finishing material examples

Finishing Material	Frequency (Hz)*					
	125	250	500	1000	2000	4000
Paint on masonry wall	0.02	0.02	0.02	0.02	0.02	0.02
Wallpaper on masonry wall	0.02	0.03	0.04	0.05	0.07	0.08
Glass (4 mm)	0.30	0.20	0.10	0.07	0.05	0.02
Gypsum board (100 mm air space)	0.30	0.12	0.08	0.06	0.06	0.05
Wood panels	0.15	0.20	0.10	0.10	0.10	0.10
Ceramic tiles	0.01	0.01	0.01	0.02	0.02	0.02
Rubber tiles (6 mm)	0.05	0.05	0.10	0.10	0.05	0.05

*. Coefficients from http://www.acoustic.ua/st/web_absorption_data_eng.pdf

2.5 Social Factors

In the literature, some studies included social factors, such as the time period the space is used, the functionality of the space and the usage density in correlation with the space acoustic environment. These correlations emerge from the fact that people are part of the sound environment as sources and receivers, which eventually affects the quality of the acoustics.

2.5.1 Time and Usage

The time of occupancy was found influential on the soundscape and sound environment of the interior space and the built environment generally. People's interaction between each other and with the environment is considered a source for sound through speech and activities (Herranz-Pascual, Garcia, Diez, Santander, & Aspuru, 2017). Moreover, Dokmeci Yorukoglu and Kang (2016) correlated the time of occupancy; morning, noon and afternoon to the sound environment of three libraries through different recording design sets. The results showed that sound pressure level and loudness differed between the three time periods, where the noon time recorded the highest values. Similar results can be expected for other contexts as the occupancy time and density varies throughout the day. In the restaurant context, a graduate research have found that the loudness and quietness period are equal through an objective sound measurement, where the weighted sound pressure levels varied between a maximum of 81.1 dBA in the loudest period and 67 dBA in the quietest period(Hannah, 2004).

2.5.2 Function

The difference in acoustics according to functionality emerges from the social factor due to the difference in human interaction types. The way people interact in classroom settings is different than restaurants or theater. Therefore, the sound sources in each environment vary based on the purpose of the interior space (Long, 2014). Moreover, Meng and Kang (2013) studied the effects of users' behavior and social interaction on loudness and acoustic comfort. The study was conducted in six shopping malls in China. Generally, relationships between the functions performed in the environment, as well as the behavior type of the users were found to negatively affect the sound environment negatively. Such hypotheses and studies show that the function of the interior space is majorly affected by the social factor, which is humbly addressed in the literature.

2.6 Indoor Acoustic Environment in Restaurants

Lindborg (2016) provided a classification of the sounds within the restaurant environment through acoustic measurements of 40 restaurants and 375 questionnaires, as there are few studies that targeted studying the acoustics of restaurants, as suggested by the author. Thirty-four sound types and sources were identified for the study from Lindborg (2015), which were tested for preference and liking by the participants. Figure 7 shows the most liked and the most disliked sounds in the restaurant environment. The results show that geophonic sounds (fountain, wind, water), positive sounds (quiet, calm, peaceful, soothing), Talking and laughter sounds, and background music are the most liked sounds in the restaurant environment. Nonetheless, walking steps sounds, screeching sounds, loud noises and crying sounds were the most disliked sounds (Lindborg, 2016).

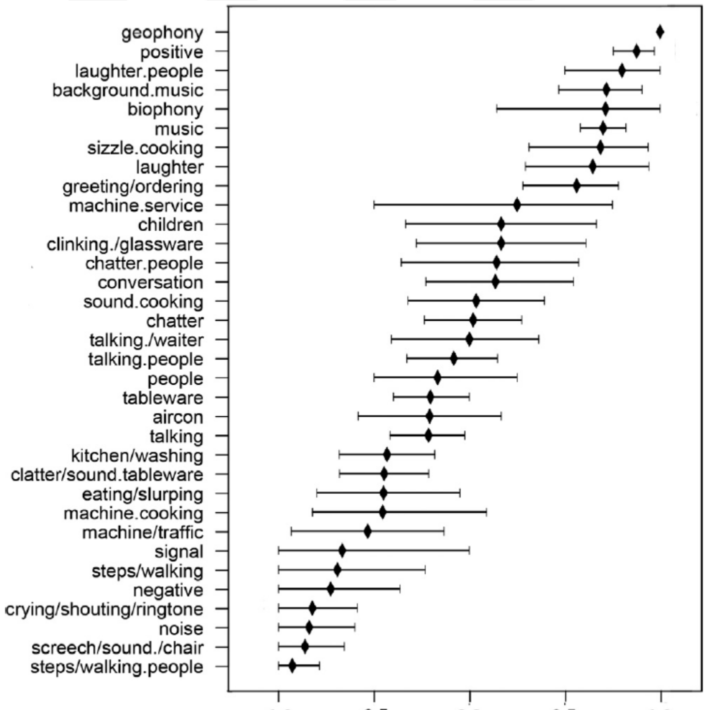


Figure 7: Liking rate for thirty-four sound sources in restaurant environments (Lindborg, A taxonomy of sound sources in restaurants, 2016)

Based on the study results, the author classified the sound sources in restaurant environments into four levels, with the fourth level being the head of the classification, as shown in Figure 8. The sounds were mainly divided into three main sources (Level 4): sound design, cuisine and customers. The majority of the sound sources fell under the customers' source as a result of eating, conversation and crowding. Kitchen and cooking were the third level classification for cuisine, while the sound design included nature, music and other noise. In the statistical analysis the findings show significant influence from all sound sources and of the different sound classification on the pleasantness rating of the restaurant users (Lindborg, A taxonomy of sound sources in restaurants, 2016).

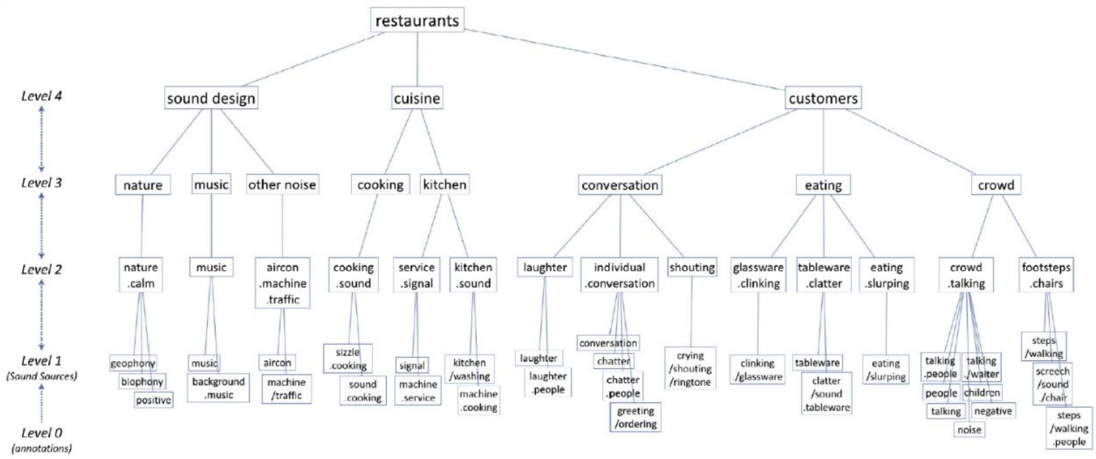


Figure 8: Taxonomy/ classification of sound sources in restaurants (Lindborg, A taxonomy of sound sources in restaurants, 2016)

Lindborg (2015) used acoustic data collected from 112 restaurants to predict the finishing material and the design style of the restaurants. With 95% reliability, the acoustic data was able to increase the prediction probability for the finishing material from 25% to 34% on average between the four restaurant types included in the study. Similarly, the acoustic data increased the ability to predict the design style from 20% to 32% on average between the five different design styles. The variance analysis of the study indicated that there are differences between restaurants in sound levels based on the food style served by the restaurant, while a significant difference was found in loudness based on the design style of the restaurant.

Other studies included different factors that have the potential to affect the sound environment in restaurants. Meng et al. (2017) found that the dining style in restaurant affect the conversation behaviour of the users. Through surveying more than 500 restaurants in China, the researchers concluded that the background music did not affect the conversation between the users. Moreover, three dining styles were tested; centralized (users on one table dining from a central serving), separate (users on one table dining from their separate plates) and dispersed (users on one table dining from several servings placed on the table), as shown in Figure 9. The speech between the users was increased through the centralized style, while the sound pressure level was reduced with the separate style with the background music. For the dispersed style, the increase in the crowd density decreased the acoustic comfort in the restaurant environment. Liu, et al. (2018) found that children playing in groups in restaurants playing areas increased the sound pressure level by 7% in comparison with individual playing, while the increase in the number of children increased the sound pressure level.

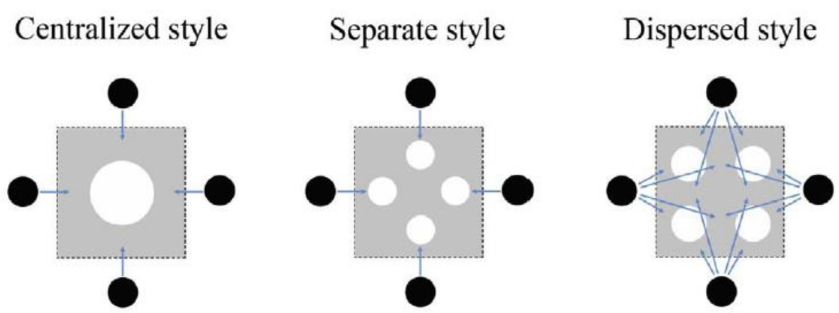
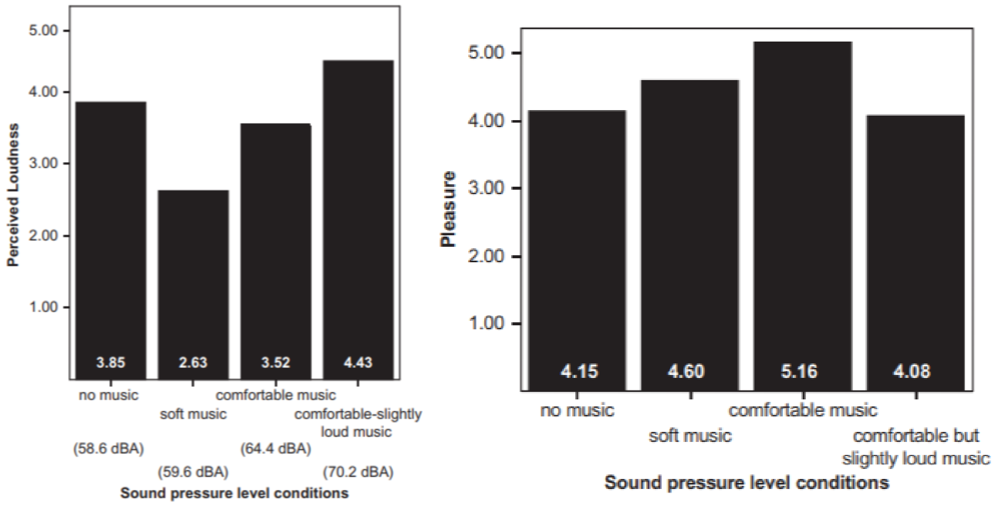


Figure 9: Dining styles assessed by Meng et al. (2017)

There are trials to develop a method to rate the acoustic environment in cafes and restaurants. In New Zealand for instance, the CRAI, Café and Restaurant Acoustic Index, was developed by the Acoustical Society of New Zealand (ASNZ) in order to develop a database with user ratings for the different venues in the country. The index depends on four acoustic questions and two occupancy questions rated by the users on a 5-point Likert scale. The acoustic questions rate the noisiness of the venue, the impact on the dining experience, conversation legibility, and noise hindering the repeat of the dining in the venue. The occupancy questions evaluate the business of the venue and the level of music played at the time of the rating. Through compiling the subjective ratings of the users, the ASNZ developed an online tool that allows users to review the acoustic rating of each restaurant. Such ratings drove the restaurants and designers to consider the acoustic parameters in a more serious manner (Camp, 2015).

There are several studies that attended to the subject of acoustic environment in the restaurant context through different approaches and relationships. A study included seventy-nine participants in order to understand the effect of the sound environment's music sound pressure level and sensitivity to noise on the pleasure and arousal factors of the restaurant users. In addition to the subjective questionnaire assessment, the authors included objective acoustic measurements in the study. Considering the fine dining theme of the restaurant, the vast majority of the participants preferred having background music, while more than 65% preferred classical music. Four sound pressure levels were recorded, as shown in Figure 10a, where the mean score for perceived loudness if provided. Areas with no music showed a high mean score for loudness, which proves the importance of ambient background sound. Sound pressure level showed a significant impact on pleasure ($p=.002$), as shown in Figure 10b (Novak, La Lopa, & Novak, 2010).



(a) (b)

Figure 10: Impact of sound pressure level on perceived loudness and pleasure in restaurants (Novak, La Lopa, & Novak, 2010)

There are several methods that can be used to study the acoustic environment of restaurants. A comprehensive study included objective measurement and a subjective evaluation in actual and virtual restaurant settings. The first experiment was conducted in the actual setting, where nine acoustic parameters were measured in five restaurants. Moreover, noise annoyance, speech difficulty and privacy difficulty were part of the subjective evaluation. The correlational analysis showed strong correlations of different nature between the three subjective indicators and four of the acoustic parameters, while three acoustic parameter showed medium correlations. Similar results were achieved in the second experiment with the virtual settings, where the participants listened to recordings of the five restaurants. Nonetheless, the correlations were stronger regarding the annoyance and privacy levels than the actual setting (Nielsen, Marschall, Santurette, & Jeong, 2016).

A more technical assessment of speech intelligibility was performed in a virtual restaurant setting with six subjects in two different layouts as shown in Figure 11. Sound recordings were taken in two experiments and further analyzed for frequency and reverberation time in order to understand the masking effect of interfering conversations on the settings. The interferers were recordings of monologues that were placed in the experiment settings. The authors started with one interferer then added a second one to understand the change in sound pressure levels. The results show that the first interferer imposed a change of -10 dB, while adding the second interferer had the impact of -5 dB, which shows that interferers had limited and decreasing effect as they are added (Culling, 2016).

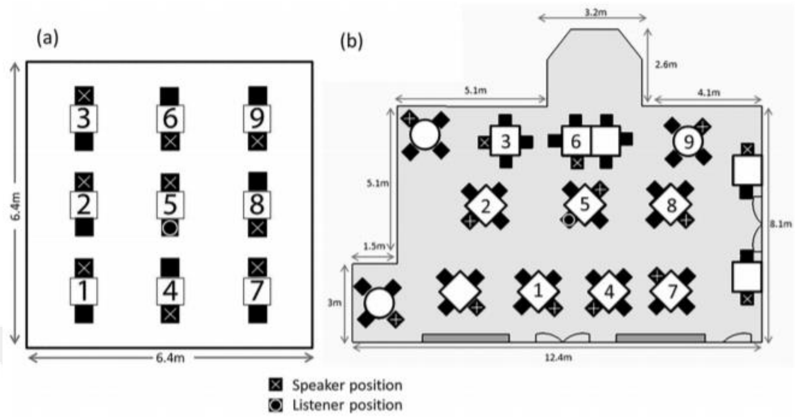


Figure 11: Virtual restaurant settings studied by Culling (2016)

An American Study researched the noise level in thirty restaurants in Florida, where sound pressure level had a minimum of 58.1 dBA and a maximum of 97.5 dBA, through a total of four hundred and eighty readings. The vast majority of the restaurants played music with large layout size. Half the restaurants had partitions, 85% had tile/ cement/ wood flooring, 55% had no wall covering, and 63% had partial occupancy. For sound pressure level readings, 40% of the restaurants had records ranging between 75 dBA and 79.9 dBA, 30% had recording ranging between 80 dB and 84.9 dBA, and 17% had recordings ranging between 85 dBA and 89.9 dBA. The average sound pressure level can be estimated to be around 80 dBA. Moreover, the research studied the influential factors affecting the noise level. The level of occupancy, location (city or suburb), and music style were found to have significant impact on the readings (Rusnock & McCauley Bush, 2012). The vast majority of the readings were found above 75 dBA, which is according to ISO9921 standards at 80% occupancy is a bad rating (Wohni, 2018).

2.7 Previous Studies

The following sections review the literature for studies that addressed the different aspects of the sound environment in different contexts. Room acoustic, architectural, soundscape and social aspects are considered in this research for understanding the current research in the field in terms of design and methodology. Moreover, the specific results of these studies are utilized for discussion of the current research's results.

2.7.1 Room Acoustic Studies

In a trial to reach an exact solution for a room acoustic problem, Branski, et al. (2017) applied the Fourier method with different wall impedance values. The researchers state that it is not possible to evaluate the exact acoustic performance of a room, as the rigidity and flexibility of the walls cannot be perfectly even. The study applies a uniform impedance values to different walls through assigning an absorption coefficient for each case. Based on that, the acoustic impedance function of the surfaces is calculated by dividing the acoustic pressure function by the particle velocity function. Moreover, the acoustic absorption coefficient can be measured through three types of methods; in-situ reflection methods, reverberation room methods and tube methods. The study connected an actual measurement of the coefficient with the calculation methods described earlier. The results of the study confirm that the absorption coefficient affects directly the acoustic performance of a room (Branski, et al., 2017).

A Brazilian study investigated the room acoustics of four classroom that were built in the 1960s in accordance with six domestic and international standards; Brazilian, French, German, Japanese, American and World Health Organization (WHO). The investigation was based on the reverberation time, sound environment frequencies, absorption coefficients and space volume of each of the cases. The standards recommend an average reverberation time between 0.6 seconds for 250 m^3 space volume and 0.7 seconds for 500 m^3 space volume and 0.8 for 750 m^3 space volume. The ceiling absorption values for type acoustic-celotex C-7, which were used in the case studies before changing them to PVC ceiling, are illustrated in Figure 12 reproduced from the study (highest α at 1024 Hz). The results show that the four case studies' PVC ceiling type achieve inadequate reverberation time in accordance with the majority of the standards, while it two of the case studies were achieving adequate results in accordance with all standards before the administrative decision (Zannin, Fiedler, & Bunn, 2013).

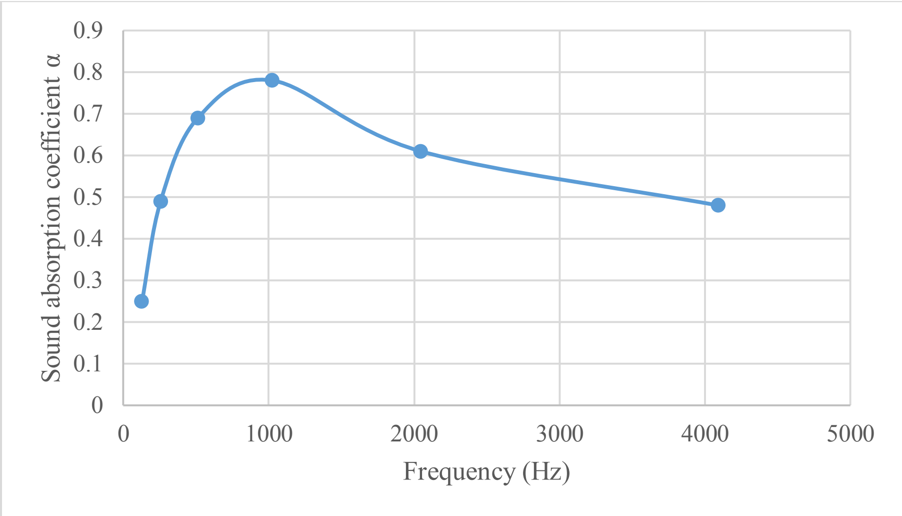


Figure 12: Sound absorption coefficient for acoustic ceiling type (Zannin, Fiedler, & Bunn, 2013)

2.7.2 Soundscape Studies

As soundscape is measured from the perception of individuals, the adopted methodologies in assessing soundscape depends mainly on the feedback of the space users. In a study that evaluated the interior soundscape of the healthcare centre within a university campus, the authors used both recordings and a questionnaire methodology to understand the soundscape of the environment. The research aimed to study the soundscape impact of the case study environment on the users' anxiety levels and the room's tranquility. The researchers then modified the soundscape of the room by introducing natural sounds, such as waterfall sounds. The recordings showed that the sound pressure level of the room has been reduced by the modifications on the majority of the frequency bands. Moreover, the participants reported a lower level of anxiety and a higher level of room tranquility under the adjusted condition (Watts, Khan, & Pheasant, 2016).

A study on interior university office environment evaluated the soundscape of the space in conjunction with the spatial experience of the users through qualitative observations of the users' behavior and spatial environment, and quantitative sonic measurements. The observations mainly focused on the sound sources and the orientations of the office spaces, in addition to other interior environment elements including lighting, shape and furniture. In the measurement section of the study, the sound pressure level ranged between 42.5 dB and 51 dB with an average of 46.3 dB. The study compared the SPL readings to the regulations, which recommend it to be less than 35 dB. Other measurements were included in the indicative study for temperature, humidity and lighting, where many of majority of the readings were not conforming to the standards and regulations (Aburawis & Dokmeci Yorukoglu, 2018).

In another interior soundscape study, where three university libraries in the city of Sheffield in the United Kingdom were selected as case studies, the authors considered three factors; sound environment, built entity and contextual experience. A total of nine factors were investigated in research of the overall soundscape assessment. The three libraries were selected to be comparable in terms pf dimensions, plan type, layout, spatial elements, interior material and occupancy density. The absorption coefficients of the interior material were compiled for different frequencies in order to be used in the acoustic calculations. Sound environments of the three libraries were recorded in three time periods of the day; morning, noon and afternoon. The research proceeded to the statistical analysis of the collected data, where the regression analysis of the occupancy density and sound pressure level yielded an R square value of 0.59 and the regression analysis of the occupancy density and loudness yielded an R square value of 0.688, which proves the significant relationship between the tested factors and confirmed by the ANOVA testing. Moreover, the effect of spatial factors on the sound environment is compared between the three libraries through ANOVA testing, which showed p values less than 0.05. Similar results were found for the difference of the daytime periods on the sound environment (Dokmeci Yorukoglu & Kang, 2016).

In the same context, a study considered two interior space environments in university environment in order to study their soundscape. Sound recordings were carried out for the two buildings in different comparable areas. A comparison was performed between the case studies based on their sound pressure level, loudness, roughness and sharpness for the highest 10% values and the 90% dominant background value of the four parameters. There were no big differences found between the 10% and 90% SPL values indicating a steady sound environment. However, the two values showed greater differences for loudness, sharpness and roughness. Finally, the correlation analysis indicated relationships between the four parameters (Dokmeci & Kang, 2011).

In a different interior environment, a soundscape study was performed on interior public spaces of a metro station. The authors investigated the sound environment through recordings that were taken from three different areas in the metro station; urban park, station entrance and underground platform. The sound pressure level was found to reach 80 dB in the underground platform. Moreover, ninety participants participated in the study, where they were asked to evaluate the sound environment of the three areas using seventeen adjective pairs corresponding to psychoacoustical factors; loudness, sharpness and roughness. The highest overall annoyance was found in the station entrance were high sounds were more continuous, followed by the underground platform then the urban park area (Yilmazer & Bora, 2017).

2.7.3 Architectural Studies

In a study that investigated the impact of the textile material on the acoustic performance of ancient churches, after an experiment on a reverberation chamber, the authors aimed to assess the sound absorption of sound absorbing materials. It is mentioned that textile materials are challenging when designing for acoustics, as they have absorption and transmission properties. A case study ancient church was selected, where the textiles were hung freely from the ceiling without mounting on any surface. Through modelling the church on a geometrical acoustic software, taking into consideration the acoustic readings from the case study, the authors were able to conclude that absorption coefficients differ between the hung case and the adjacent case. The adjacent case coefficients were taken from the literature and compared with the findings of the research, which proved that not only the type of

material has an impact on the acoustic performance of the space, but also the placement of the material (Alonso & Martellotta, 2015).
Another study evaluated the acoustical condition of open plan offices based on the change in material acoustic absorption. Material with higher acoustic absorption coefficients were installed at the walls between different sections of the offices in order to compare the conditions before and after the adjustment. Similarly, reflective tiles were installed between office section in a different floor as a worst case for comparison purposes. The results show that the absorbing tiles have decreased the sound pressure level values, while the reflective tiles increased them from the original acoustic conditions of the offices. As recordings were taken at different distances, it was also observed that disruption was decreased lower distanced with the absorbing material and an adverse effect was imposed by the reflective material (Seddigh et al., 2015).

2.7.4 Social Studies

People and their social interactions within the environment are considered important sound sources that can affect the acoustics and soundscape of the space. Soundscape can be affected by the different non-acoustic events that occur in the environment. A Spanish study, that measured acoustic and non-acoustic parameter of five public areas in Balibo, Spain, compared the case studies based on sound pressure levels and the sound energy averages. The measurements were taken through a sonic meter that provided the minimum, maximum and average values. A questionnaire evaluating the acoustic environment was collected for a total of 406 participants in the five locations. Moreover, data of the significant events that occurred in each of the locations were obtained and categorized to natural events, positive events and negative events. The statistical analysis shows that gender, education level and working status were significant in influencing acoustic evaluation. Furthermore, natural events were correlated positively with acoustic parameter and negative events were correlated negatively with acoustic parameters (Herranz-Pascual, et al., 2017).
A study on six shopping malls in china investigated the impact of the social characteristics and users' behavior on the sound environment of the interior space. Subjective soundscape evaluation was performed through a questionnaire with 2,134

total valid questionnaires. The participants evaluated the shopping malls based on their loudness and acoustic comfort. Moreover, objective sound measurements were obtained through a sound pressure level for each questionnaire through hundred readings. Other environmental readings, including lighting, temperature and humidity were measured. In the statistical analysisshowed no relationship between occupation and acoustic comfort; however, relationships between each of the income and education level were found through correlational and regression analyses (Meng & Kang, Influence of Social and Behavioural Characteristics of Users on Their Evaluation of Subjective Loudness and Acoustic Comfort in Shopping Malls, 2013).

2.8 Discussion

Through the review of more than fifty sources from the literature, there is variety of studies that addressed the acoustic environment from different perspectives and using different methodologies. The definitions and concepts that were reviewed enabled the researcher to understand the technical aspects of the sound environment and the interaction between the different parameters. Acoustic modelling and design are a significant part in understanding the sound environment, as it allows the designer to understand the changes and challenges that occur by using different design elements. Moreover, the perception of the space users is as significant as the technical assessment due to the fact that some of the sound attributes are evaluated based on the perception of the individuals and according to their hearing abilities. While psychoacoustical factors are used in subjective evaluations, there are several parameters that are used in acoustical model testing.

The most important parameters in acoustic model design is reverberation time, sound pressure level and frequency. Furthermore, the architectural elements that are used to design the restaurant's environment have direct and indirect influence on the acoustic performance of the interior space. It was shown in the literature that the geometry and volume, layout type, and finishing material have impacts on the parameters of acoustic model design. The previous studies of all approaches and methodologies can help the researcher establish the discussion in comparison with the case study results presented in the next chapter.

3. METHODOLOGY AND RESULTS

3.1 Research Questions

As stated by the aim of the study, the main objective of this research is to investigate the effect of plan types and the physical environment elements on the acoustic performance of the restaurant context and to find out the most optimal physical criteria that can yield the best acoustic performance. Therefore, the research questions are:

Q1: What are the geometrical factors (plan type and volume) that yield the best acoustic performance for restaurant environments?

Q2: How do finishing material impact the acoustic performance of the interior environment of restaurants?

Q3: What are the best geometrical and material combinations that can achieve the best acoustic performance in restaurant environments?

The first and second questions identify the factors that are influential on acoustic performance from the geometric and finishing material types, respectively. Furthermore, the third question is answered through understanding the most effective physical environment factors and the optimal performance criteria that can be achieved in the restaurant environment. Thus, prior starting with obtaining and analysing the results, it is important to understand the criteria optimal performance indices that are expected. In this research, three performance criteria are assessed, which are reverberation time (RT), sound pressure level (SPL) and speech transmission index (STI). Table 2 shows the optimal readings of the three performance indices for the restaurant environment. Close ranges were found for each index; however, for RT a range of 0.5 – 0.7 seconds is considered as per Battaglia (2015). For SPL a range between 62 to 67 dBA is considered as per Novak, et al. (2010), while a ratio range of 0.5 to 0.7 is considered for STI as per Rindel (2019). Battaglia (2015), Novak, et al. (2010) and Rindel (2019) stated that RT, SPL and STI are amongst the most important acoustic performance indicators for restaurants.

Table 2: Value range of RT, SPL and STI for restaurants

Acoustic Performance Index	Value Range	Reference
RT	0.5 – 0.7 sec	(Battaglia, 2015)
	0.5 – 0.6 sec	(Astolfi & Filippi, 2004)
SPL	62 – 67 dBA	(Novak, et al., 2010)
	69 – 71 dBA	(Chen & Kang, 2017)
STI	0.5 – 0.7	(Rindel, 2019)

3.2 Hypothesis

Dokmeci Yorukoglu and Kang (2016) showed a direct and positive relationship between plan types and the sound environment. The absorption coefficient of the physical environment directly affects its acoustic performance as shown by Branski, et al. (2017). Zannin, et al. (2013) and Masmoudi (2017) showed that the volume of the space influences its acoustic performance. Therefore, the hypothesis tested in this research, in addition to the sub-hypotheses, is:

H_0: The interior design is influential in enhancing the acoustic performance of restaurant interior environments.

H_{0A}: The plan type and volume are influential in enhancing the acoustic performance of restaurant interior environments.

H_{0B}: The finishing material is influential in enhancing the acoustic performance of restaurant interior environments.

3.3 Methodology Design

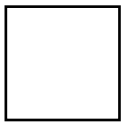
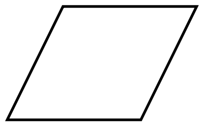
The method aims to test three main architectural factors that are expected to impact the acoustic performance in a restaurant interior environment; plan type, volume and finishing material. The study sets assumptions for the three parameters as shown in Table 3, where three plan types are considered; square, rectangular and rhombus. three finishing material types are also considered for the wall, floor and ceiling finish: reflective, absorptive and diffusive. Moreover, two ceiling heights are considered, which are three meters and four meters.

Different scenarios are tested through the combination of the three variables, which are each entered into the acoustic simulation software: Odeon. A single sound source is positioned at the centre of the space with a fixed value corresponding to the average dB value in restaurant environments. Furthermore, several receivers are positioned at the surfaces of the geometrical shape, the corners and internal points within the space in order to measure the acoustic performance at different points within each space: reverberation time. After acquiring the software output, the results are presented graphically, and different scenarios are compared in order to conclude with the most recommended combinations of plan type, volume and finishing material.

Table 3 is a representation of the different scenarios that are simulated on Odeon. The total number of combinations is 54 combinations, where each of the different three choices of the plan type, wall finish, ceiling finish and floor finish is tested for a ceiling height of 3 meters and a ceiling height of 4 meters. The floor finish is always assumed reflective.On the Table, each square within the bold square represent two combinations; 3 meters and 4 meters ceiling height; therefore, different space volumes. The positions of the sound sources and receiver are planned to be identical in all combinations in order to produce comparable results.

The shapes chosen in this research are based on common restaurant plan types. Square plan types are used in fine dining and fast casual dining restaurants, while rectangular plan types are often used for casual dining, family dining and fast food restaurants. Due to the presence of plan types with angled walls in family style and fine dining restaurants, the rhombus shape is selected providing with angled walls and angles with different degrees(Malekshahi, 2013; Yu, 2009).

Table 3: Scenarios tested in the investigation

		Plan Types										
		Square			Rectangle			Rhombus				
		15 x 15 m			10 x 37 m			15 m side				
		675 & 900 m^3			1,110 & 1,480 m^3			477.3 &636.4 m^3				
												
Wall finish	R	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	R	Floor finish
	A	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	R	
	D	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	R	
		R	A	D	R	A	D	R	A	D		
		Ceiling finish										

R = Reflective; A = Absorptive; D = Diffusive
● = 3-meter ceiling height; ▲= 4-meter ceiling height

3.4 Models and Assumptions

ODEON v.10 licensed for Çankaya university was used for acoustic environment simulation. Experiment was conducted in Çankaya university faculty of architecture acoustics laboratory. The models tested are constructed on Sketchup and imported into ODEON after defining the room elements. The six models are presented in Figure 13 and their geometrical information and ODEON settings are provided in Appendix A (Models Geometry) and Appendix B (Datasheet), respectively. The choice of the plan types and their relationship with restaurant layouts is clarified in the previous section. The acoustic assumptions are based on the average sound pressure level recorded in restaurant, as per Rusnock and McCauley Bush (2012). In acoustic simulation, the following assumptions were made.

- The sound source (white noise type) is positioned at the center of the room plan at a height of 1.1 meters. The settings of the sound source are specified as 250 Hz, 500 Hz, 1000 Hz and 2000 Hz.
- Material are defined on ODEON as specified for each experiment combination.
- Receivers on the corners are placed at the middle distance between the floor and the ceiling at a height of 1.1 meters.
- Receivers on the walls are placed at the middle of the wall plane at a height of 1.1 meters.
- Testing is performed at Sound Power Level (SPL) of the source of 75 dB as an average in restaurant environment (Rusnock and McCauley Bush, 2012).
- Nine material variations are tested for each model, as shown in Table 4. Reflective surfaces are always assumed for the floor finish of the models to simulate the most common types of flooring used in restaurant, such as marble, ceramic tiles and exposed concrete (Stein, 2017).

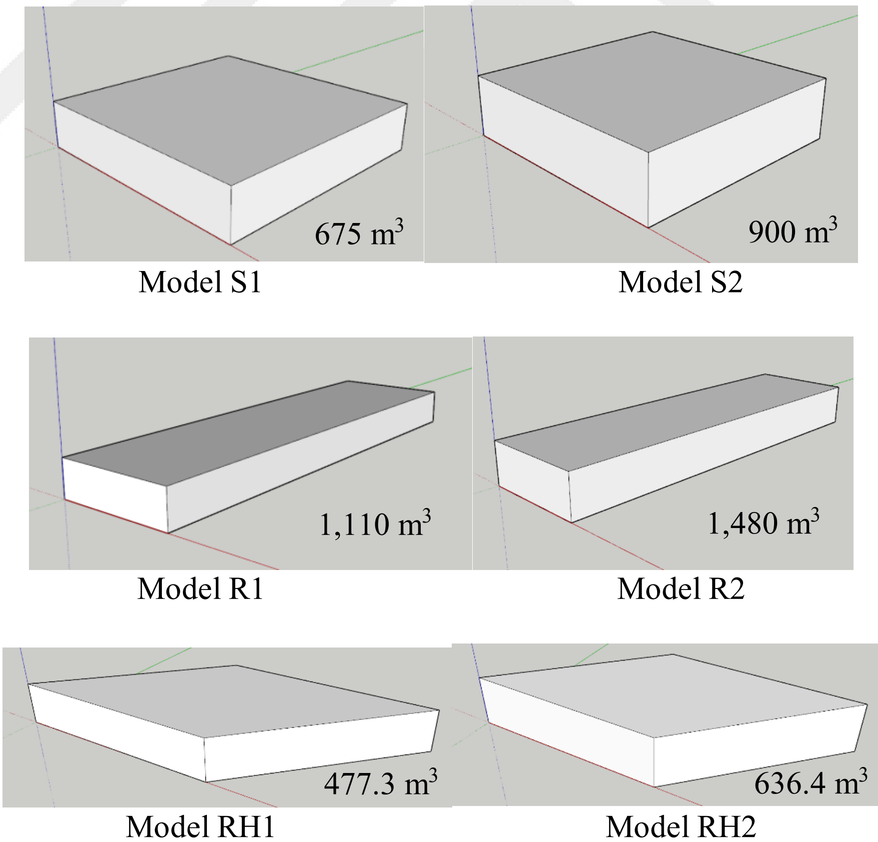


Figure 13: Models constructed on Sketchup and imported to ODEON

Table 4: Material types variations tested on the models

	Floor Material	Wall Material	Ceiling Material
RRR	Reflective	Reflective	Reflective
RRA	Reflective	Reflective	Absorptive
RRD	Reflective	Reflective	Diffusive
RAR	Reflective	Absorptive	Reflective
RAA	Reflective	Absorptive	Absorptive
RAD	Reflective	Absorptive	Diffusive
RDR	Reflective	Diffusive	Reflective
RDA	Reflective	Diffusive	Absorptive
RDD	Reflective	Diffusive	Diffusive

R: Reflective; A: Absorptive; D: Diffusive

3.5 Results

The analysis carried out in this section aims to investigate the differences in acoustic performance between the different models based on their plan types and volumes (geometry) and the finishing material types that has nine different variations created from three types: reflective, absorptive and diffusive. A descriptive analysis is carried out through controlling one of the two factors and observing the differences in the other one. Therefore, the first part of the analysis fixes the material types combinations used in order to monitor the changes in RT, SPL and STI with the geometric properties of each model. The second part studies the variations in the three indices within the same model with the use of different material combinations. The third part reviews the data compliance with the limits provided in the literature and presented in Table 2 in order to identify the models that can achieve the best acoustic performance for restaurants.

3.5.1 Effect of Plan Type and Volume

In order to understand the impact of the plan types on the acoustic performance indices, reverberation time, sound pressure level and speech transmission index values of the same material variations are compared to each other. The analysis of reverberation time of the different geometries shows that there are apparent differences between them, despite the similarity in the finishing material, as shown in Figures RH1 and RH2 in Appendix C.

The values of reverberation time for the six models changed with the change of the model plan type, while keeping the material combinations constant. The change within the same model RT values is minimal in the majority of the cases throughout the change of frequency. Nonetheless, there are apparent differences that are attributed to the changes in geometrical factors, while many overlaps can be observed between models with different plan types and material type combinations (Figures RH1 and RH2 in Appendix C).

The range of reverberation time depended mainly on the material combination of each case; however, the majority of the cases showed differences in reverberation time values. RT values at the corners and the walls were different for the same model but their exhibited the same behavior. The differences between the RT values of the different models ranged from zero to 1.05 seconds. The ANOVA testing showed no significant differences to the 0.05 level for the RT values based on volume, internal surface area or plan type. The results of the ANOVA testing are shown in appendix D.

As shown in Figures C3 and C4 (Appendix C) for differences in sound pressure levels between the models, the values of SPL have changed minimally within the same model, while keeping the material combination constant. However, the difference between the highest and the lowest SPL ranged between 4 dBA and 15 dBA at both corner and wall cases, with an average difference of 6.94 dBA.

Similar to RT values, the SPL values behaved the same between the corner and wall cases. Therefore, it can be understood that geometrical factors influence the sound pressure level values while using the same material combination. Moreover, the ANOVA test performed on all study values using SPSS showed a significant difference at the 0.05 level between the SPL values at the walls based on the change in space volume and internal surface area. The same results were found based on the plan type, as shown in Appendix D.

For speech transmission index (STI), Figures C5 and C6 (Appendix C), show the change in values with the geometrical factors and frequency for corner and wall cases, respectively. There were no changes between the STI values with the change of source frequency. The values were very close for some plan types at certain material types combinations, while a few plan types had values far from the grouping plan types.

The ANOVA testing showed no significant differences in STI values at the 0.05 level based on volume, internal surface area or plan type. The ANOVA analysis is provided in Appendix D: ANOVA testing for geometric factors.

3.5.2 Effect of Finishing Material

Through studying the changes in acoustic performance indices within a single model, it is possible to understand the effect of the finishing materials on the sound environment. Each of the six models were tested for differences in RT, SPL and STI at the same point of reading. Nevertheless, nine material types combinations are evaluated for each model, as shown in Table 2. In Figure E1 (Appendix E), the differences in RT, SPL and STI are illustrated for the square model S1. The results show that there are differences between the majority of the readings for the three indices, while a few had close readings. The maximum differences reached to 1.8 seconds for RT, 14 dBA for SPL and 0.5 for STI. In order to assess these differences statistically, an ANOVA testing was carried out, where significant differences at the 0.05 level were found for all readings. The test is available for reference in Appendix F.

The square model S2 has the same dimensions as model S1, except for the ceiling height, which rises from 3-meters to 4 meters. As shown in Figure E2 (Appendix E), the reverberation time of the model changes between one material type combination to another. The highest reverberation time was recorded for RDR, while the lowest was recorded for RAA, where the difference between them is around 1 second. In SPL, RDR and RAA sustained the extreme recordings, while groups of the nine combinations group around a few readings. A similar phenomenon is observed for the STI recordings of the nine combinations, while RAA achieved the maximum recording and RDR was amongst the lowest recordings. However, the ANOVA testing shows that there are significant differences at the 0.05 level for the same model or plan type (refer to Appendix F).

In the third model R1, which is a rectangular shaped plan type, the same procedure was followed. As shown in Figure E3 (Appendix E), there were differences observed between the RT readings of the different material combinations with some intersection and overlaps, especially between RRA and RDA. It is an interesting phenomenon, despite the difference in the combination composition. The range of the RT readings is similar between the corner and wall recordings, which is around 1.5 seconds. The wide range reflects the influence of the finishing material on changing the acoustic performance of the space. For SPL, the nature of the graphs is similar to the RT graphs, with differences in the overlaps. RAD almost overlaps with RRA and RDA. The STI values lay mostly in the interval between 0.6 and 0.8, while the records range is 0.4. Based on the ANOVA testing (refer to appendix F), there were significant differences found at the 0.05 level for all RT, SPL and STI records.

Model R2 is similar to model R1 in terms of the plan type, while model R2 has a 4-meter ceiling height. The effect of finishing material is studied on the model through comparing the readings under different material types combinations, as shown in Figure E4 (Appendix E). By increasing the volume of the space, the range of RT records increased to reach 1.8 seconds. Nonetheless, the graph arrangement is similar to the one of model R1. In SPL, the overlap between RRA and RDA continues to this model with differences between the values of other material combinations. The range of STI records shifted higher with the least reading of 0.5. In the statistical analysis, all RT, SPL and STI readings indicated significant differences at the 0.05 level based on material types combination and through using ANOVA testing (Appendix F).

For model RH1, which has unequal internal angles, the data is compared in Figure E5 (Appendix E) with different finishing material combinations. In RT records, the performance of the different material types combinations appears similar at the corner and the wall. However, the overlaps between RRA and RRD is different in the two cases. The overlap between the closeness between the readings of the other material types combinations, except for RDR, is slightly different in the two cases. SPL graphs show similar performance, while a group of combinations are close to each other with two or three eccentric combinations. RAD and RDA appear to completely overlap in both conditions. The majority of the STI records lay between 0.6 and 0.8. As per the ANOVA testing (Appendix F), all RT, SPL and STI categories indicated significant differences at the 0.05 level.

The last model is RH2, which is a rhombus similar to model RH1 but with a higher ceiling (4-meters). The RT records are more distributed in comparison with model RH1 RT records, with minimal overlapping. The highest RT reading was achieved by RRR, which is different from RRA highest records in RH1. Clear differences can be observed between reverberation times of models with different material types combinations, as shown in Figure E6 of Appendix E. Moreover, SPL readings exhibit differences between them based on material combinations, in addition to a similar case for STI readings. The ANOVA testing (refer to Appendix F) shows that all RT, SPL and STI categories have significant differences between them at the 0.05 level based on the material combinations used in the model.

3.5.3 Compliance with the Acoustic Specifications of Restaurants

In this research, several geometric and material variations and combinations were assessed through an acoustic design software in order to understand the effects of these factors on the acoustic performance of the interior environment of a restaurant. Another objective that is targeted by this section is to evaluate the compliance of the designed models with their variations with the acoustic norms and standards that are expected to be found in the restaurant design. As reviewed previously in Table 2, three value ranges were suggested by the literature for the optimal values for reverberation time, sound pressure level and speed transmission index. The values varied from one literature reference to another. Therefore, a range was chosen, and a 10% margin is added to each range. Table 5 shows the ranges that are set to judge the compliance of the models.

Table 5: Compliance range for model investigation

Acoustic Performance Index	Literature Value Range	Investigation Compliance Range with 10% margin
RT	0.5 – 0.7 sec	0.4 – 0.8
SPL	62 – 67 dBA	54 – 73 dBA
STI	0.5 – 0.7	0.4 – 0.8

Through studying the values provided in Appendix B, 11 out of the 54 variations of the model complied fully with the RT range, while 3 variations complied partially. Twenty-six variations comply fully with the SPL range, while there are 12 partial compliances. For STI, 42 variations comply fully with the specified range, while two variations achieved partial compliance. Throughout the fifty-four variation that were tested in this study, there is no single variation that conformed with all recordings to the specified ranges of RT, SPL and STI. However, three variations achieved compliance on 22 recordings out of the total 24, which are variation no. 6, variation no. 13 and variation no. 37. The geometric and material specifications of these three cases are presented in Table 6. It is expected that a bit of refinement to these models will allow them to achieve an ideal acoustic performance for the restaurant context.

Table 6: Models' variations achieving the most optimal acoustic performance for a restaurant context

Exp. Serial	Type	Layout Type	Dimesnsions			Volume (m^3)	Material Types*			Ratios*		
			X (m)	Y (m)	Z (m)		Floor	Wall	Ceiling	R	A	D
6	S1	Square	15	15	3	675	R	A	D	0,36	0,29	0,36
13	S2	Square	15	15	4	900	R	A	R	0,65	0,35	0
37	RH1	Rhombus (side 15 m)	27,716	11,481	3	477.3	R	R	R	1	0	0

*. R = Reflective; A= Absorptive; D = Dissusive

3.6 Discussion

The objectives of this research were to investigate the effects of plan types, geometric factors and finishing material on the acoustic performance of restaurants' interior environment. In addition to their influence on users' comfort (including acoustic comfort), as suggested by Tüzünkan and Albayrak (2016), the findings of the research indicate that geometric factors, including plan types, volume and surface area are influential in altering the acoustic performance of the interior space. Furthermore, the type of finishing material in accordance with their abilities to reflect, absorb or diffuse sound are important in controlling the acoustic environment.

By comparing reverberation time (RT), sound pressure level (SPL) and speech transmission index (STI) for the different plans with the same finishing material types, differences were observed, which shows that geometric factors are affect the acoustic performance of the space. Such a results confirms the literature findings of Prawirasasra, et. al. (2016), who suggested the impact of plan types on the sound energy, sound strength and reverberation time. Moreover, Dokmeci Yorukoglu and Kang (2016) used plan types to evaluate their effect on the acoustic performance. The results show that the acoustic parameters differed between the different plans and geometric factors. Culling (2016) also showed that the internal layout of the restaurant influences its acoustic environment through assessing a regular and irregular floor plans and table layouts.

The second finding of this research is the high effect of the finishing material type on the sound environment and acoustic performance. The study compared readings of the same geometric setting with different finishing material types combinations. A total of nine combinations were tested composed of three material types: reflective, absorptive and diffusive. The graphic illustrations of the results indicated the changes in acoustic performance through the different material combinations.

The statistical analysis confirmed the significance of the differences to the 0.05 level through an ANOVA test. The literature confirms that finishing material has a major role in creating such an impact. Amares, et. al. (2017) attributed the difference in the material's ability to reflect, absorb or diffuse sound to the physical properties of the material, including its thickness, density and porosity. Several successful attempts to enhance acoustic performance in the interior environment can be found in the literature, such as the experiments of Arenas and Crocker (2010) and Seddigh, et al. (2015). Based on those physical properties a coefficient is assigned to each material to indicate its reaction to sound waves. Alonso and Martellotta (2015) stressed on the importance of material within the interior environment in influencing the acoustics within it, not only through its presence, but also through its placement.

4.CONCLUSION

The acoustic environment of restaurants is complex due to the several sources that contribute into creating its soundscape. Thus, it is important to understand those factors, which are divided into physical, psychoacoustic and social factors. The focus of the current research on the investigating the physical factors that influence the sound environments in restaurants. The main aim of the study is to investigate the variations in plan types and material types that affect the acoustic performance in the restaurant context. Key acoustic performance indicators are selected to perform the judgement, which are reverberation time, sound pressure level and speech transmission index.

The research is carried out through constructing six models for assessment that have their similarities and differences in plan type, including geometry and volume. Three main geometries are designed, square plan, rectangular plan and rhombus plan. Moreover, nine material type combinations were constructed from three options: reflective, absorptive and diffusive material.

The results of the research show that geometric factors, including plan types, volume and surface area are influential in altering the acoustic performance of the interior space. Furthermore, the type of finishing material in accordance with their abilities to reflect, absorb or diffuse sound are important in controlling the acoustic environment. By comparing reverberation time (RT), sound pressure level (SPL) and speech transmission index (STI) for the different plans with the same finishing material types, differences were observed, which shows that geometric factors are affect the acoustic performance of the space. The study compared readings of the same geometric setting with different finishing material types combinations. A total of nine combinations were tested composed of three material types: reflective, absorptive and diffusive. The graphic illustrations of the results indicated the changes in acoustic performance through the different material combinations.

Based on the findings of the study and the statistical analysis performed for confirmation, the hypothesis of the research stating "H_0: The interior design is influential in enhancing the acoustic performance of restaurant interior environments.”, through an ANOVA test at a significance level of $p<0.05$. As shown in Table 6, three plan types and material variations were the most compliant with the value ranges for restaurant use. Although no specific plan type or material type variation was able to achieve full compliance, it is possible to enhance these three variations to provide the most suitable condition for the restaurant context.

Two out of the three most compliant plan types were squares, while the third most compliance shape was a rhombus. Such results indicate that the square shape plans and plans with angles (rhombus) are the most suitable for a better acoustic performance of restaurant. The data is highlighted with a different colour in Appendix B in order to show the readings that comply with the ideal RT, SPL and STI readings with a margin of 10%. As shown in the results summary in Table 7, it is observed that the square shape has the most compliant readings with 130 compliant readings out of 216 readings for model S1 (60.2%) and 138 compliant readings out of 216 readings for model S2 (63.9%).

Rhombus plan type is the second best in terms of compliant readings. Model RH1 had 123 compliant readings (56.9%), while model RH2 had 117 compliant readings (54.2%). The rectangular plan type had less compliant readings out of the total 216 readings for each model simulation. Model R1 had 95 compliant readings (44.0%), while model R2 had 93 compliant readings (43.1%). Moreover, the best compliance for reverberation time (RT) was for model RH1 with 32 compliant readings out of 72 total readings (44.4%), followed by model S1 with 24 compliant readings (33.3%). Model S2 had the best compliance for sound pressure level with 58 readings (80.6%), followed by model S1 with 50 compliant readings (69.4%). For speech transmission index (STI), model S2 had the highest compliance with 64 readings (88.9%). Out of the three factors measured in the simulation, reverberation time was the hardest to achieve compliance.

Table 7: Reading compliance of the six models for restaurant optimal ranges

Models	Total Readings		RT		SPL		STI	
	216		72		72		72	
	n	%	n	%	n	%	n	%
S1	130	60.2	24	33.3	50	**69.4**	56	77.8
S2	138	**63.9**	16	22.2	58	80.6	64	**88.9**
R1	95	44.0	8	11.1	31	43.1	56	77.8
R2	93	43.1	5	6.9	32	44.4	56	77.8
RH1	123	56.9	32	**44.4**	43	59.7	48	66.7
RH2	117	54.2	17	23.6	44	61.1	56	77.8

Based on the results of the study, it is recommended that square plan types are used for restaurant contexts for the best compliance based on sound pressure level and speech transmission index. Nevertheless, the rhombus shape is recommended for restaurant contexts for the best compliance with reverberation time. Therefore, a square plan type with angled surfaces (walls) can achieve the best acoustic performance for the interior environments of restaurants.

Recommendations are provided for future research to use the data provided within this study in order to test the compliance of different contexts and interior environments. Moreover, additional geometric shapes and floor plan types can be tested using the same methodology adopted in the current research for further comparison and understanding. A comparison between actual measurements in restaurant environments and software simulations can be carried out in order to lay down the differences.

The following recommendations are provided for architects and interior designers in designing for the optimal acoustic performance for restaurants:

- The plan type used in the restaurant shall consider the restaurant type; however, through the findings of the current study, square plan types with angles provided in certain locations can yield the best acoustic performance for restaurants.

- The finishing material used for restaurants shall be assigned according to the spatial element in the space; reflective material for floor and angled walls, diffusive material for straight wall surfaces, and absorptive material for ceiling.
- Usage of excessive absorptive material yields the worst acoustic results, regardless of the plan type. As seen in material combination RAA, the majority of the readings for the three acoustic performance indices were far from the desired range for this combination.
- Acoustic simulation software is important to use in restaurant acoustic design. ODEON used in the current study allowed for the understanding of the effects of plan types and finishing material used in the restaurant environment.
- Due to the complexity of the interior design environment, it is difficult to attribute the optimal acoustic performance to a single architectural factor, plan type, finishing material, volume, surface area, etc. It is the optimal combination between all of these elements that produce the optimal acoustic environment for restaurants, which is recommended to be verified with an acoustic software simulation and actual readings in the interior environment after execution.
- Optimal acoustic performance parameters should be verified with other architectural elements, such as furnishing. The results of the research show that the slightest change in architectural factors can enormously affect the acoustic performance of the interior environment.

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APPENDIX A:MODELS GEOMETRY

Exp. Serial	Model Type	Layout Type	X (m)	Y (m)	Z (m)	Volume (m3)	Floor area (m)	Wall area (m)	Ceiling area (m)	Total area	Floor Material	Wall Material	Ceiling Material	R ratio	A ratio	D ratio
1	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Reflective	Reflective	1	0	0
2	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Reflective	Absorptive	0,64	0,36	0
3	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Reflective	Diffusive	0,64	0	0,36
4	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Absorptive	Reflective	0,71	0,29	0
5	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Absorptive	Absorptive	0,36	0,64	0
6	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Absorptive	Diffusive	0,36	0,29	0,36
7	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Diffusive	Reflective	0,71	0	0,29
8	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Diffusive	Absorptive	0,36	0,36	0,29
9	Model S1	Square	15	15	3	675	225	180	225	630	Reflective	Diffusive	Diffusive	0,36	0	0,64
10	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Reflective	Reflective	1	0	0
11	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Reflective	Absorptive	0,67	0,33	0
12	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Reflective	Diffusive	0,67	0	0,33
13	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Absorptive	Reflective	0,65	0,35	0
14	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Absorptive	Absorptive	0,33	0,67	0
15	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Absorptive	Diffusive	0,33	0,35	0,33
16	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Diffusive	Reflective	0,65	0	0,35
17	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Diffusive	Absorptive	0,33	0,33	0,35
18	Model S2	Square	15	15	4	900	225	240	225	690	Reflective	Diffusive	Diffusive	0,33	0	0,67
19	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Reflective	Reflective	1	0	0
20	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Reflective	Absorptive	0,64	0,36	0
21	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Reflective	Diffusive	0,64	0	0,36
22	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Absorptive	Reflective	0,72	0,28	0
23	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Absorptive	Absorptive	0,36	0,64	0
24	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Absorptive	Diffusive	0,36	0,28	0,36
25	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Diffusive	Reflective	0,72	0	0,28
26	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Diffusive	Absorptive	0,36	0,36	0,28
27	Model R1	Rectangle	10	37	3	1110	370	282	370	1022	Reflective	Diffusive	Diffusive	0,36	0	0,64

Exp. Serial	Model Type	Layout Type	X (m)	Y (m)	Z (m)	Volume (m3)	Floor area (m)	Wall area (m)	Ceiling area (m)	Total area	Floor Material	Wall Material	Ceiling Material	R ratio	A ratio	D ratio
28	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Reflective	Reflective	1	0	0
29	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Reflective	Absorptive	0,67	0,33	0
30	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Reflective	Diffusive	0,67	0	0,33
31	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Absorptive	Reflective	0,66	0,34	0
32	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Absorptive	Absorptive	0,33	0,67	0
33	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Absorptive	Diffusive	0,33	0,34	0,33
34	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Diffusive	Reflective	0,66	0	0,34
35	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Diffusive	Absorptive	0,33	0,33	0,34
36	Model R2	Rectangle	10	37	4	1480	370	376	370	1116	Reflective	Diffusive	Diffusive	0,33	0	0,67
37	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Reflective	Reflective	1	0	0
38	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Reflective	Absorptive	0,68	0,32	0
39	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Reflective	Diffusive	0,68	0	0,32
40	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Absorptive	Reflective	0,64	0,36	0
41	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Absorptive	Absorptive	0,32	0,68	0
42	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Absorptive	Diffusive	0,32	0,36	0,32
43	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Diffusive	Reflective	0,64	0	0,36
44	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Diffusive	Absorptive	0,32	0,32	0,36
45	Model RH1	Rhombus (side 15 m)	27,716	11,481	3	477,31	159,10	180	159,10	498,21	Reflective	Diffusive	Diffusive	0,32	0	0,68

Exp. Serial	Model Type	Layout Type	X (m)	Y (m)	Z (m)	Volume (m3)	Floor area (m)	Wall area (m)	Ceiling area (m)	Total area	Floor Material	Wall Material	Ceiling Material	R ratio	A ratio	D ratio
46	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Reflective	Reflective	1	0	0
47	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Reflective	Absorptive	0,71	0,29	0
48	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Reflective	Diffusive	0,71	0	0,29
49	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Absorptive	Reflective	0,57	0,43	0
50	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Absorptive	Absorptive	0,29	0,71	0
51	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Absorptive	Diffusive	0,29	0,43	0,29
52	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Diffusive	Reflective	0,57	0	0,43
53	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Diffusive	Absorptive	0,29	0,29	0,43
54	Model RH2	Rhombus (side 15 m)	27,716	11,481	4	636,41	159,10	240	159,10	558,21	Reflective	Diffusive	Diffusive	0,29	0	0,71

APPENDIX B: ODEON SIMULATION DATASHEET

Exp. Serial	RT(Corner 1)				RT(Wall 1)				SPL(Corner 1)				SPL(Wall 1)				STI(Corner 1)				STI(Wall 1)			
	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz
1	0,89	0,89	0,88	0,87	0,99	0,99	0,97	0,93	58,7	58,6	58,4	58	59	58,9	58,7	58,4	0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,65
2	1,02	1,02	1,04	1,05	1,11	1,16	1,12	1,08	54,7	54,8	54,6	54,2	55	55	54,9	54,6	0,62	0,62	0,62	0,62	0,69	0,69	0,69	0,69
3	1,72	1,74	1,7	1,58	1,77	1,74	1,71	1,62	62,9	62,8	62,6	62,1	62,9	62,8	62,6	62,1	0,51	0,51	0,51	0,51	0,5	0,5	0,5	0,5
4	0,4	0,41	0,42	0,43	0,39	0,4	0,4	0,4	53,7	53,5	53,2	52,8	55	54,9	54,7	54,4	0,84	0,84	0,84	0,84	0,83	0,83	0,83	0,83
5	0,09	0,08	0,08	0,08	0,09	0,09	0,08	0,08	48,9	48,7	48,4	48,1	51,3	51,1	50,9	50,7	0,99	0,99	0,99	0,99	1	1	1	1
6	0,51	0,53	0,54	0,54	0,47	0,48	0,49	0,49	54,4	54,2	53,9	53,5	55,7	55,5	55,3	55,1	0,81	0,81	0,81	0,81	0,8	0,8	0,8	0,8
7	1,14	1,13	1,11	1,05	1,19	1,18	1,17	1,12	59,8	59,7	59,5	59,1	59,9	59,9	59,7	59,3	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
8	0,94	0,95	0,93	0,98	1,01	1,03	1,03	0,99	56,2	56,2	56	55,6	56,3	56,2	56	55,7	0,64	0,64	0,64	0,64	0,68	0,68	0,68	0,68
9	1,29	1,26	1,23	1,18	1,29	1,28	1,26	1,21	60,8	60,7	60,5	60	61	60,9	60,7	60,3	0,57	0,57	0,57	0,57	0,57	0,57	0,57	0,57
10	1	1,01	1	0,97	1,07	1,06	1,04	1,01	58,2	58,1	57,9	57,5	58,6	58,5	58,3	58	0,61	0,61	0,61	0,61	0,62	0,62	0,62	0,62
11	1,23	1,24	1,24	1,21	1,14	1,16	1,17	1,14	56	56	55,8	55,4	56,4	56,3	56,1	55,8	0,61	0,61	0,61	0,61	0,63	0,63	0,63	0,63
12	1,13	1,12	1,1	1,06	1,18	1,17	1,15	1,11	59	59	58,7	58,3	59,4	59,3	59,1	58,8	0,59	0,59	0,59	0,59	0,59	o,59	0,59	0,59
13	0,61	0,65	0,68	0,68	0,63	0,68	0,71	0,71	54,2	54	53,7	53,3	55,5	55,3	55,1	54,8	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
14	0,26	0,24	0,22	0,22	0,25	0,23	0,23	0,22	50,3	49,9	49,5	49,1	51,9	51,6	51,3	51,1	0,92	0,92	0,92	0,92	0,92	0,92	0,92	0,92
15	0,48	0,51	0,53	0,53	0.50	0,53	0,55	0,56	53,5	53,3	52,9	52,6	54,8	54,6	54,4	54,1	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78
16	1,3	1,33	1,32	1,27	1,38	1,37	1,35	1,29	70,6	68,6	67,1	68,3	60,5	60,4	60,1	59,8	0,57	0,57	0,57	0,57	0,55	0,55	0,55	0,55
17	0,88	0,9	0,9	0,89	0,88	0,91	0,92	0,9	55,3	55,2	55	54,6	55,8	55,6	55,4	55,2	0,67	0,67	0,67	0,67	0,68	0,68	0,68	0,68
18	1,02	1,01	1	0,97	1,07	1,06	1,04	1,01	58,2	58,1	57,9	57,5	58,6	58,5	58,3	58	0,61	0,61	0,61	0,61	0,62	0,62	0,62	0,62
19	1,27	1,26	1,25	1,21	1,08	1,01	0,99	0,94	55,2	55,2	55,1	54,7	55,4	55,3	55,1	54,6	0,69	0,69	0,69	0,69	0,7	0,7	0,7	0,7
20	1,64	1,6	1,54	1,47	1,25	1,01	1,01	0,92	52,3	52,4	52,3	52	52,5	52,4	52,1	51,7	0,72	0,72	0,72	0,72	0,73	0,73	0,73	0,73
21	1,21	1,2	1,18	1,15	1,15	1,1	1,09	1,04	56,3	56,3	56,2	55,7	56,4	56,4	56,1	55,7	0,66	0,66	0,66	0,66	0,67	0,67	0,67	0,67
22	0,39	0,38	0,38	0,38	0,4	0,39	0,39	0,39	48,4	48,6	48,6	48,2	48,8	48,8	48,6	48,2	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85
23	0,29	0,23	0,09	0,13	0,34	0,27	0,05	0,14	40	40,4	41,2	41.0	40,4	40,8	41,5	40,2	1	1	1	1	1	1	1	1
24	0,65	0,64	0,63	0,61	0,71	0,71	0,71	0,69	51,5	51,5	51,5	51,1	51,7	51,7	51,5	51,1	0,77	0,77	0,77	0,77	0,77	0,77	0,77	0,77
25	1,23	1,23	1,23	1,19	1,28	1,25	1,24	1,2	57,6	57,6	57,4	56,9	57,7	57,6	57,4	56,9	0,62	0,62	0,62	0,62	0,63	0,63	0,63	0,63
26	1,7	1,66	1,6	1,53	1,27	0,97	0,98	0,9	51,9	52	52	51,6	52,1	52	51,7	51,3	0,73	0,73	0,73	0,73	0,74	0,74	0,74	0,74
27	1,21	1,2	1,18	1,15	1,16	1,1	1,09	1,05	56,3	56,3	56,2	55,7	56,5	56,4	56,1	55,7	0,66	0,66	0,66	0,66	0,67	0,67	0,67	0,67

Exp. Serial	RT(Corner 1)				RT(Wall 1)				SPL(Corner 1)				SPL(Wall 1)				STI(Corner 1)				STI(Wall 1)			
	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz
28	1,69	1,66	1,63	1,56	1,85	1,82	1,77	1,68	59	59	58,7	58,2	59,4	59,2	59	58,5	0,53	0,53	0,53	0,53	0,54	0,54	0,54	0,54
29	1,12	1,1	1,08	1,03	1,04	1,04	1,02	0,99	52,5	52,5	52,3	51,9	52,7	52,5	52,2	51,8	0,69	0,69	0,69	0,69	0,73	0,73	0,73	0,73
30	1,23	1,22	1,2	1,15	1,22	1,21	1,18	1,13	56,1	56,1	55,9	55,5	56,5	56,4	56,2	55,8	0,62	0,62	0,62	0,62	0,64	0,64	0,64	0,64
31	0,56	0,55	0,54	0,54	0,44	0,43	0,43	0,43	48,1	48,3	48,1	47,7	49	48,9	48,6	48,2	0,82	0,82	0,82	0,82	0,81	0,81	0,81	0,81
32	0,15	0,12	0,09	0,1	0,14	0,12	0,09	0,1	43	43	43	42,7	43,5	43,4	43,4	43,1	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98
33	0,99	0,99	0,98	0,98	0,78	0,79	0,81	0,8	51	51	50,8	50,4	51,8	51,7	51,4	51	0,72	0,72	0,72	0,72	0,73	0,73	0,73	0,73
34	1,36	1,35	1,34	1,32	1,41	1,4	1,37	1,32	57,2	57,2	57	56,5	57,7	57,6	57,4	56,9	0,59	0,59	0,59	0,59	0,6	0,6	0,6	0,6
35	1,12	1,1	1,07	1,01	1,05	1,05	1,02	0,99	52,1	52,2	52	51,6	52,3	52,1	51,8	51,4	0,7	0,7	0,7	0,7	0,74	0,74	0,74	0,74
36	1,24	1,23	1,21	1,17	1,21	1,2	1,18	1,13	56,1	56,1	55,9	55,5	56,6	56,5	56,2	55,8	0,64	0,64	0,64	0,64	0,63	0,63	0,63	0,63
37	0,74	0,73	0,72	0,71	0,8	0,79	0,78	0,76	54	54,1	53,8	53,3	59,6	59,5	59,3	58,9	0,72	0,72	0,72	0,72	0,68	0,68	0,68	0,68
38	2,13	2,18	2,15	2,09	1,68	1,67	1,67	1,53	53,3	53,5	53,2	52,8	58,9	58,9	58,7	58,3	0,68	0,68	0,68	0,68	0,61	0,61	0,61	0,61
39	1,72	1,7	1,67	1,61	1,59	1,58	1,56	1,48	58,1	58	57,7	57,2	63,5	63,4	63,1	62,6	0,55	0,55	0,55	0,55	0,53	0,53	0,53	0,53
40	0,56	0,58	0,63	0,63	0,56	0,61	0,46	0,66	50,4	50,6	50,3	49,8	56	55,9	55,6	55,3	0,83	0,83	0,83	0,83	0,77	0,77	0,77	0,77
41	0,17	0,1	0,07	0,14	0,11	0,08	0,09	0,1	40,2	41,5	41,3	40,8	49	48,8	48,6	48,5	0,99	0,99	0,99	0,99	1	1	1	1
42	0,56	0,58	0,63	0,63	0,56	0,61	0,64	0,66	50,4	50,6	50,3	49,8	56	55,9	55,6	55,3	0,83	0,83	0,83	0,83	0,77	0,77	0,77	0,77
43	0,98	0,97	0,96	0,93	1	1	0,99	0,96	56,1	56,1	55,8	55,3	61,6	61,6	61,3	60,9	0,64	0,64	0,64	0,64	0,61	0,61	0,61	0,61
44	0,67	0,68	0,68	0,67	0,75	0,73	0,73	0,7	50,7	50,8	50,5	50,1	56,3	56,2	56	55,6	0,81	0,81	0,81	0,81	0,74	0,74	0,74	0,74
45	0,83	0,82	0,81	0,78	0,86	0,85	0,84	0,82	55	55	54	54,2	60,5	60,5	60,2	59,8	0,68	0,68	0,68	0,68	0,65	0,65	0,65	0,65
46	1,71	1,69	1,65	1,58	1,61	1,59	1,56	1,49	57,7	57,6	57,3	56,8	62,9	62,8	62,5	62	0,53	0,53	0,53	0,53	0,51	0,51	0,51	0,51
47	0,67	0,68	0,66	0,65	0,82	0,83	0,82	0,8	51,1	51	50,7	50,2	56,6	56,5	56,2	55,9	0,75	0,75	0,75	0,75	0,7	0,7	0,7	0,7
48	0,98	0,97	0,96	0,93	0,99	0,98	0,97	0,95	54,8	54,7	54,4	54	60,1	60	59,7	59,4	0,65	0,65	0,65	0,65	0,62	0,62	0,62	0,62
49	0,36	0,37	0,39	0,4	0,36	0,4	0,44	0,45	47,7	47,9	47,6	47,1	52,9	52,8	52,5	52,3	0,86	0,86	0,86	0,86	0,84	0,84	0,84	0,84
50	0,08	0,08	0,08	0,09	0,09	0,09	0,09	0,1	42,5	42,8	42,5	42	49,4	49,3	49,1	48,9	0.99	0,99	0,99	0,99	0,99	0,99	0,99	0,99
51	0,53	0,56	0,59	0,61	0,68	0,72	0,76	0,77	49,9	49,9	49,6	49,2	54,9	54,7	54,5	54,2	0,8	0,8	0,8	0,8	0,76	0,76	0,76	0,76
52	1,18	1,17	1,15	1,11	1,16	1,15	1,13	1,09	55,8	55,7	55,4	54,9	61,1	61	60,7	60,3	0,61	0,61	0,61	0,61	0,58	0,58	0,58	0,58
53	0,67	0,68	0,66	0,65	0,82	0,82	0,82	0,8	50,7	50,6	50,3	49,8	56,2	56,1	55,9	55,5	0,75	0,75	0,75	0,75	0,7	0,7	0,7	0,7
54	0,98	0,97	0,96	0,92	0,99	0,98	0,97	0,95	54,8	54,7	54,5	54	60,1	60	59,8	59,4	0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,65

APPENDIX C: DIFFERENCES IN PLAN TYPES - GRAPHS

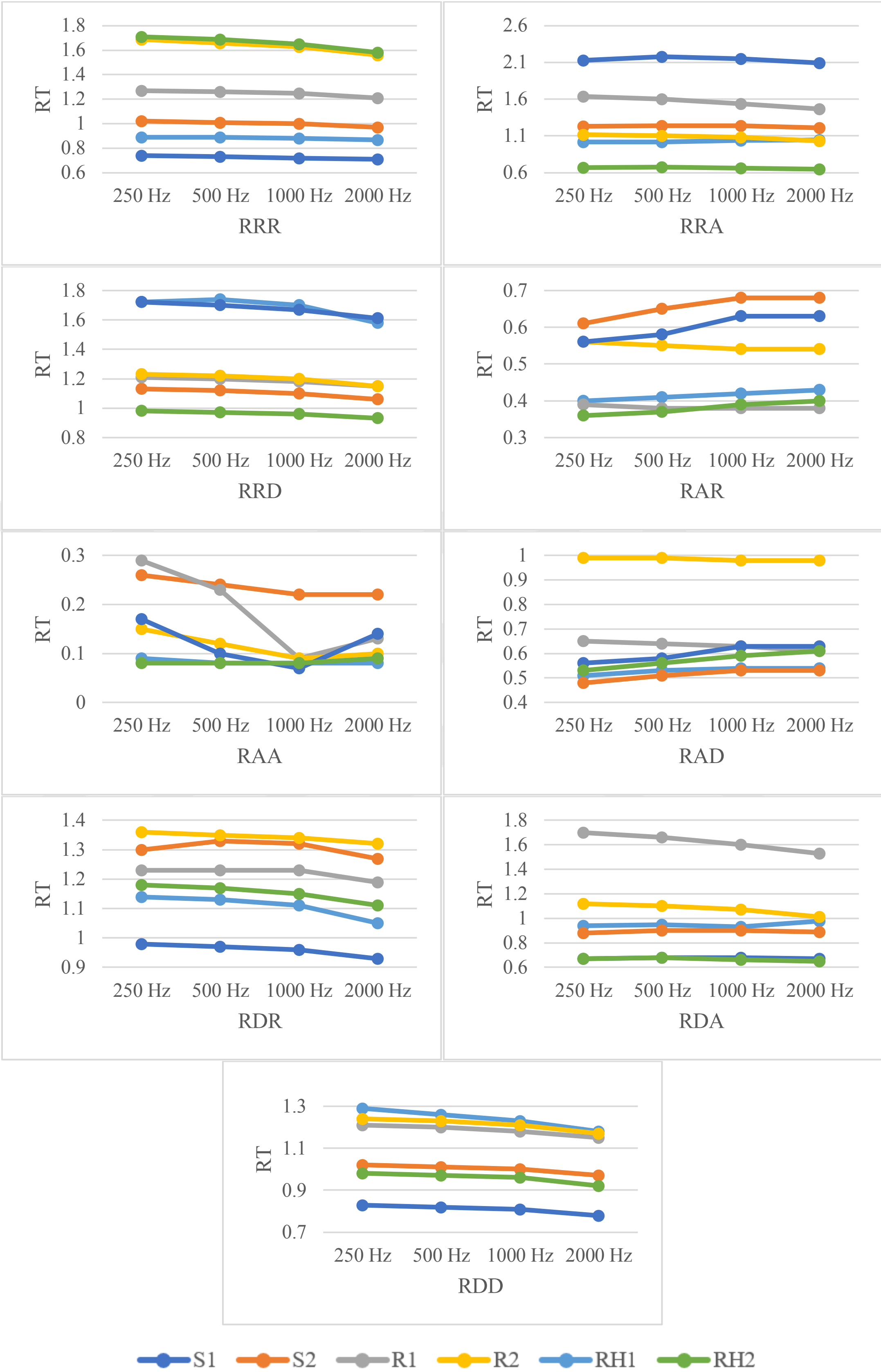

Figure RH1: Reverberation time at corner of different plan types

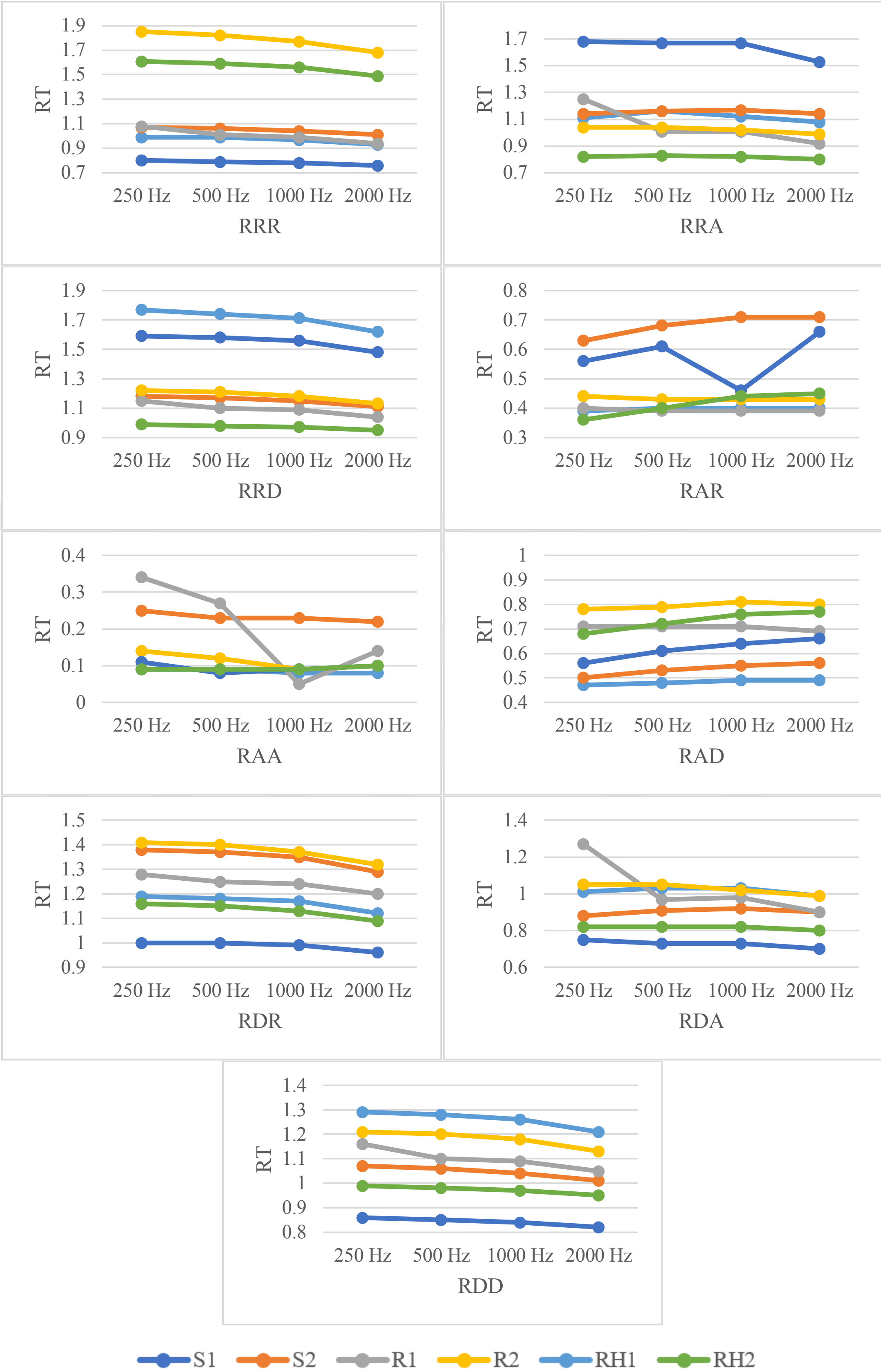

Figure RH2: Reverberation time at wall of different plan types

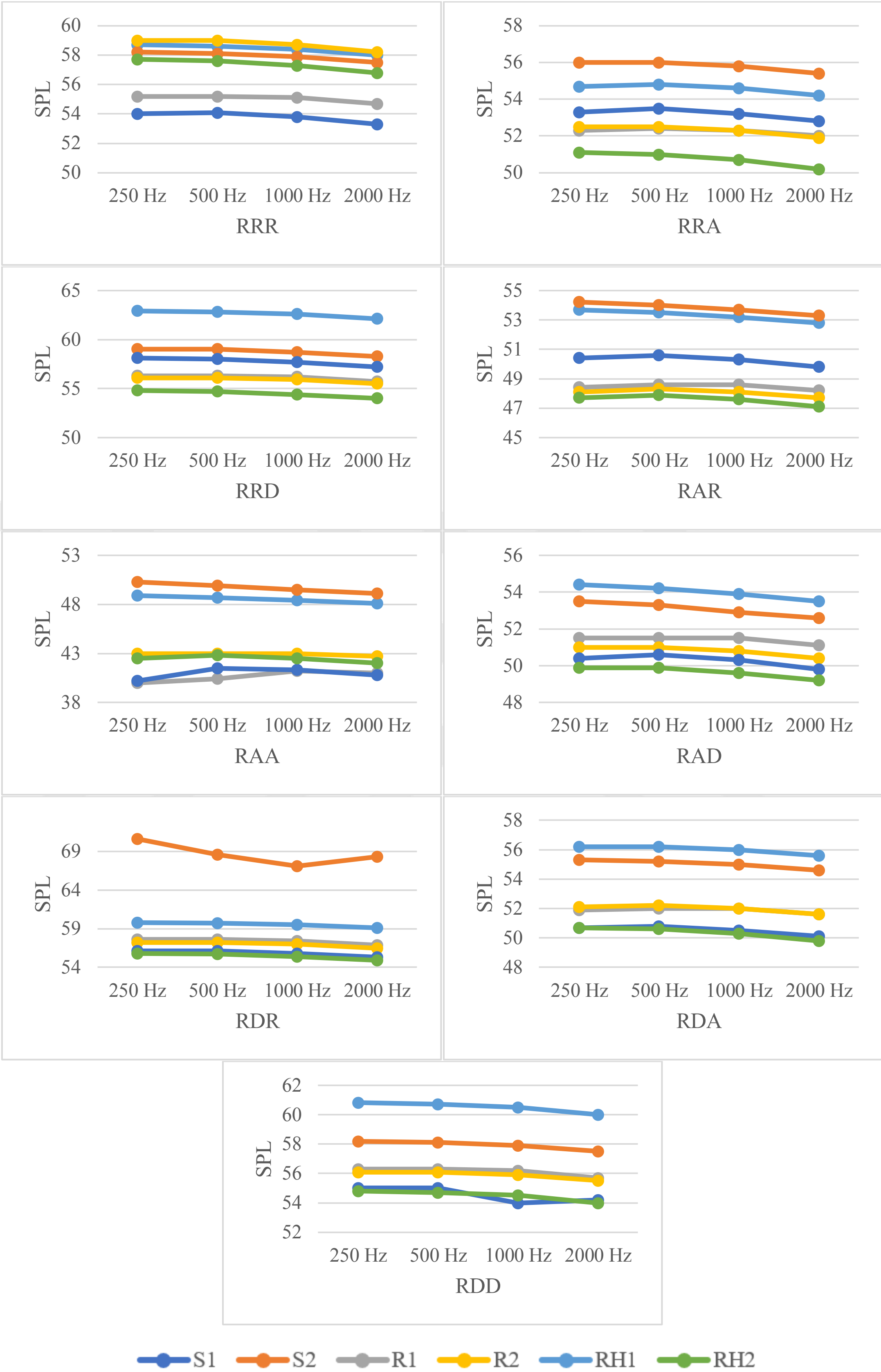

Figure C3: Sound pressure level at corner of different plan types

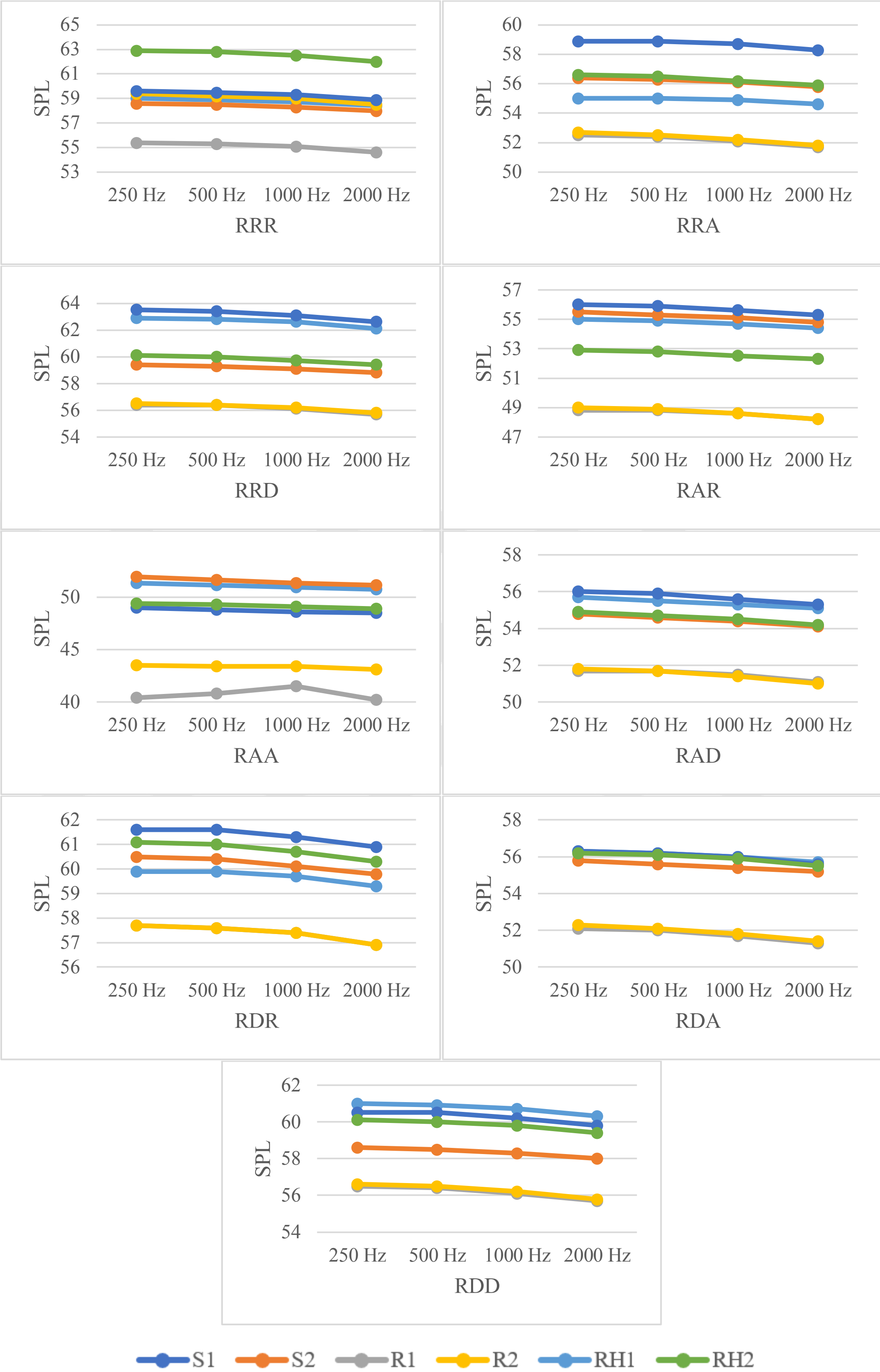

Figure C4: Sound pressure level at wall of different plan types

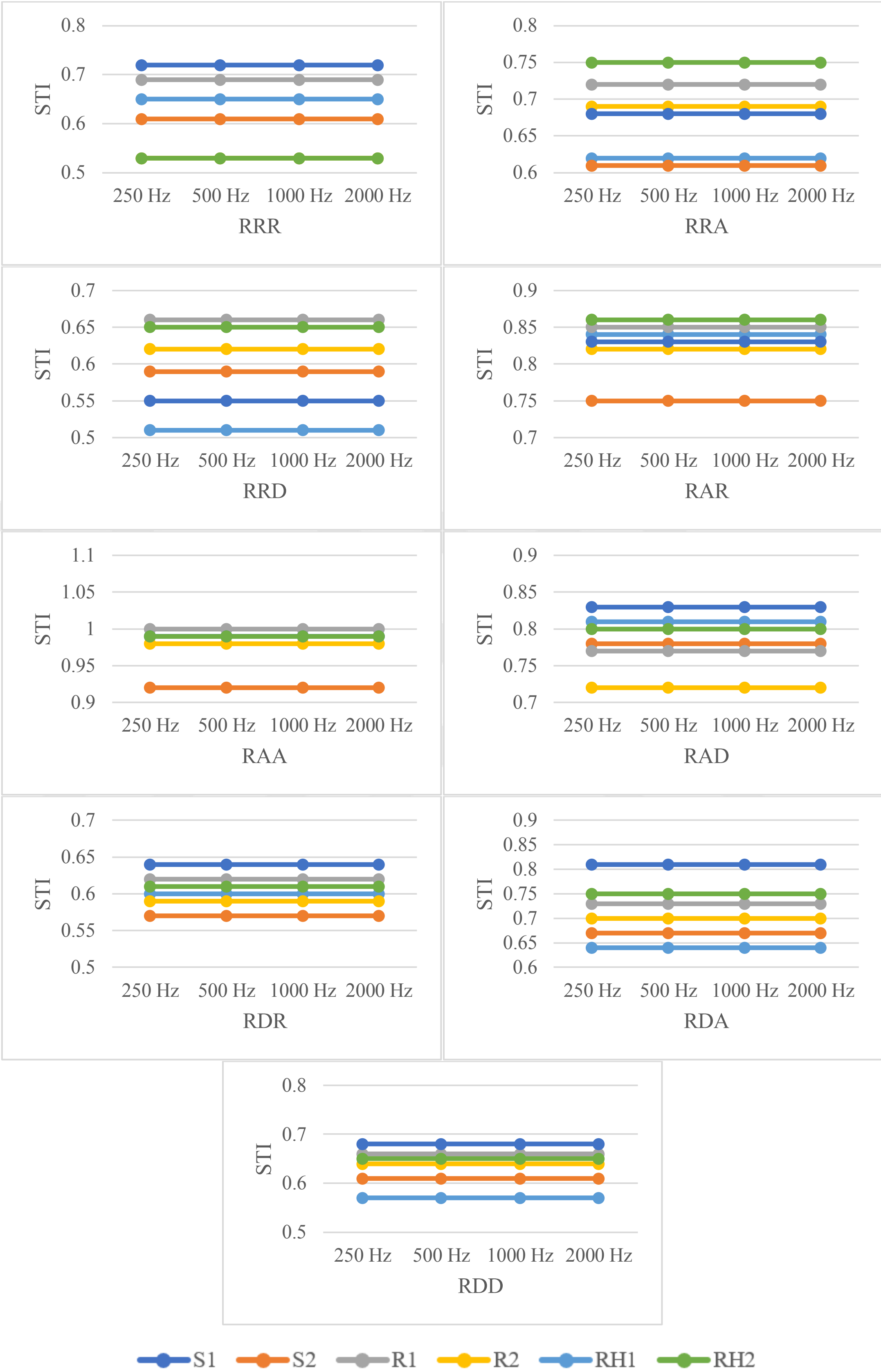

Figure C5: Speech transmission index at corner of different plan types

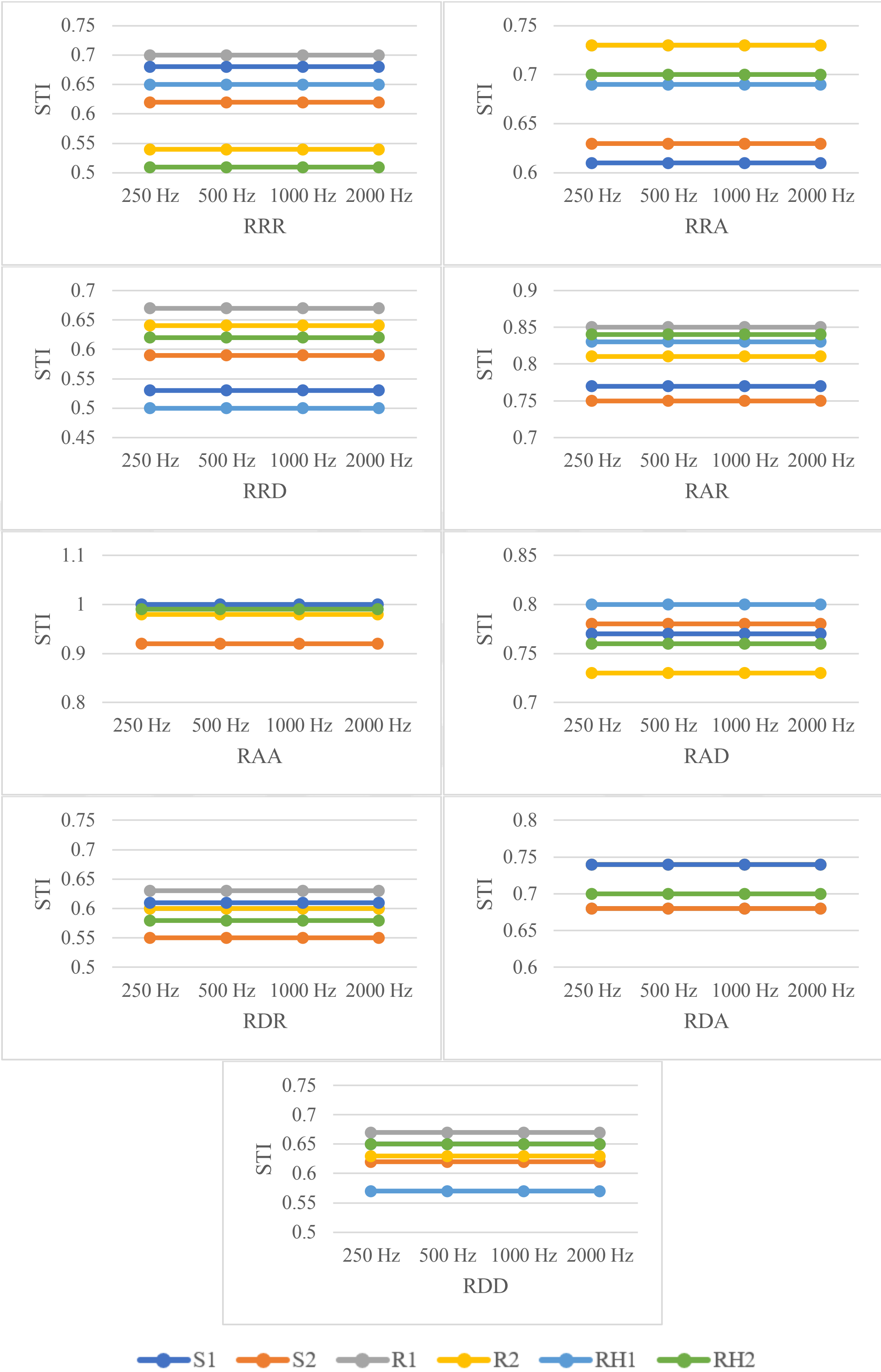

Figure C6: Speech transmission index at wall of different plan types

APPENDIX D: DIFFERENCES IN PLAN TYPES - ANOVA

ANOVA testing for differences in RT, SPL and STI based on plan type (p<.05)

		Sum of Squares	df	Mean Square	F	Sig.
RT250C	Between Groups	,498	5	,100	,413	,837
	Within Groups	11,567	48	,241		
	Total	12,064	53			
RT500C	Between Groups	,407	5	,081	,334	,890
	Within Groups	11,688	48	,244		
	Total	12,095	53			
RT1000C	Between Groups	,331	5	,066	,278	,923
	Within Groups	11,410	48	,238		
	Total	11,741	53			
RT2000C	Between Groups	,294	5	,059	,279	,923
	Within Groups	10,135	48	,211		
	Total	10,429	53			
RT250W	Between Groups	,180	5	,036	,173	,972
	Within Groups	9,993	48	,208		
	Total	10,173	53			
RT500W	Between Groups	,154	5	,031	,155	,978
	Within Groups	9,536	48	,199		
	Total	9,690	53			
RT1000W	Between Groups	,143	5	,029	,144	,981
	Within Groups	9,538	48	,199		
	Total	9,681	53			
RT2000W	Between Groups	,121	5	,024	,143	,981
	Within Groups	8,125	48	,169		
	Total	8,246	53			
SPL250C	Between Groups	284,544	5	56,909	2,207	,069
	Within Groups	1237,542	48	25,782		
	Total	1522,086	53			
SPL500C	Between Groups	249,627	5	49,925	2,096	,082
	Within Groups	1143,287	48	23,818		
	Total	1392,913	53			
SPL1000C	Between Groups	238,667	5	47,733	2,105	,081
	Within Groups	1088,713	48	22,682		
	Total	1327,380	53			
SPL2000C	Between Groups	251,824	5	50,365	2,172	,073
	Within Groups	1113,244	48	23,193		
	Total	1365,068	53			
SPL250W	Between Groups	249,995	5	49,999	2,724	**,030**
	Within Groups	881,027	48	18,355		
	Total	1131,021	53			
SPL500W	Between Groups	245,714	5	49,143	2,691	**,032**
	Within Groups	876,533	48	18,261		
	Total	1122,248	53			
SPL1000W	Between Groups	240,486	5	48,097	2,720	**,030**
	Within Groups	848,653	48	17,680		
	Total	1089,139	53			
SPL2000W	Between Groups	255,993	5	51,199	2,912	**,022**
	Within Groups	843,847	48	17,580		
	Total	1099,840	53			

ANOVA testing for differences in RT, SPL and STI based on plan type (p<.05)

		Sum of Squares	df	Mean Square	F	Sig.
STI250C	Between Groups	,039	5	,008	,440	,818
	Within Groups	,847	48	,018		
	Total	,886	53			
STI500C	Between Groups	,039	5	,008	,440	,818
	Within Groups	,847	48	,018		
	Total	,886	53			
STI1000C	Between Groups	,039	5	,008	,440	,818
	Within Groups	,847	48	,018		
	Total	,886	53			
STI2000C	Between Groups	,039	5	,008	,440	,818
	Within Groups	,847	48	,018		
	Total	,886	53			
STI250W	Between Groups	,023	5	,005	,260	,933
	Within Groups	,849	48	,018		
	Total	,872	53			
STI500W	Between Groups	,023	5	,005	,260	,933
	Within Groups	,849	48	,018		
	Total	,872	53			
STI1000W	Between Groups	,023	5	,005	,260	,933
	Within Groups	,849	48	,018		
	Total	,872	53			
STI2000W	Between Groups	,023	5	,005	,260	,933
	Within Groups	,849	48	,018		
	Total	,872	53			

APPENDIX E: DIFFERENCES IN MATERIAL TYPES - GRAPHS

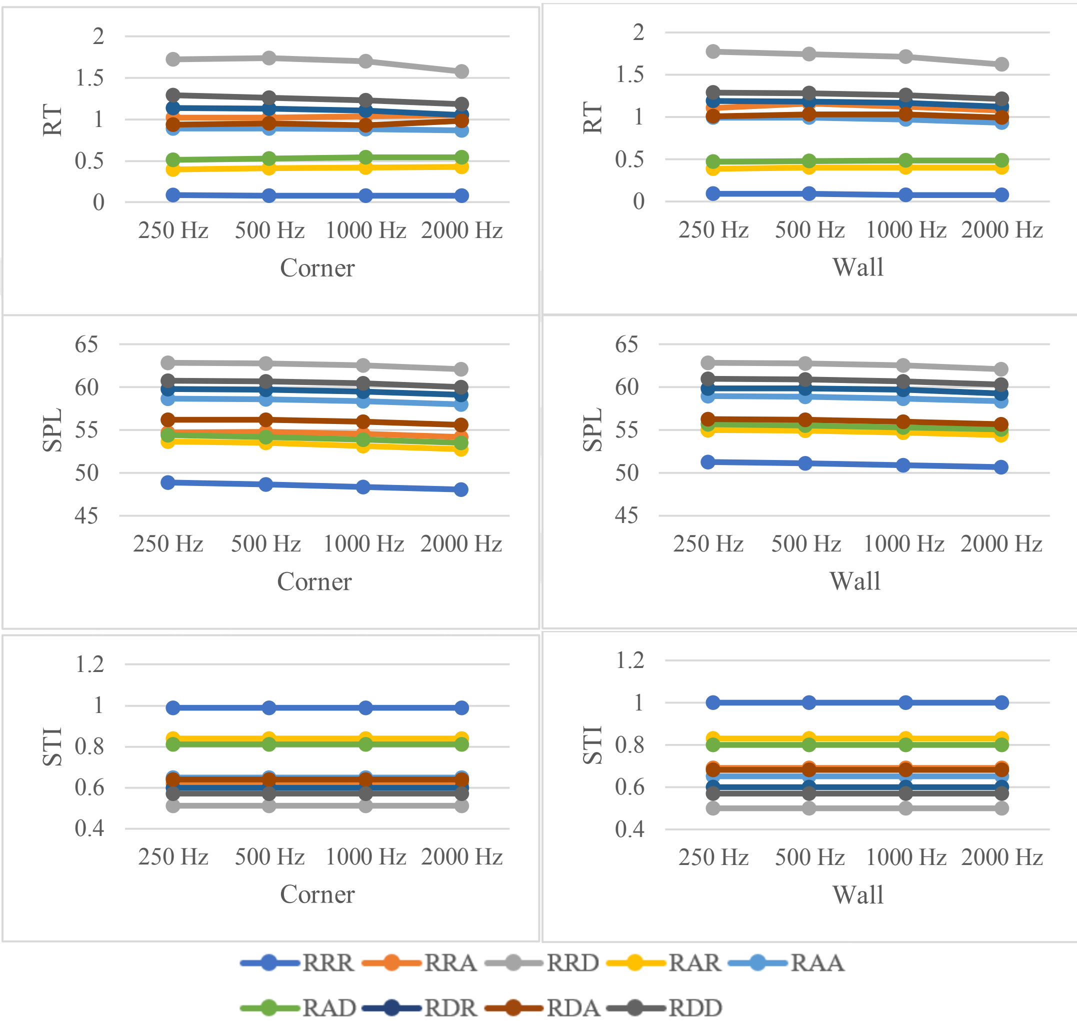

Figure E1: Acoustic indicators changes with material types for model S1 (square)

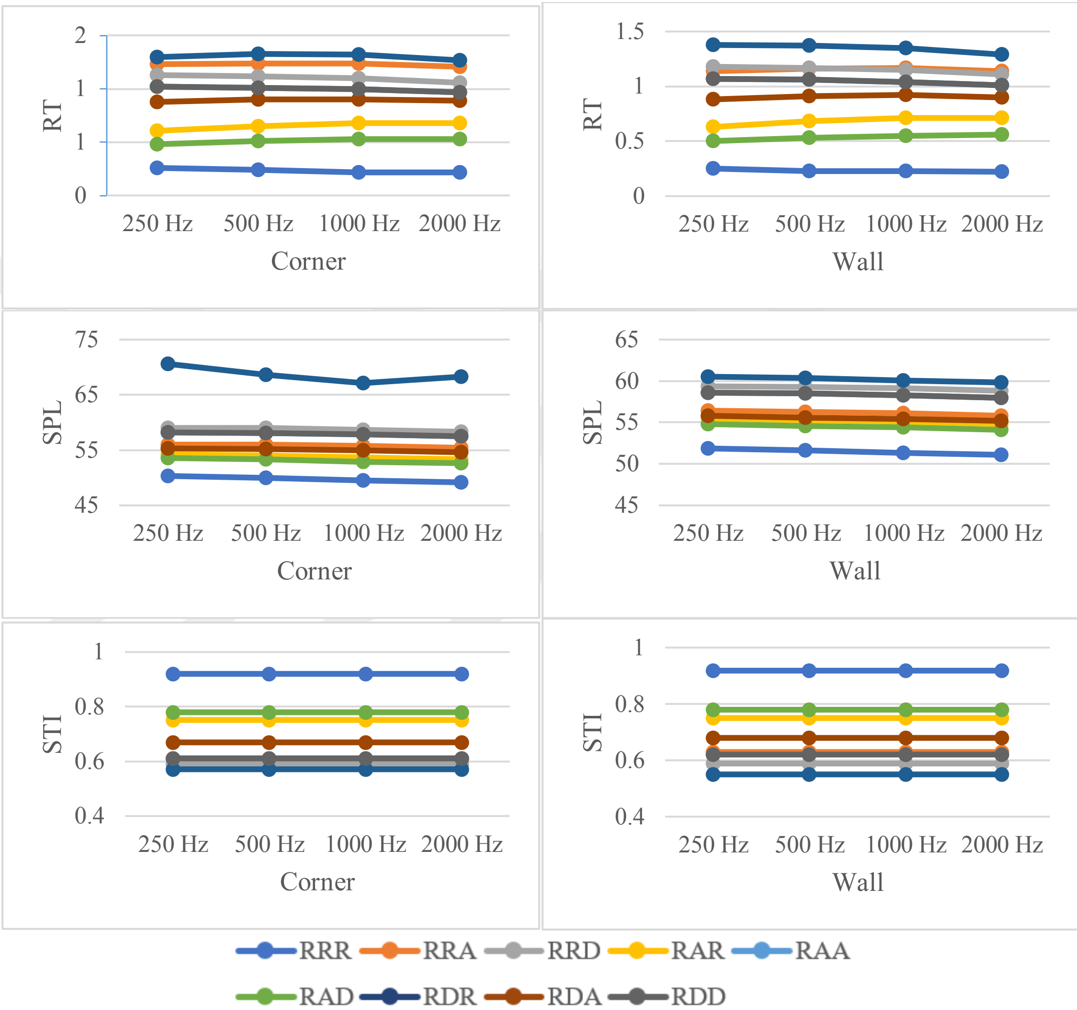

Figure E2: Acoustic indicators changes with material types for model S2 (square)

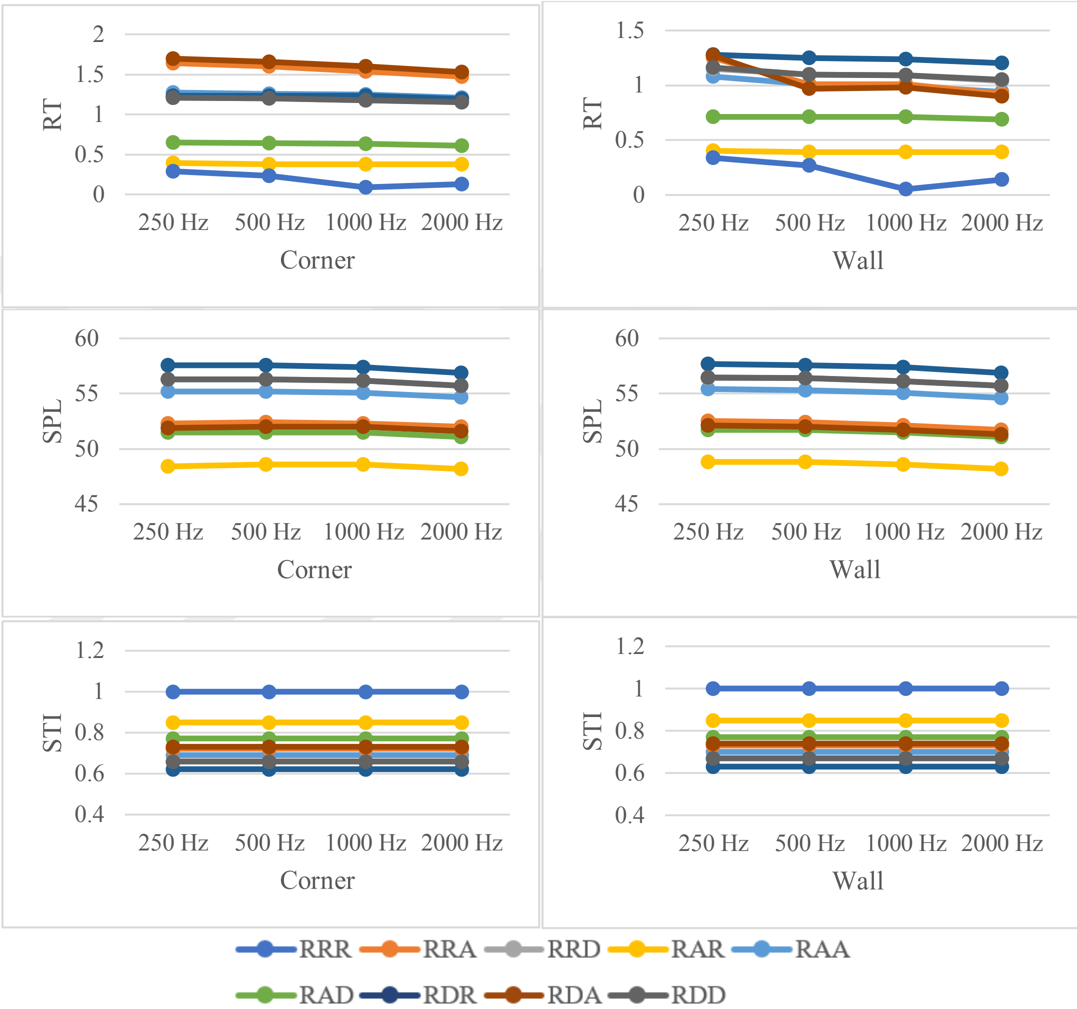

Figure E3: Acoustic indicators changes with material types for model R1 (rectangle)

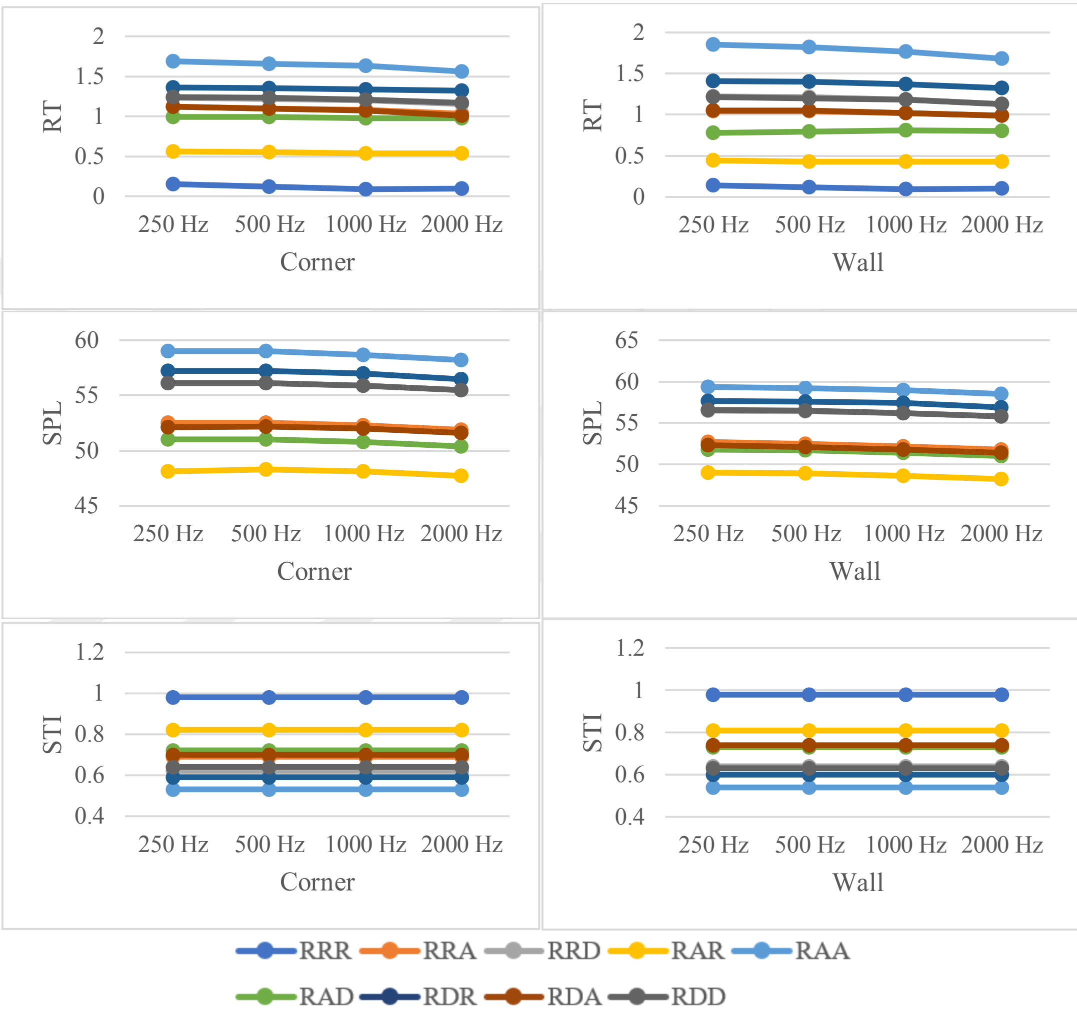

Figure E4: Acoustic indicators changes with material types for model R2 (rectangle)

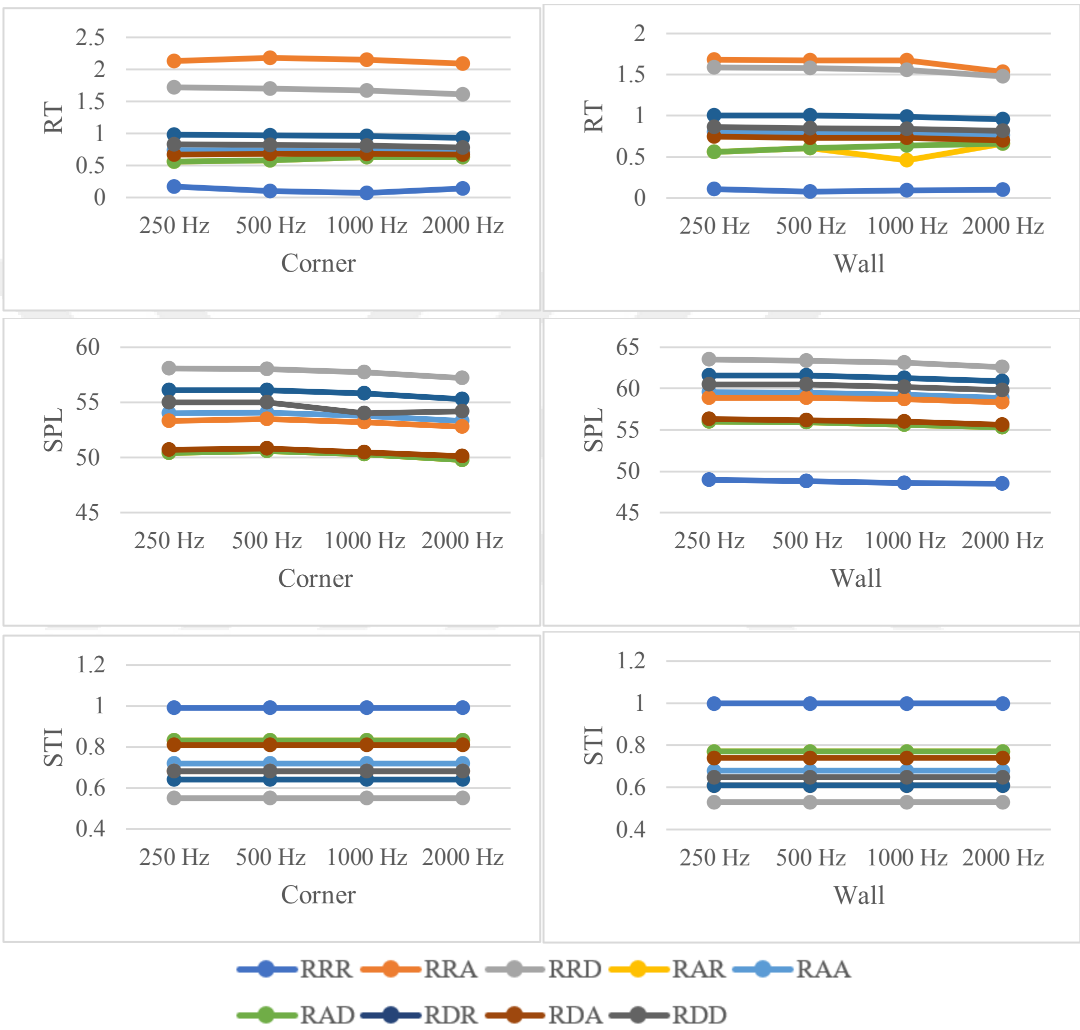

Figure E5: Acoustic indicators changes with material types for model RH1 (rhombus)

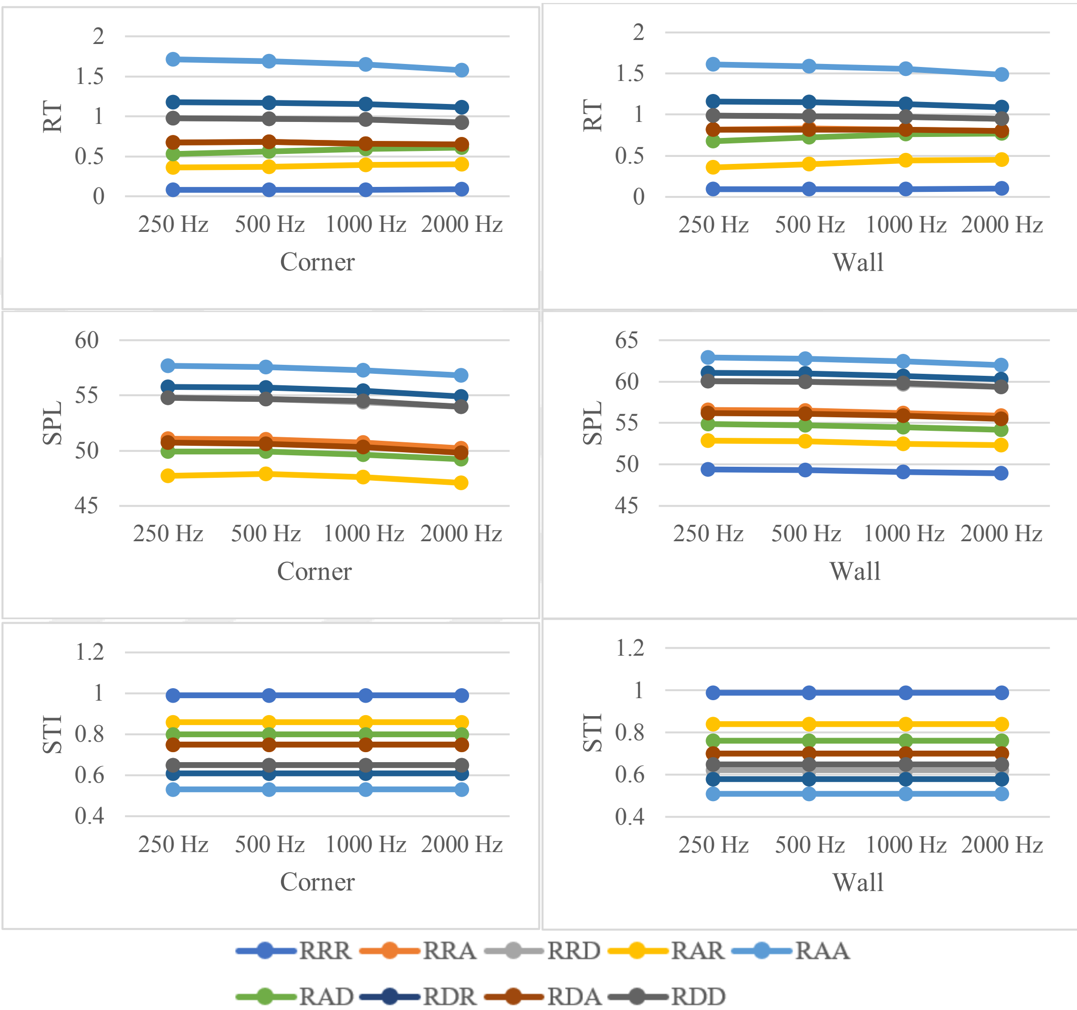

Figure E6: Acoustic indicators changes with material types for model RH2 (rhombus)

APPENDIX F: DIFFERENCES IN MATERIAL TYPES - ANOVA

ANOVA testing for differences in RT, SPL and STI based on material type (p<.05)

		Sum of Squares	df	Mean Square	F	Sig.
RT250C	Between Groups	8,138	8	1,017	11,657	**,000**
	Within Groups	3,927	45	,087		
	Total	12,064	53			
RT500C	Between Groups	8,234	8	1,029	11,997	**,000**
	Within Groups	3,861	45	,086		
	Total	12,095	53			
RT1000C	Between Groups	8,118	8	1,015	12,602	**,000**
	Within Groups	3,623	45	,081		
	Total	11,741	53			
RT2000C	Between Groups	7,183	8	,898	12,448	**,000**
	Within Groups	3,246	45	,072		
	Total	10,429	53			
RT250W	Between Groups	7,897	8	,987	19,516	**,000**
	Within Groups	2,276	45	,051		
	Total	10,173	53			
RT500W	Between Groups	7,550	8	,944	19,843	**,000**
	Within Groups	2,140	45	,048		
	Total	9,690	53			
RT1000W	Between Groups	7,637	8	,955	21,011	**,000**
	Within Groups	2,044	45	,045		
	Total	9,681	53			
RT2000W	Between Groups	6,484	8	,810	20,697	**,000**
	Within Groups	1,762	45	,039		
	Total	8,246	53			
SPL250C	Between Groups	1077,349	8	134,669	13,626	**,000**
	Within Groups	444,737	45	9,883		
	Total	1522,086	53			
SPL500C	Between Groups	1018,303	8	127,288	15,290	**,000**
	Within Groups	374,610	45	8,325		
	Total	1392,913	53			
SPL1000C	Between Groups	982,907	8	122,863	16,050	**,000**
	Within Groups	344,473	45	7,655		
	Total	1327,380	53			
SPL2000C	Between Groups	990,805	8	123,851	14,891	**,000**
	Within Groups	374,263	45	8,317		
	Total	1365,068	53			
SPL250W	Between Groups	793,838	8	99,230	13,243	**,000**
	Within Groups	337,183	45	7,493		
	Total	1131,021	53			
SPL500W	Between Groups	795,503	8	99,438	13,695	**,000**
	Within Groups	326,745	45	7,261		
	Total	1122,248	53			
SPL1000W	Between Groups	775,053	8	96,882	13,880	**,000**
	Within Groups	314,087	45	6,980		
	Total	1089,139	53			
SPL2000W	Between Groups	767,067	8	95,883	12,966	**,000**
	Within Groups	332,773	45	7,395		
	Total	1099,840	53			

ANOVA testing for differences in RT, SPL and STI based on material type (p<.05)

		Sum of Squares	df	Mean Square	F	Sig.
STI250C	Between Groups	,773	8	,097	38,596	**,000**
	Within Groups	,113	45	,003		
	Total	,886	53			
STI500C	Between Groups	,773	8	,097	38,596	**,000**
	Within Groups	,113	45	,003		
	Total	,886	53			
STI1000C	Between Groups	,773	8	,097	38,596	**,000**
	Within Groups	,113	45	,003		
	Total	,886	53			
STI2000C	Between Groups	,773	8	,097	38,596	**,000**
	Within Groups	,113	45	,003		
	Total	,886	53			
STI250W	Between Groups	,779	8	,097	46,732	**,000**
	Within Groups	,094	45	,002		
	Total	,872	53			
STI500W	Between Groups	,779	8	,097	46,732	**,000**
	Within Groups	,094	45	,002		
	Total	,872	53			
STI1000W	Between Groups	,779	8	,097	46,732	**,000**
	Within Groups	,094	45	,002		
	Total	,872	53			
STI2000W	Between Groups	,779	8	,097	46,732	**,000**
	Within Groups	,094	45	,002		
	Total	,872	53			