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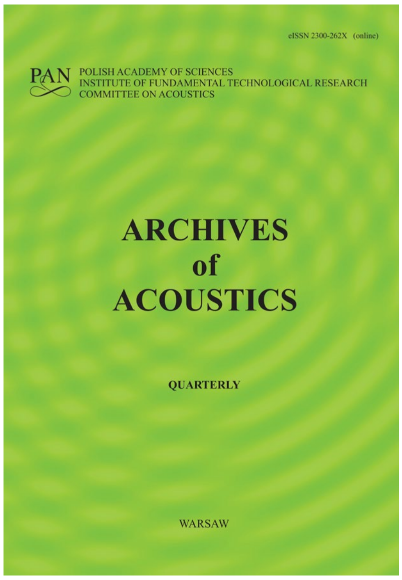

Title: Shaping the Soundscape: Exploring the Influence of Building Layout on Outdoor Acoustic Environments

Author(s): Sami Hamouta, Atef Ahriz, Noureddine Zemmouri, Ahmed Mansouri

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Shaping the Soundscape: Exploring the Influence of Building Layout on Outdoor Acoustic Environments

Sami Hamouta [a,b] * (https://orcid.org/0000-0003-4932-4252) , **Atef Ahriz** [c,d] (https://orcid.org/0000-0001-5891-0275),

Noureddine Zemmouri [e,f] (https://orcid.org/0000-0001-8400-5690), **Ahmed Mansouri** [g] (https://orcid.org/0000-0002-4243-0426)

[a] Department of Architecture, 8 Mai 1945 – Guelma University, Guelma, Algeria

[b] Laboratory of Civil Engineering and Hydraulics (LGCH), 8 Mai 1945 – Guelma University, Guelma, Algeria

[c] Department of Architecture, University of Tebessa, Algeria

[d] Applied Civil Engineering Laboratory (LGCA), University of Tebessa, Algeria

[e] Department of Architecture, University of Biskra, Biskra, Algeria

[f] Laboratory of Design and Modeling of Architectural and Urban Forms and Ambiances (LACOMOFA), University of Biskra, Biskra, Algeria

[g] Department of Architecture, University of Batna 1, Batna, Algeria

*Corresponding Author: hamouta.sami@univ-guelma.dz

This study investigated the influence of building layout on the outdoor acoustic environment through field measurements conducted in four courtyards at the University of Batna 1. Acoustic parameters including Sound Pressure Level (SPL) attenuation, Reverberation Time (RT20), Early Decay Time (EDT), Clarity (D50), and the Rapid Speech Transmission Index (RaSTI) were evaluated. Results showed that square-shaped courtyards retained sound the longest (RT20 exceeding 2.3 s at 1000 Hz), U-shaped courtyards exhibited the most irregular reverberation patterns, and linear courtyards provided the most stable sound decay. D50 and RaSTI values were highest in linear courtyards, indicating superior speech intelligibility, while square and U-shaped layouts demonstrated reduced intelligibility due to extended reverberation. SPL attenuation was also more consistent in linear configurations compared to the variable patterns observed in

enclosed geometries. These findings demonstrate that building form plays a decisive role in shaping outdoor acoustic conditions and highlight the importance of considering acoustic performance in early design decisions. The results are broadly applicable to the planning of courtyards, plazas, and semi-enclosed urban spaces. Future work should explore additional variables such as building height, façade materials, vegetation, and seasonal effects to develop comprehensive guidelines for acoustically optimized outdoor environments.

Keywords: outdoor acoustic environment; architectural design optimization; building geometry and acoustics; noise mitigation strategies; acoustic comfort in urban spaces

1. Introduction

In urban outdoor environment, the shifting toward the dependence on more mechanization has led to a gradual acceptance of noise as a fact (L. K. Wang et *al.,* 2005). However, noise may have both immediate and long-term detrimental impacts on human health and the environment, with real and perceived repercussions, interfering with sleep, concentration, communication, and recreation (*Environmental Noise Guidelines for the European Region*, n.d.; Goines and Hagler, n.d.). The university environment, for instance, encompasses an urban complexity relevant to this dilemma.

In the last decade, sound environment at the cognitive performance contexts has received considerable attentions (Çolakkadıoğlu et al., 2018; Goswami et al., 2011; Su et al., 2013; Xie et al., 2011). These contexts have become more and more exposed to high level of environmental noise (Zannin et al., 2013; Zannin & Ferraz, 2016; Zannin & Zwirtes, 2009). The auditory environment has an impact on students' behavior and comprehension, i.e., loud environments are not conducive to learning, making instruction laborious and generating annoyance and difficulty focusing (Çolakkadıoğlu et al., 2018; Su et al., 2013; Zannin & Ferraz, 2016).

University outdoor spaces are essentially designed to be aiming at preserving the restorative and relaxation of students (Gulwadi et *al.,* 2019). Nevertheless, outdoor areas enclosed by buildings are the first ones to be exposed and impacted by noise sources. Buildings provide several complex acoustic effects when sound travels through the air, affecting both the transient sound levels associated with Reverberation Time (RT) and the continuous noise levels, such as Sound Pressure Level (SPL), often generated by road traffic (Yang et *al.,* 2013). The occurrence of many reflections, diffractions, and diffusions is contingent upon factors such as the dimensions, irregularity, material characteristics, architectural arrangement, and ground surfaces of the structure. They can affect auditory comfort for both leisure and relaxation in open-air environments. They also can impact indoor facilities, such as classrooms, libraries, and laboratories that might be exposed to high noise background of those outdoor spaces. Hence, creating outdoor places that have pleasant acoustics may enhance the overall quality of life for educational, instructional, and relaxation purposes.

The shape of the built environment greatly influences the acoustic properties of outdoor areas (Benameur et al., 2022; Bouzir & Zemmouri, 2017; Guedes et al., 2011; Oliveira & Silva, 2011; Silva et al., 2014; B. Wang & Kang, 2011). Its various features have the potential to modify noise levels. building layout shape and arrangement, being one of these key elements, can contribute to altering the acoustic parameters of the sound environment.

Previous research endeavors have delved into the impact of fabric environment features related to building layout shape on shaping the acoustic ambiance of outdoor spaces.(Ariza-Villaverde et *al.,* 2014; Lee and Kang, 2015; Thomas et *al.,* 2013) investigated the effect of street width and building height. The findings indicate that the H/W ratio had an impact on the variance of sound characteristics. Echevarria Sanchez et *al.,* (2016) researched on the design of the street canyon effect through general building shape on noise exposure. the results indicated that flat vertical, flat upwardly inclined, flat downwardly inclined, upwardly stepped convex, downwardly stepped, and concave may significantly influence individuals' noise exposure. The study conducted by (Eggenschwiler et *al.,* 2022) examined the impact of building rotation, specifically the orientation of walls (parallel vs. nonparallel), on the perception of noise discomfort. Rotating the building (which leads to walls that are not parallel) was shown to be linked to reduced noise nuisance compared to the initial orientation with parallel walls. Although the decrease in sound intensity contributed to this outcome, the beneficial impact also persisted when the sound level was equivalent for both rotating and parallel structures.

Additional research has also shown that different morphological elements of building layouts might impact the acoustic environment. The studies (Flores et *al.,* 2017; Yang et *al.,* 2013, 2017) focus on investigating the effect of configuration and disposition of building on acoustical parameters such as RT, EDT, D50, and RASTI, as well as the attenuation of the sound pressure level in outdoor spaces. They highlight that the configuration and disposition of the building such as linear-shaped, square-shaped, U-shaped, and parallel -shaped has a crucial effect on sound environment.

Han et *al.,* (2018) aims to examine the impact of geographical landscape features on Urban Environment Noise (UEN) and traffic noise in the Shenzhen metropolitan area of China. The study revealed substantial correlations between urban morphology and regional traffic noise levels (RN/TN). The design and structure of buildings have a substantial correlation with registered nurses (RN). The arrangement of buildings is associated with traffic noise (TN), and continuous and interconnected structures along the sides of highways are more efficient in reducing the impacts of traffic noise (TN). The scattered distribution and uneven forms of buildings aid in the reduction of regional noise (RN). Buildings are more efficient in mitigating noise when they are dispersed across metropolitan areas, rather than being concentrated in one area.

Prior investigations, using site measurement, have been carried out to assess the impact of buildings on reverberation time (RT) and noise levels in outdoor areas (Aylor et al., 1973; Flores et al., 2017; Picaut et al., 2005; Steenackers et al., 1978; Thomas et al., 2013; Wiener et al., 1965; Yang et al., 2013, 2017; Yeow, 1977; Zuccherini Martello et al., 2015). In conclusion, the site measurements' findings show that buildings in urban areas are a contributing factor to rising noise levels and RT because of multiple reflections. Street width and the acoustic characteristics of ground surfaces, building layouts, and façades are some of the factors that affect these reflections.

While outdoor spaces at universities may have certain similarities with urban streets, squares, and built-up regions, they exhibit diverse layouts, sorts, and sizes. Additional investigation is necessary to examine the acoustic properties of outdoor areas inside these specific cognitive structures, since there are variations in the arrangement of buildings, materials used, and façade layout.

The objective of this research is to analyze the acoustic properties of outdoor spaces surrounding by buildings by examining data collected from four outdoor areas at Banta 1 University, each with distinct building layouts. The outdoor areas were classified into four distinct building layouts: U-shaped, square-shaped, linear-shaped, and L-shaped. The reverberation time (RT), early decay time (EDT), and SPL attenuation were assessed based on the site measurements taken at the location, taking into account the distances between the sound source and the receiver. An analysis was conducted on the features of room acoustical factors utilizing the rapid speech transmission index (RASTI) and the Definition (D50), both of which are associated with speech intelligibility.

2. Methods

2.1. Description of the case study

This study aims to investigate the impact of building facades on the sound environment in four outdoor spaces within the campus of the university of Batna 1, situated in Batna city (Aures region) North East of Algeria.

The Outdoor areas were chosen for their close proximity to university buildings and their regular use by students, as seen in Fig. 1 and Fig. 2. Furthermore, the selection process took into account the building components and layout forms. These spaces share a set of architectural features. Among these features an almost square shape measuring about 40m by 40m, facades composed of concrete walls and large glass windows. Façade heights range from 2 to 3 floors. However, each outdoor space has a different building layout. These architectural aspects of the structure may be seen as surfaces that reflect sound, resulting in a longer reverberation time (RT) and an increase in sound pressure level (SPL) owing to intense reflections compared to an open area. Building layouts surrounding outdoor spaces are categorized into four types: square-shaped (i.e. □), U-shaped (i.e. U), L-shaped (i.e. L), and linear shaped (i.e. –).

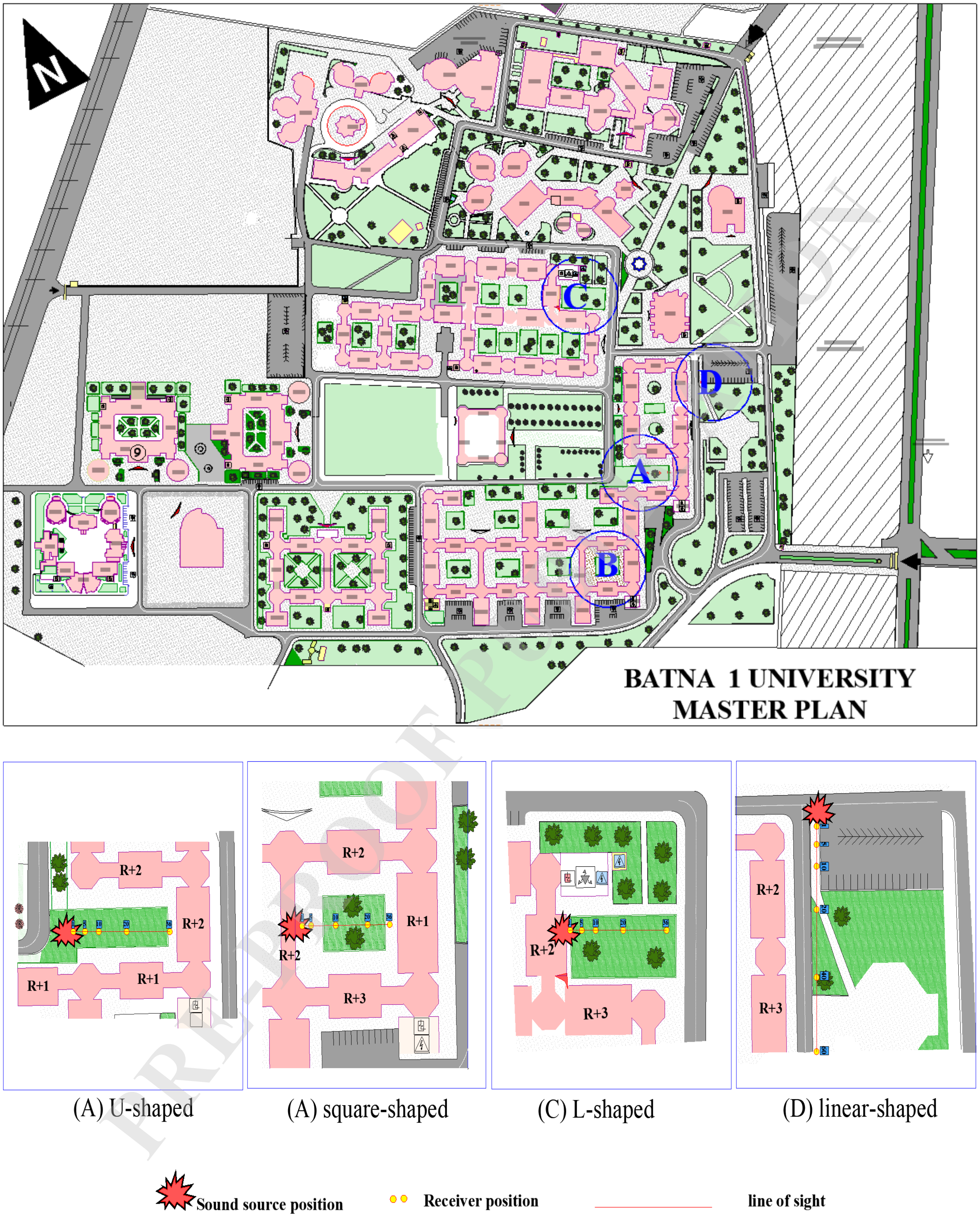
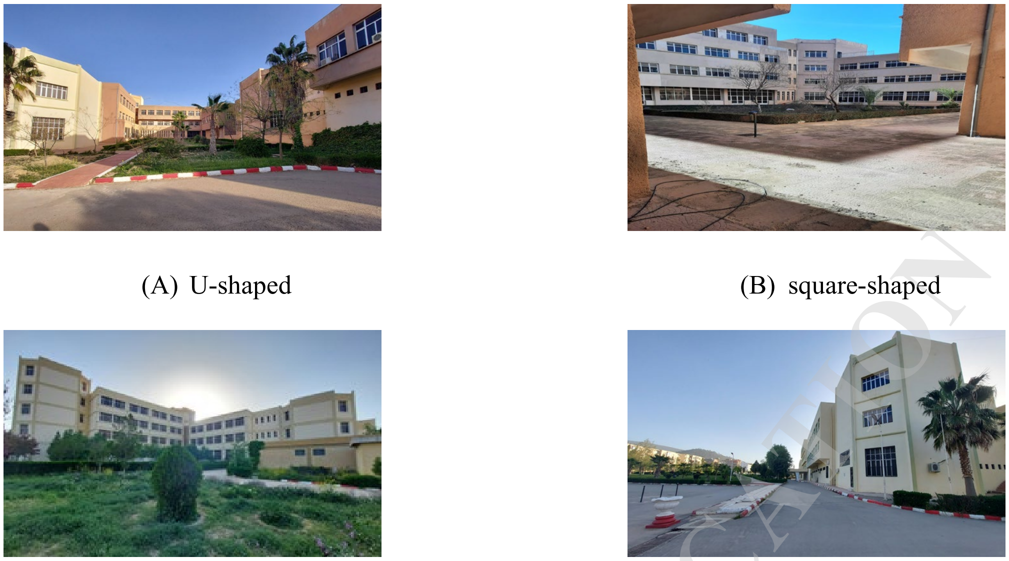


Fig. 1 University of Batna1, Master Plan and measurements' station's location.



(A) U-shaped (B) square-shaped

(C) L-shaped (D) linear-shaped

Fig. 2 Photographs of each measurement stations.

2.2. Measurement protocol

Figure 3 displays the workflow of this research to analyze the impulse response, including RT, EDT, D50 and RaSTI and the SPL.

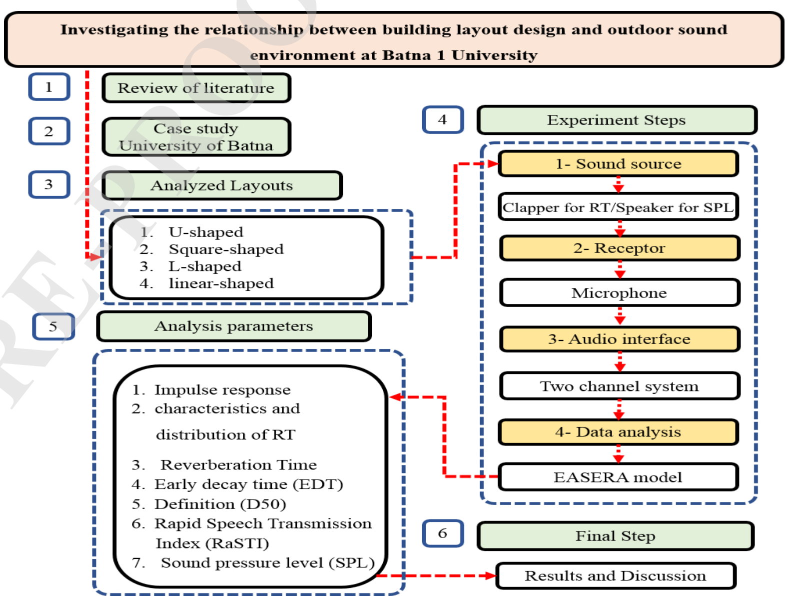


Fig. 3 *Investigation workflow*

The measurement of sound pressure level (SPL) attenuation with distance was conducted using the Scarlet Solo Focusrite audio interface, a ½ inch measuring microphone (Dayton audio type EMM-6), and a real-time analyzer (RTA) inside the ESERA software developed by AFMG. The receiver was calibrated before the measurement and set up to 1.5m of height.

The measurement used white noise as the sound source, which was produced by a directional speaker at a height of 1.5 meters. The signal-to-noise ratio (S/N) for the measurement was 53 decibels (dB) at a distance of 1 meter from the source. This indicates that there was enough sound power to accurately measure the sound pressure level (SPL) attenuation at distances up to 40 meters between the source and the receiver. The signal-to-noise ratio (S/N ratio) measured at a distance of 40 meters from the source was around 25 decibels (dB).

The impulsive signal was generated using a starting clapper, selected because it provides higher sound levels relative to background noise compared to an omni-directional speaker. The clapper produces a broadband impulsive signal with a nearly omnidirectional radiation pattern in the horizontal plane, making it well suited for outdoor impulse response measurements. The impulse responses for the starting clapper were captured via the Scarlet Solo Focusrite audio interface and a ½ inch measurement microphone (Dayton audio type EMM-6). The acoustical characteristics, such as reverberation time (RT), early decay time (EDT), clarity (D50), and speech intelligibility (RASTI), were examined using the EAZERA software from AFMG. This program has a noise compensation algorithm that minimizes the impact of background noise on the computation of RT. Both the source and the receiver were positioned at a height of 1.5 units above the ground. Each measurement represented the average value obtained from five consecutive claps performed in succession. Prior to each measurement, the microphone underwent calibration.

Before and after each measurement session, the microphones and acquisition system were calibrated using acoustic calibrator (94 dB at 1 kHz). This ensured the accuracy and reliability of the recorded acoustic parameters across all measurement points.

All measurements, conducted on the same winter day under the meteorological conditions detailed in Table 1, ensured consistent conditions and minimized the influence of weather variations between sites, thereby guaranteeing comparability across the different measurement zones.

Meteorological data were verified to ensure compliance with guidance and regulations for outdoor acoustic measurements. The slight exceedances in two cases (5.25 and 5.59 m/s) are considered negligible in terms of their potential influence on the results.

Weather condition	**U-shaped**	**Square-shaped**	**Linear-shaped**	**L-shaped**
Temp. (°C)	12.1	12.7	13.1	12.7
Humidity (%)	35	35	48	35
Wind speed (m/s)	<2.2	<5.25	<5.59	<5.25

Table 1. Weather conditions of each measurement zone.

Ground surface materials play a significant role in outdoor sound propagation and reflections, as they influence both absorption and scattering. In this study, however, all investigated spaces had ground surfaces composed mainly of natural soil and green cover. Since this condition was uniform across the sites, its effect on differentiating the acoustic outcomes is minimal, ensuring that the observed variations are more strongly related to architectural configuration.

The number and position of the source and recipient points in each measurement zone are outlined in Table 2. Figure 1 depicts the positions of source to receiver points in the four regions, with a total of 21 sites used for measuring impulse responses and sound pressure levels (SPL). Although the source sound, namely a starting clapper for RT and a speaker for SPL attenuation, remained constant in all outside areas, the positions of the reception points, which were microphones, were adjusted along their respective line of sight. The distance between the source and receiver for each measurement zone was obtained by taking into account the size of the outdoor spaces. The source receiver distance was logarithmically scaled within a range of 40 meters in four zones. This was done in order to study the distribution of reverberation time (RT) and the attenuation of sound pressure level (SPL) in these outdoor spaces.

A single source position was selected in each courtyard to represent a typical noise source location and to ensure direct comparability between sites. This approach helped isolate the effects of layout, while the enclosed nature of the spaces limited variability from source relocation.

The INR was found to be 22 dB at 125 Hz, 30 dB at 250 Hz, 39 dB at 500 Hz, 51 dB at 1000 Hz, 63 dB at 2000 Hz, 63 dB at 4000 Hz, and 49 at 8000 Hz at a distance of 40 m, which is considered to be the greatest source to receiver distance.

For accurate RT measurement of T20 and T30, respectively, ISO 3382-2 recommends an INR of at least 35 dB and 45 dB. Based on the INRs in the one band displayed above, the RT calculation method was based on T20 (-5 dB to -25 dB) in one-octave bands from 500 Hz to 8000 Hz for source to receiver distances within 40 m.

In this study, the 125 Hz and 250 Hz octave bands were excluded from the analysis because their Impulse-to-Noise Ratio (INR) values did not meet the minimum threshold required for reliable measurement, as recommended in ISO 3382. This approach is consistent with previous outdoor acoustic studies, including those by Yang et al. (2013) and Yang et al.(2017), where low-frequency bands were omitted when the INR was insufficient. In outdoor environments, low frequencies are particularly vulnerable to interference from background noise and environmental factors, which can lead to measurement inaccuracies. Therefore, excluding these bands ensured that the reported results were based on robust and reliable data.

Type of the building layouts	Number of sources	Number of receivers	Source - receiver distance(m)	Measurement parameter	
				SPL attenuation	Impulse response
U-shaped	01	05	1-5-10-20-36	x	x
Square-shaped	01	05	1-5-10-20-36	x	x
L-shaped	01	05	1-5-10-20-36	x	x
Linear-shaped	01	06	1-5-10-20-40-60	x	x

Table 2: Number and position of the source and receiver points at every measurement areas.

3. Results and discussion

3.1. Impulse response

Figures 4 and 5 provide the pressure squared impulse responses and decay curves recorded at receiver distances of 20 m, in order to verify the impact of building layouts on multiple reflections. In order to analyze the variations in sound energy reflection patterns across the four outdoor locations, it is beneficial to compare the impulse responses and decay curves obtained from the same sound source.

The outcome shown in Fig. 4 displays impulse responses that include sound reflections coming later to the direct sound from building facades, ground, and other obstructions. Therefore, it can be concluded that the sound energy that bounces back produces an increase in sound pressure level (SPL) and reverberation time (RT), which are directly linked to the perception of noise discomfort and spatial impressions. The reflection patterns of impulse responses vary throughout the four outside areas, despite the tests being conducted at equal distances between the source and receiver. The reflection pattern is impacted by several design aspects, including building layout, building form, gaps between buildings, and arrangement of building façades. Based on the various forms of outdoor spaces, the sound energy reflected in U and square-shaped areas is comparatively strong compared to that in linear and L-shaped areas. This observation is further supported by the decay curve shown in Fig. 5.

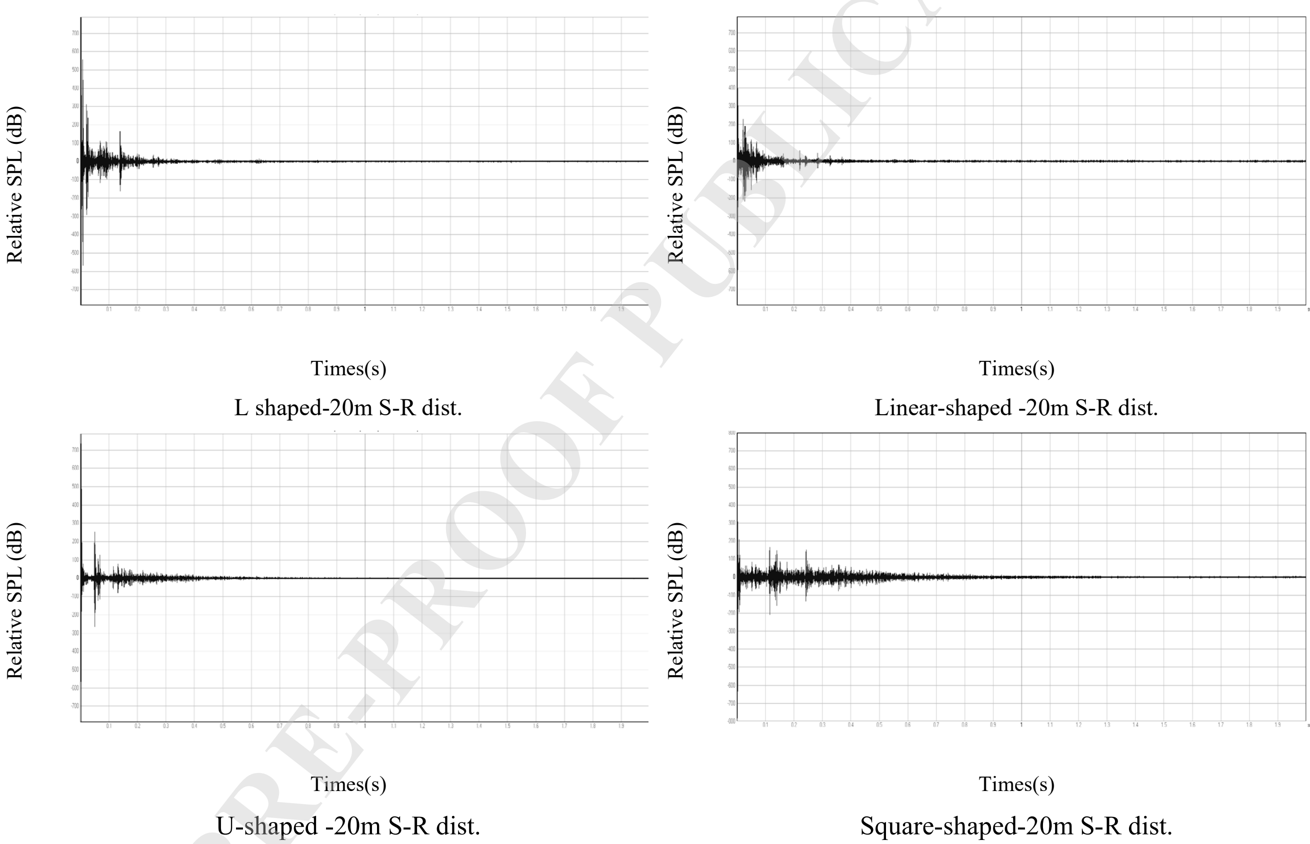
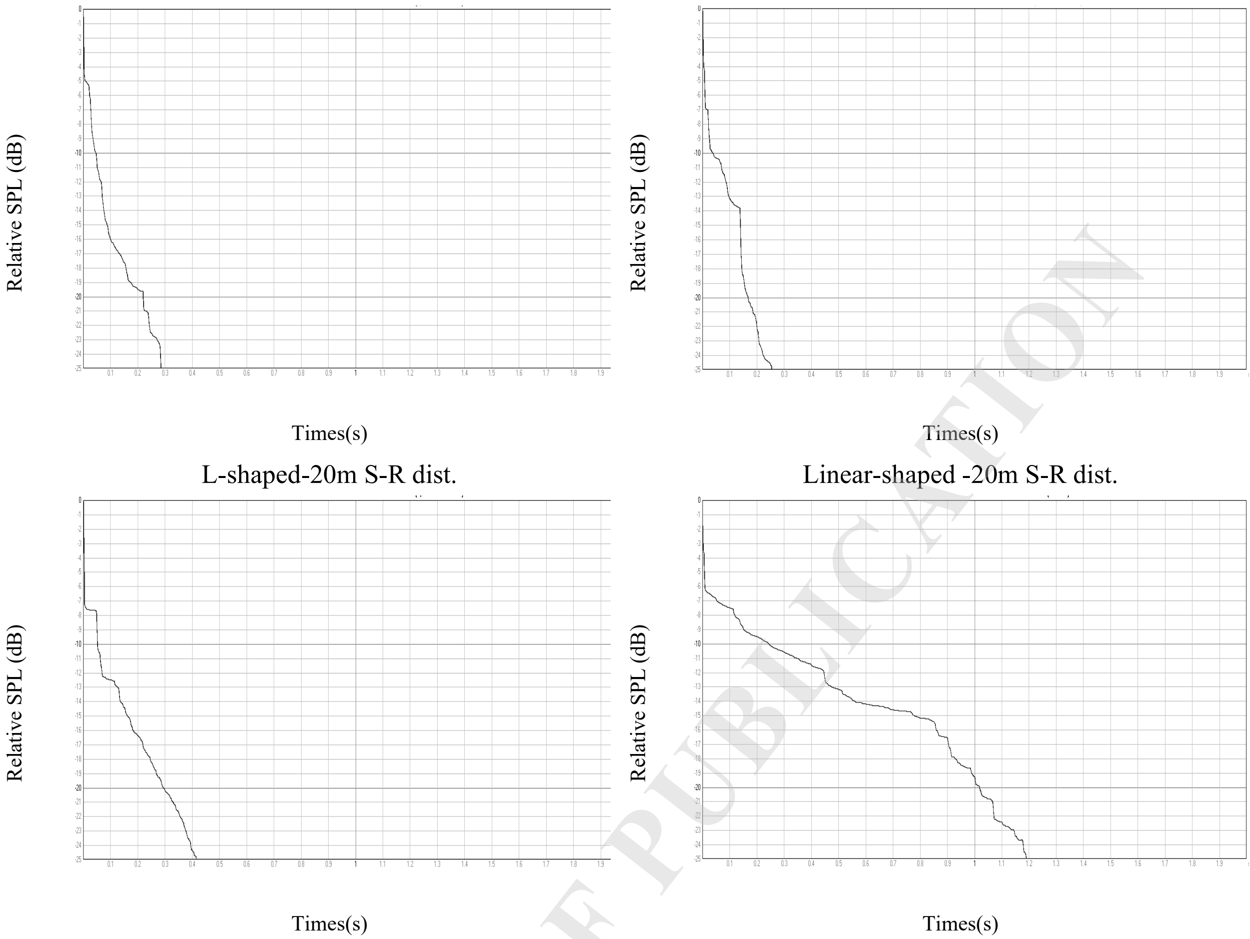


Fig. 4. Impulse responses at 1000 Hz for each of the four outdoor sites measured at a source-to-receiver distance of about 20 meters.



L-shaped-20m S-R dist. Linear-shaped -20m S-R dist.

U-shaped -20m S-R dist. Square-shaped-20m S-R dist.

Fig. 5. Decay curves at 1000 Hz for each of the four outdoor sites measured at a source-to-receiver distance of about 20 meters.

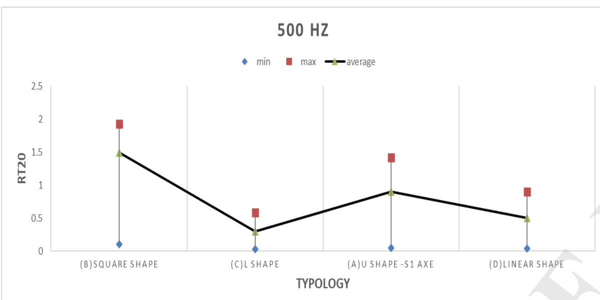
3.2. General features and RT distribution

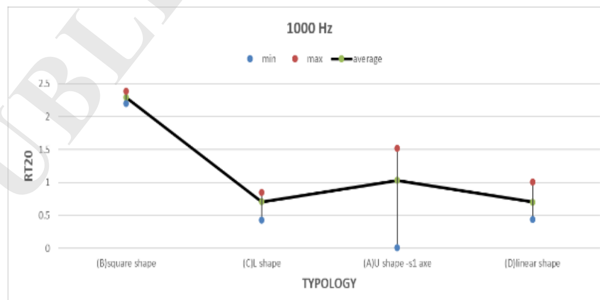
Analyzing the RT at the low frequencies (125Hz and 250Hz) are excluded in this presentation because the insufficient INR.

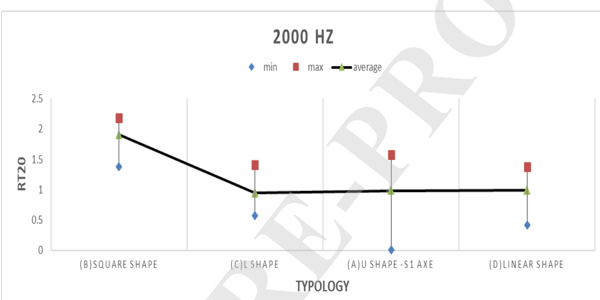
Figure 6 displays the maximum, average, and lowest RT20 values recorded at each measurement area across various frequencies ranging from 500 Hz to 8000 Hz in octave bands. This analysis aims to assess the general features and distribution of RT20 in outdoor environments.

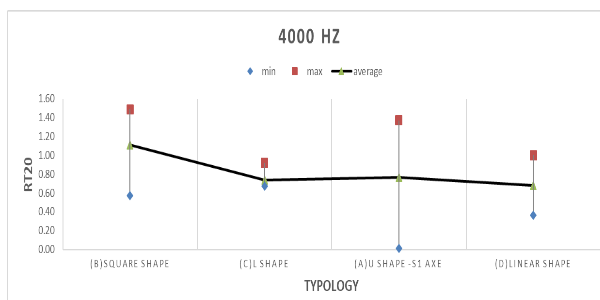
The findings indicate that there is a significant variation in RT20 between the highest and lowest values across different measurement areas, suggesting an uneven distribution of RT20 in the outdoor environment.

Building layout has a significant impact on RT20, as seen by the varying maximum, average, and lowest values of RT20 based on the measurement regions. The RT20 has considerably longer durations at frequencies of 500 Hz, 1000 Hz, and 2000 Hz when compared to other frequencies. The maximum reverberation time (RT20) occurs at a frequency of 1000 Hz for a square (□) shaped that is longer than 2.38 seconds.









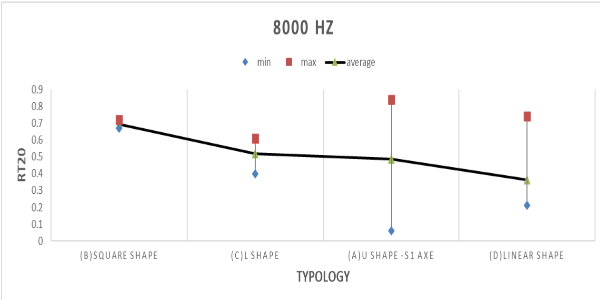


Fig. 6. RT20 values, including the maximum, average, and minimum, with their corresponding frequencies, measured at the four outdoor places, at 500 Hz; 1000 Hz; 2000 Hz; 4000 Hz; 8000 Hz.

The distance between source and receiver determines RT20 In urban settings. Therefore, the measurement of RT20 at various source receiver distances in the four measurement zones using different sources and receivers were shown in Fig. 7. Despite the consistent source-receiver distance, the findings demonstrate that there is a significant disparity in RT20 across various measurement zones. This suggests that various architectural designs may have an impact on RT20.

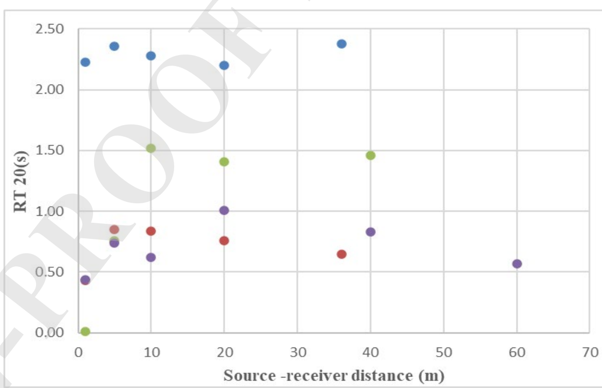


Fig. 7. The general reverberation time (RT20) at a frequency of 1000 Hz, measured at four distinct areas using varying source-receiver distances.

In conclusion, the findings referring to the distribution and general features of RT20 suggest that RT20 may be influenced by building layouts and architectural design.

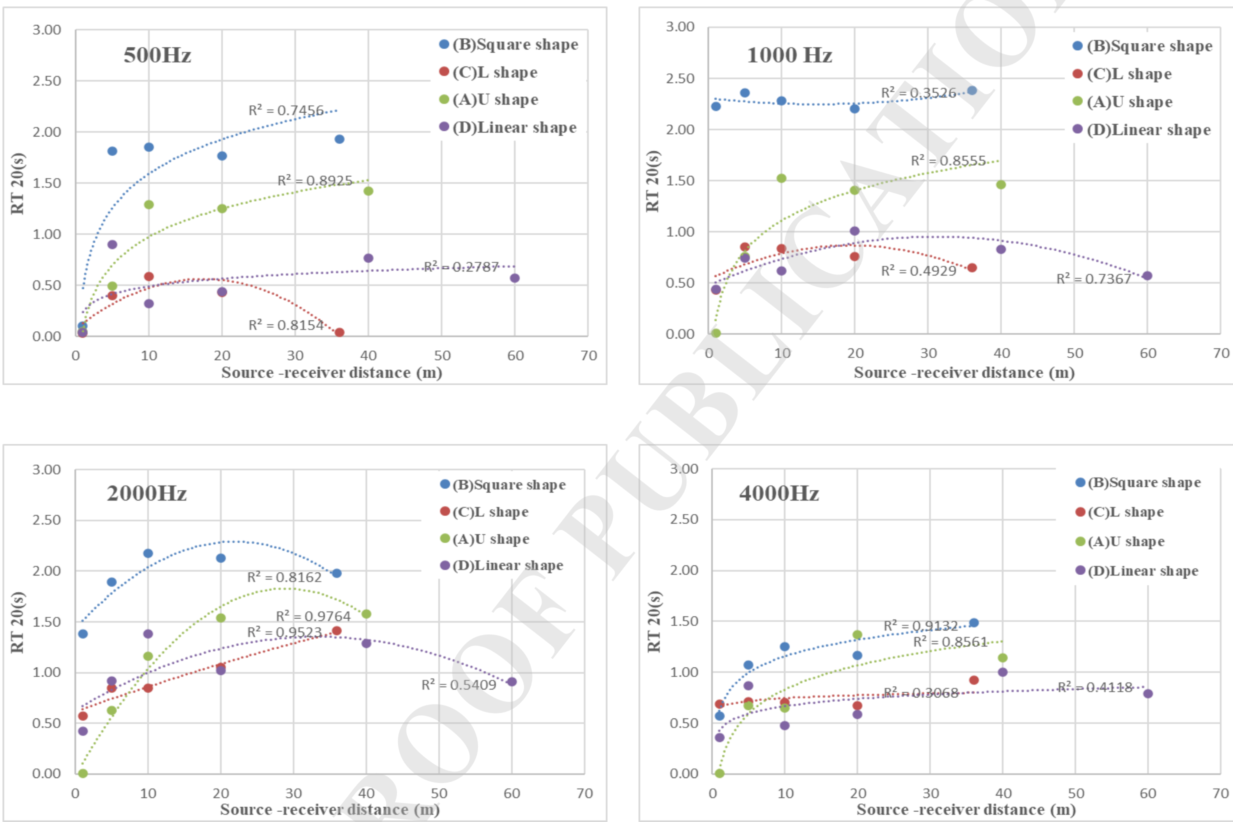
3.3. Acoustic parameters

3.3.1.Reverberation Time

Reverberation time is one of the main quantitative measures of acoustic parameters that describe the sound behavior in a space. To assess the reverberation time in outdoor spaces, source receiver distance is the determinant factor. Figure 8 displays the observed reverberation time (RT) based on the distance between the sound source and receiver for four distinct building layouts. The graph includes regression curves and correlation coefficients (R2) specifically for the frequency of 500 Hz. The determination of the calculating technique for the regression curve is based on selecting the correlation coefficient with the greatest value. For the polynomial regression curve, the equation of the 2nd order is used.

At 500 Hz, the regression curves across all typologies show a consistent pattern, increasing logarithmically or polynomially with distance. This trend likely results from the decrease in direct sound energy at shorter distances, while the amplitude of reflected sound grows at longer distances. Notably, in the L-shaped configuration, starting from a distance of 20 meters, the Reverberation Time (RT) begins to decline with increasing distance, which can be attributed to the reduced effects of reflections. The correlation coefficients (R) observed between these phenomena range from 0.52 to 0.94, signifying a strong correlation.

It is worth noting that the reverberation time (RT) values at the same source-receiver distance varied significantly among the (□), (U), (-) and (L) types. For instance, in the (□) type, the RT values were relatively strong compared to those in the (U), (-) and (L) types. This difference can be attributed to the number of facades surrounding the outdoor space. In the (□) type, where the outdoor space is enclosed by a larger number of facades, the sound reflections and reverberations are more pronounced, causing longer RT values. On the other hand, in the (U) and (L) types, which have fewer surrounding facades, the sound reflections and reverberations are less prominent, leading to shorter RT values. These variations in RT values demonstrate the significant influence of the architectural design and surrounding structures on the acoustic characteristics of the outdoor space.



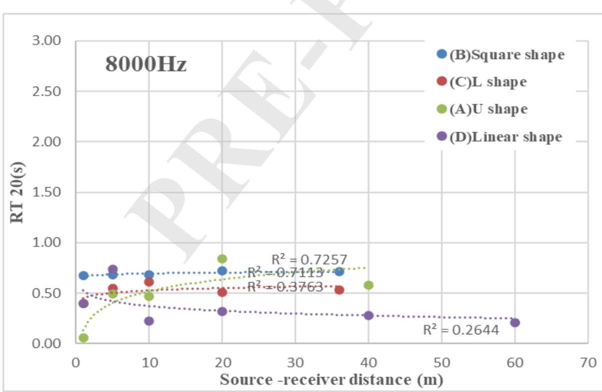


Fig. 8. RT measured based on source–receiver distance for the four different types of building layouts, with regression curves and correlation coefficients R2 at: 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz.

The observed variation in RT20 between the different courtyard shapes is consistent with Yang et *al.,* (2013) and Yang et al., (2017), who also found that reverberation characteristics change significantly with architectural configuration. In both studies, more enclosed layouts exhibited higher RT values, while more open configurations showed lower sound persistence.

3.3.2. Early decay time (EDT)

In the Fig. 9, The EDT at each measurement context is shown according to the source to receiver distances. EDT is a parameter extrapolated from the decay curve portion that spans between 0 dB and 10 dB below the initial level. Therefore, the sound energy generation from early reflections affects significantly this parameter. The result in Fig. 9 Shows that EDT tends to increase with increasing source to receiver distances (polynomialy), which is similar to RT in all outdoor spaces.

Figure 9 displays the EDT (Early Decay Time) for each measurement context, based on the distances between the sound source and the receiver. EDT is a metric extrapolated from the section of the decay curve that extends from 0 dB to 10 dB below the original level. Consequently, the creation of sound energy from early reflections has a considerable impact on this parameter. The data shown in Fig. 9 demonstrates that the (EDT) tends to rise in a quadratic manner as the distance between the source and receiver increases. This trend is consistent with the behavior of the Reverberation Time (RT) in all outdoor environments.

Similarly to Rt, the correlation coefficient falls within the range of 0.87 to 0.96, signifying a strong and clear correlation between the variables. It can also be seen that at the same source to receiver distance, EDT is similar to RT, it has different values due to the different number of facades surrounding the outdoor space. Understanding such differences is crucial for designing outdoor areas with desired acoustic qualities, whether it is to enhance sound projection and reverberation in performance venues or to ensure speech clarity in public gathering spaces.

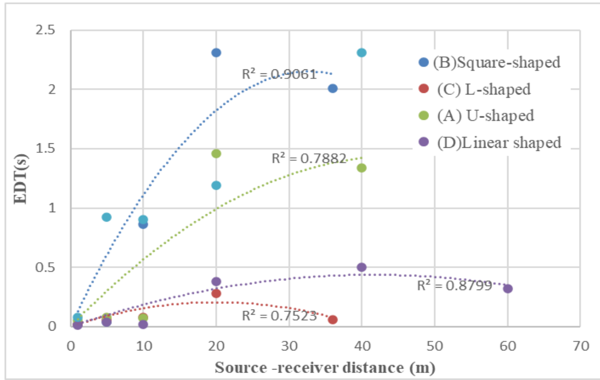


Fig. 9. Measured EDT at 500 Hz with different source to receiver distances for the four different types of building layouts.

The variation in EDT observed across courtyard shapes aligns with and Yang et al., (2017), where more enclosed configurations yielded longer early decay times due to stronger and more sustained reflections, while open layouts produced shorter EDT values.

3.3.1.Definition (D50)

The clarity of the speech is assessed using D50, a criterion that quantifies the ratio of sound energy arriving within the first 50 milliseconds to the overall sound energy, measured as a percentage.

Figure 10 displays the D50 values at various source receiver distances for the four outdoor areas. In most type spaces, like RT, D50 decrease (polynomial) with the increase of distances. That means that with increasing distances the clarity of sound decreases. Like that of RT, the correlation coefficient of regression curves among these contexts falls within 0.50 and 0.97, indicating strength relationship between variables. At the same distance, despite the D50 is categorized within the range of good to excellent levels, the values differ in each outdoor space. for example, at 20m source receiver distance, the D50 is 0.60, 0.61, 0.89, and 0.79 in (□), (U), (L) and (-) shape respectively. This can be attributed to the varying number of facades that encompass the outdoor space. Hence, when designing outdoor spaces, it becomes crucial to consider the distinctive attributes of the building layouts that encircle these open areas.

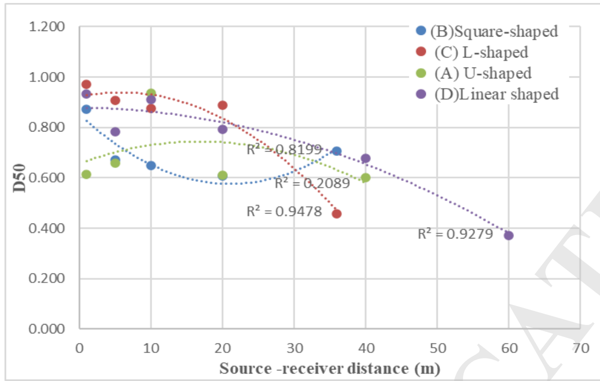


Fig. 10. D50 with different source to receiver distances for the four different types of building layouts.

The differences in D50 across configurations are consistent with and Yang et al., (2017),which reported that open courtyard forms tend to enhance speech clarity (higher D50) by reducing late reflections, whereas enclosed forms can lower clarity due to increased reverberant energy.

3.3.2.Rapid Speech Transmission Index (RaSTI)

The assessment of speech intelligibility in outdoor environments is performed using the RaSTI measure, which takes into account the distance between the sound source and the receiver. The evaluation is determined by five unique levels, with each level corresponding to a particular range. 0–0.3 is classified as extremely bad, 0–0.45 as poor, 0.45–0.6 as fair, 0.6–0.75 as good, and 0.75–1.0 as exceptional.(*IEC 60268-16:2020 | IEC Webstore*, n.d.)

According to the data shown in Fig. 11, the RaSTI generally decreases as the distance increases in most typology settings. This trend is comparable to the findings of D50. The reason for this is because while the distance between the source and receiver is small, the direct sound has a greater influence on the initial sound energy of the impulse response, leading to a shorter reverberation time (RT). However, as the distance rises, the amplitude of the direct sound decreases, causing the RT to increase.

At the same distance, despite the RaSTI is characterized within the range of good to excellent, the values vary in each outdoor space. For example, at the 20m source receiver distance, the RaSTI value is 0.6, 0.68, 0.77, 0.89 in (□), (U), (L) and (-) shape respectively. This is because of the different number of facades surrounding the outdoor space. Hence, the design of outdoor spaces must take into account the attributes of the building layouts that surround the outdoor area.

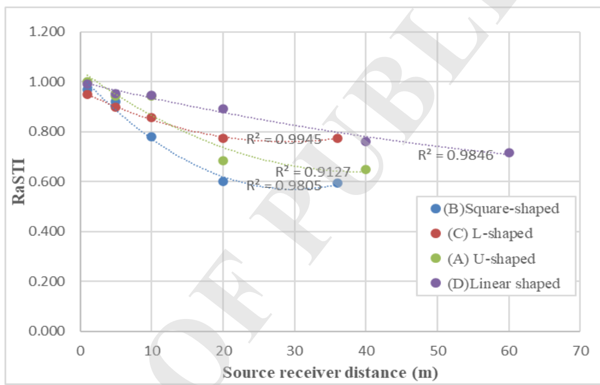


Fig. 11. RASTI with different source to receiver distances for the four different types of building layouts.

The measured changes in RaSTI with different courtyard shapes correspond with Yang et al., (2017), indicating that open configurations generally improve speech intelligibility, while more enclosed geometries may limit it due to prolonged reverberation and multiple reflection paths.

3.3.3. Sound pressure level (SPL)

Figure 12 presents the SPL attenuation results in comparison to the reference SPL, which was obtained at a distance of 1 meter between the source and receiver, in five outdoor areas. To interpret the results, the measurements were compared with the semi-free field attenuation, where sound pressure levels are expected to decrease by approximately 6 dB each time the distance from the source doubles in an unobstructed environment. This provided a reference baseline to evaluate how the presence of surrounding building façades and courtyard configurations modified sound propagation in the studied outdoor spaces. The findings indicate that SPL diminishes as the distance between the source and receiver increases in all outdoor areas, owing to the properties of the non-diffuse field. Within a distance of 1-5m between the source and receiver, there is no notable variation in sound pressure level (SPL) reduction across the five outdoor areas. This is because the direct sound plays a prominent role.

However, in the far field, at the same position where the sound source and receiver are located, it can also be seen that the sound pressure level (SPL) decreases differently depending on the outdoor arrangement and the features of the surrounding geometry. Although the linear (-) shape is surrounded by one side of building façade, it shows the lowest SPL attenuation. This is because the high sound reflections off surfaces such as bitumen and pavement ground. The SPL attenuations in (□), (U) shaped outdoor spaces are similar within the source -receiver distance of 10-20, with (□) shaped space exhibiting lower attenuation beyond that distance. This difference occurs because U-shaped spaces allow for less reflection energy compared to square (□) shaped ones. The highest SPL attenuation is revealed in the (L) shaped outdoor spaces showing a similarity with SPL attenuation in the semi free field. This because a lack of reflections toward the outdoor space. The overall outcome suggests that the architecture of the building layout has a substantial impact on the degree of noise irritation that students feel.

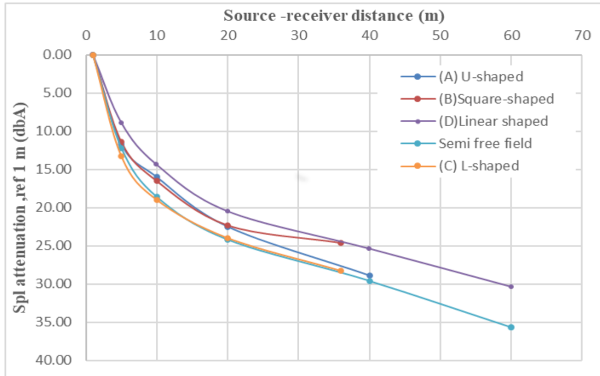


Fig. 12. SPL attenuation according to source to receiver distance.

The SPL attenuation patterns match findings from Yang et al., (2017), showing that open layouts allow sound to disperse more rapidly, leading to higher attenuation rates, while enclosed layouts slow down attenuation due to boundary reflections and energy confinement.

4. Conclusion

The present research conducted a series of field measurements to assess Sound Pressure Level (SPL) attenuation and room acoustical parameters including Reverberation Time (RT), Early Decay Time (EDT), the Rapid Speech Transmission Index (RASTI), and Clarity (D50) across four outdoor spaces within the University of Batna1. These spaces were chosen to represent diverse building layouts and blocks.

Overall, Variations in the maximum, average, and minimum values of RT20 were noted across different measurement areas, underscoring the influence of building layout on RT20 distribution. The square shape retains sound the longest, the U shape shows the most irregular reverberation, and the linear shape is the most stable. At high frequencies, all layouts have faster sound decay and less variability due to greater absorption and scattering.

similarly, as the distance between the sound source and receiver increased, the findings indicated that architectural design substantially influences the dispersion of acoustic energy. Among the many layouts examined—square, U-shaped, L-shaped, and linear—the square and U-shaped courtyards had the highest RT20 values, especially at mid-range frequencies (1000 Hz–2000 Hz), attributable to their enclosed geometry that captures sound energy. The linear and L-shaped courtyards promoted expedited sound fading, demonstrating reduced RT20 values and enhanced SPL attenuation stability, rendering them more appropriate for settings necessitating improved speech intelligibility.

The impulse response research verified that U-shaped and square layouts produced more intense reflections, resulting in extended reverberation, whilst the linear arrangement had the lowest RT20 values, indicating effective sound dissipation.

The D50 and RaSTI values were greatest in linear courtyards, indicating enhanced speech intelligibility owing to less reverberation and increased direct sound prominence. In contrast, square and U-shaped courtyards had reduced D50 and RaSTI values, indicating diminished speech intelligibility resulting from extended reverberation.

The SPL attenuation research indicated that linear courtyards had a more steady decline in SPL with distance, whereas square and U-shaped areas displayed variable SPL patterns, affected by heightened reflections inside their confined perimeters.

The results of this study highlight that building layout plays a decisive role in shaping the outdoor acoustic environment, with measurable impacts on both sound persistence (RT20, EDT) and speech intelligibility (D50, RaSTI). This knowledge can inform architectural and urban design decisions, particularly when planning courtyards, campus spaces, and other semi-enclosed outdoor areas.

For instance, layouts with more enclosed geometries, such as square and U-shaped forms, may be preferred in contexts where sound retention is desirable—such as cultural performances or ceremonial events—due to their capacity to preserve acoustic energy. Conversely, linear and L-shaped configurations, which promote quicker sound dissipation and higher speech clarity, may be better suited for everyday circulation spaces, recreational zones, or public areas where speech intelligibility and reduced noise buildup are priorities.

Furthermore, these findings provide a basis for integrating acoustic considerations early in the spatial planning process, alongside visual, thermal, and functional criteria. By anticipating how form and enclosure affect sound propagation, designers can create outdoor environments that are acoustically tailored to their intended uses.

Finally, while this study focuses on a specific university setting, the principles identified are broadly applicable to urban courtyards, plazas, and pedestrian streets. Future research could extend this work by incorporating variations in building height, façade material properties, vegetation, and seasonal changes to develop comprehensive design guidelines for acoustically optimized outdoor spaces.

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