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Improving Traffic-noise-mitigation Strategies with LiDAR-based 3D Tree-canopy Analysis

Abstract: The leaves on trees absorb road noise and serve as noise barriers. Tree structures such as tree belts and isolated trees have various methods for absorbing sounds. The depth, surface area, and noise-absorption coefficient of trees contribute to noise absorption. Therefore, this study aims to address this issue of traffic-noise pollution through the use of trees; in particular, by analyzing the noise-absorption coefficient of leaves, the surface area of the leaves, and the depths of the trees. However, the study stresses the need for 3D tree-canopy visualization to identify these factors. To achieve this, the study used LiDAR point clouds to provide accurate data for the convex hull visualizations of canopies. Additionally, a formulated equation for calculating traffic noise after absorption has been suggested by combining the traffic-noise absorption and Henk de Kluijver traffic-noise models. The study also compares the effectiveness of tree belts and isolated trees in reducing noise pollution, concluding that, below a canopy of trees, there is no noise reduction. Finally, the study has demonstrated that the number and sizes of leaves affect noise absorption, showing that noise pollution can be reduced by 1 to 3 dB(A) in the research area by using trees.

Keywords: traffic-noise pollution, trees, 3D tree-canopy visualization, LiDAR, noise-absorption coefficient

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1. Introduction

Along with air pollution, noise pollution is a serious issue in urban areas [1], as it causes health problems and reduces the quality of life [2]. Road-traffic noise pollution contributes to approximately 90% of the overall noise pollution in urban areas [3], making it essential to reduce it to protect people's health and quality of life [4]. The health of people (both mentally and physically) is thought to be seriously stressed by noise exposure [5]. Anyone who is exposed to more than 100 dB(A) for more than 15 minutes may be candidates for temporary deafness [6]; thus, strategies for reducing traffic noise are essential in urban areas [1]. A sound barrier is anything that prevents sound waves from traveling from a source to a listener [7]. A number of studies have recommended planting trees alongside roads to reduce noise pollution from vehicles in urban areas [8–10]. Roadside tree belts have long been known to have the ability to reduce noise [11]. The performance of individual trees in tree belts is significant considering their noise mitigation [12, 13]. According to the results of previous studies, the primary factors that influence the reduction of traffic noise through a tree belt are its depth, its width, and the spacing between the trees [14, 15]. Moreover, tree structure such groups of trees and tree belts are more effective than individual isolated trees in reducing traffic-noise pollution [15].

In addition to these aspects, trees' leaves are especially good at filtering out traffic noise [16]; therefore, it is important to comprehend how well trees absorb noise. Well-grown vegetation belts are effective parts of the mitigation of road-traffic noise levels [17]; therefore, the identification and recommendation of suitable pants for vegetation belts are vital [18].

The amounts of noise absorption increase as leaves get bigger and thicker [19]. A leaf's ability to absorb more noise increases with its green content [20]. Evergreen trees can function as a continuous sound barrier better than dry leaves, as they typically have dense foliage throughout the year [8, 20]. Leaves lose some of their elasticity and density when they dry out. On the other hand, dry leaves may not be as effective at reducing noise when compared to evergreen foliage [20]. Younger leaves often have higher moisture contents, are softer, and are more flexible than older leaves. In addition to covering larger areas than tree bark and branches, leaves are essential to increase noise absorption; therefore, it is important to concentrate on leaves to absorb noise [21]. This means the canopy of a tree is vital for absorbing noise.

Previous studies have identified that trees can absorb traffic noise from 5 to 10 dB(A), accounting for 10–24% of traffic-noise pollution [22]. To calculate the traffic-noise absorption of trees, however, detailed information on the trees is necessary [23]. In addition, several studies have noted how tree belts reduce road noise. This study used three different planting schemes (minimal, medium, and dense) to measure traffic-noise levels at 5, 10, and 20 m from moving cars. The results of the study are shown in Table 1. The amounts of the noise reduction with and without trees along the roadsides were indicated by the results. The noise reduction was 2, 3, and 2 dB(A) relative to the site when the tree belt width reached 5 m. Additionally, the reduction in noise was 1, 2, and 2 dB(A) relative to the site when the width of the tree belt was 10 m. Furthermore, the noise reduction with the site was 4, 8, and 6 dB(A) when the width of the tree belt was 20 m [15].

Table 1. Noise-absorption of plants

Site	At source [dB(A)]	Difference between source and at 5 m [dB(A)]	5 m from source [dB(A)]	Difference between 5 m and 10 m	10 m from source [dB(A)]	Difference between 10 m and 20 m [dB(A)]	20 m from source [dB(A)]	Total reduction [dB(A)]
Minimal planting scheme	78	1	77	2	75	1	74	4
Sparse to medium planting scheme	73	3	70	3	67	2	65	8
Dense planting scheme	67	2	65	2	63	2	61	6

This study presents a discussion on the identification of tree-based noise absorption. Still, there is a problem in identifying noise absorption. In this study, a sound-level meter was used to measure noise levels (even though a number of factors affect how noisy roads can be). However, these types of studies lack a suitable formula for determining whether trees absorb noise when they are in tree belts or not. For the sake of research accuracy, it is preferable to determine the level of road-traffic noise using standard noise equations [24]. However, there are a number of variables that affect both the noise-absorption capacity of trees and the noise of road traffic. To identify the noise absorption by trees, the current study attempted to close this research gap by combining an equation for noise absorption with one for road-traffic noise. It is important to measure traffic-noise levels before determining how much noise is absorbed by trees [14].

The primary determinants of road-traffic noise levels are vehicle traffic flow, vehicle speed, noise absorption by the air and ground, noise reflection, and environmental factors. Road-traffic noise calculations can be performed using a number of different types of noise models, including the Henk de Kluijver model [25], the Stop and Go model in Bangkok, the RLS-90 model in Germany, and the CoRTN road-traffic noise model in the United Kingdom. Additionally, a number of studies have been linked to the most recent models for calculating road-traffic noise, such as the statistical pass-by method (SPB-ISO) with the close proximity index (CPX) and the CNOSSOS-EU model [26, 27]. Even though a lot of research has been performed to pinpoint the sources of road-traffic noise pollution [1, 28], a number of studies have also discussed how trees absorb noise

Therefore, this paper tries to develop a method that uses noise absorption and road-traffic noise levels to identify tree noise absorption. To further identify the noise absorption by trees, the research [29] developed an equation that can be inserted to identify the noise absorption by the leaves of trees [13, 29]. To find the noise absorption by trees, the next challenge is to insert this equation. The noise-absorption coefficient of leaves is vital for absorbing road-traffic noise. The primary elements of leaves that absorb noise are their sizes, thicknesses, and textures [19, 29]. Furthermore, the surface area of the leaves in a tree canopy and the depths of the tree canopies are prime for noise absorption. Furthermore, green leaves play a better role in absorbing noise when compared to dry leaves [30].

2. Research Background

Previous research has indicated scientific approaches for determining the noise-absorption coefficient of leaves; this coefficient depends on the sizes, thicknesses, and textures of leaves. According to these primary elements, the noise-absorption coefficient varies [29]; however, discussions are still being developed to identify the surface areas of the leaves of tree canopies and the depths of tree canopies.

The 3D modeling of trees is essential in determining critical information about trees, such as the surface area of the leaves and the depths of the trees [29, 31]. A detailed three-dimensional (3D) model of a tree is needed to capture the unique characteristics of each tree and the environment in which it is situated [32]. Three-dimensional modeling incorporates x-coordinates, y-coordinates, and z-coordinates into mapping, and light detection and ranging (LiDAR) point clouds from tree canopies support precise canopy detection [33, 34]. However, modeling tree canopies from LiDAR point clouds remains an issue [35] that requires a demonstration to find a solution to these problems [36].

Creating 3D surfaces on tree canopy, it is possible to determine the depth of a tree canopy and the surface area of the leaves using LiDAR point clouds [36]. While accurately identifying the surfaces of leaves and the depth of a tree canopy remains a challenge, a number of studies have proposed 3D surface modeling using LiDAR point clouds [36]. In order to address the aforementioned problems, this study uses an equation for noise absorption and an equation for road-traffic noise to try and determine the amount of noise absorption by trees with 3D tree-canopy modeling. Further, this study focuses on identifying noise absorption through the performance of the structures of trees.

2.1. Equation Formulation

Tree canopies along roadways and in front of building facades act as barriers for absorbing traffic noise [10]. To identify the noise levels on the facades of buildings, the traffic-noise levels of vehicles should be calculated [37]. Then, reducing the noise absorption of the canopies from the traffic noise of the vehicles is vital for identifying the final traffic-noise levels [8]. Therefore, a standard and accurate traffic-noise equation should be integrated to calculate the traffic-noise and noise-absorption levels. The number of vehicles, speed of the vehicles, types of vehicles, noise reflection, noise reduction with distance, noise absorption by grounds, and weather conditions are the main influences for traffic noise [35]. Therefore, the Henk de Kluijver traffic-noise model is vital for calculating traffic-noise levels.

Equation (1) [25] shows that:

$$L_{\text{Aeq}} = E + C_{\text{optrek}} + C_{\text{reflectie}} - D_{\text{afstand}} - D_{\text{lucht}} - D_{\text{bodem}} - D_{\text{meteo}} - D_{\text{barrier}} \tag{1}$$

where:

L_{Aeq} – the average noise level,
E – the noise emission,
C_{oprek} – the noise emission from vehicle braking and accelerating,
$C_{\text{reflectie}}$ – the reflection noise,
D_{afstand} – the reduction of noise over distance,
D_{lucht} – the reduction of noise due to absorption by air,
D_{bodem} – the ground absorption,
D_{meteo} – the noise reduction by weather,
D_{barrier} – the noise reduction by barriers along a road.

The surface area of the leaves, the depth of the tree, the noise-absorption coefficient of the leaves, and the frequency of the traffic noise affect the noise absorption of the tree. An equation has formulated an equation for calculating noise absorption by trees.

Equation (2) [29] shows that:

$$A = -10\log\left(1 - \frac{G \cdot F \cdot L \cdot f^{0.5}}{8}\right) \tag{2}$$

where:

G – the coefficient (the frequency-absorption factor of leaves),
F – the surface area of the leaves for unit volume,
L – the depth of the tree,
f – the frequency of the road-traffic noise.

By compiling Equations (1) and (2), final noise levels (F_{dB}) equal road-traffic noise levels minus noise absorption by canopies of trees (leaves). Equation (3) shows the final noise level:

$$F_{\mathrm{dB}} = E + C_{\mathrm{optrek}} + C_{\mathrm{reflectie}} - D_{\mathrm{afstand}} - D_{\mathrm{lucht}} - D_{\mathrm{bodem}} - D_{\mathrm{meteo}} - D_{\mathrm{barrier}} - \\ - 10\log\left(1 - \frac{G \cdot F \cdot L \cdot f^{0.5}}{8}\right) \tag{3}$$

2.2. Tree-canopy Detection

Terrestrial laser scanning (TLS) refers to light detection and ranging (LiDAR). LiDAR detects the *x*, *y*, and *z* coordinates of objects by emitting laser pulses toward them and detecting the distances between the terrestrial laser scanner and the objects. LiDAR technology works in the same way as airborne laser scanning (ALS), mobile laser scanning (MLS) and TLS [38]. TLS is a ground-based observation method that rapidly acquires accurate 3D point clouds of objects on the ground. Most green space inventories are based on a combination of TLS and ALS [39]. MLS also works quite well; however, this relies on the user's experience [40].

TLS can be used to obtain detailed information about the properties of trees, such as the depth of the trees, area of the canopy, and canopy volume [41]. However, 3D tree visualization is essential for deriving the area and volume of the canopy [42]. Observing line-shaped 3D objects is not an issue for TLS, but there is a small issue in acquiring circle-shaped objects by TLS. On the other hand, TLS works with most tree-modeling applications, including urban-planning and tree-based environmental applications such as air and noise [43].

Identifying the surface areas and volumes of canopies and the depth of the canopies are vital for deriving the absorption of traffic noise by tree canopies [42]. Most tree canopies are circle-shaped; therefore, detecting all of the details of a canopy by the one-time scanning of TLS is not possible. At least three TLS stations are vital for detecting the full details of trees [39]. However, there is an issue when calculating the size of the leaves and the number of leaves based on the resolution of the LiDAR point clouds being higher [41]. However, compiling 3D point clouds of canopies to a 3D visualization enhances the accuracy of the details of the canopies [44].

2.3. 3D Convex Hull

Identifying the depths of trees is not an issue, but calculating the surface area of the leaves for the unit volume of the canopy remains an issue [34]. Three-dimensional tree modeling is a significant solution for determining the surface area of the leaves [31]. Embedding LiDAR point clouds to a surface fitting is one method for visualizing the canopies of trees; thus, the surface area of the leaves can be calculated. Unfortunately, these methods are not more accurate [45], but they are good enough to identify and compare traffic-noise absorptions by canopies. Triangular irregular networks (TIN), hulls, and voxels are widely used to create surfaces from point clouds [34, 42].

TIN provides crowded edges for 3D point clouds and goes from the surface to the inner portions of the point clouds [46]. This means that TIN provides an inaccurate surface area of 3D point clouds. Additionally, the voxel provides the overestimated surface of point clouds [42]. Moreover, the gaps in a canopy structure are eliminated in the voxel representation. The convex hull method minimizes the vertex of the points on the surface; it takes only the outer surface of points to create surfaces in 3D point clouds. Furthermore, it does not embed with the inner points (such as with TIN) to create the surfaces [46]. Therefore, the convex hull is prime for visualizing tree canopies; this visualization can be used to determine the surface areas of the leaves of the canopies in unit volumes [34]. Figure 1 illustrates the convex hull visualization of a tree canopy [42].

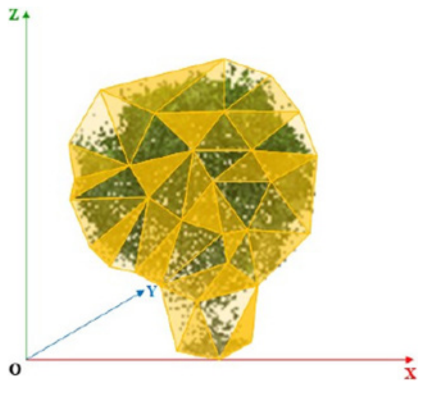

Fig. 1. Visualization of convex hull of tree canopy

Source: [42]

3. Materials and Methods

3.1. Study Area

This study was carried out to determine traffic-noise levels and the noise absorption by trees around the faculty buildings of Universiti Teknologi Malaysia (UTM). The location of the study area was 1°33’37.6”N 103°38’16.4”E. There is typically higher traffic-noise pollution in the mornings and evenings; therefore, it is vital to find solutions to mitigate traffic-noise levels. There are several areas of trees along the roads and surrounding the buildings. When considering traffic-noise absorption, the canopies of trees are vital [47]. Therefore, identifying the influence of trees on traffic-noise levels is primary. In all, 11 sets of trees were selected in the inner circle of UTM. Figure 2 shows the area of the research study.

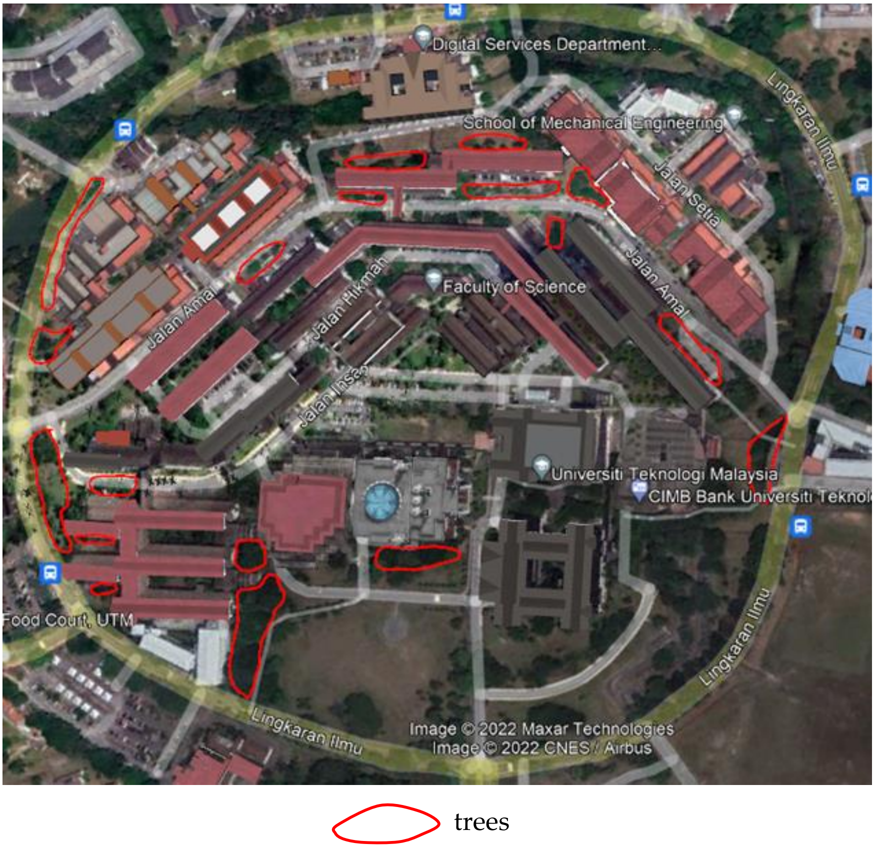

Fig. 2. Overview of study area
Source: Google Earth

3.2. Methodology

The research flow of the study is shown in Figure 3. The main objective of this research was to identify how effective trees were in noise absorption along roads and around the buildings of the university. However, there are considerable traffic-noise levels during the morning and evening periods at UTM [48]. Moring traffic-noise pollution was considered for this case study. However, the locations and arrangements of the trees on the ground affected the amounts of noise absorption [49]. Groups of trees, isolated trees, and tree belts act in different ways when absorbing noise [13]. Furthermore, the number of leaves in a tree and the nature of the leaves (size, dryness, texture, and thickness) impact traffic-noise absorption [19]. To examine all of these conditions, the trees that are shown in Figure 4 were selected. The 11 areas of trees (11 sets) were considered for examining the influence of trees on the traffic-noise observations in this research area.

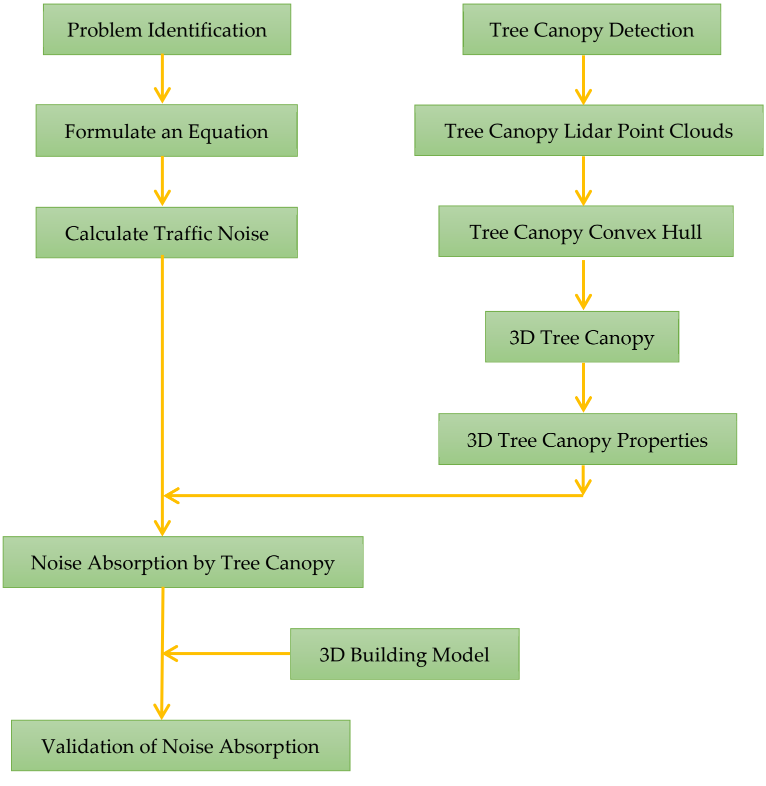

Fig. 3. Research workflow

The Henk de Kluijver traffic-noise model (Equation (1)) was used to calculate traffic-noise levels at sample road-traffic-noise observation points (see Fig. 4). The numbers of light vehicles (less than 2000 cc), medium vehicles (2000–3000 cc), and heavy vehicles (more than 3000 cc) were manually counted, and the average vehicle speed of each vehicle category was observed for our noise calculations. Cubic centimeters (cc) are the measurement of the capacities of car engines. The noise absorption by the ground, the noise reflection of the buildings on the opposite side, and the weather conditions were considered according to the elements of the equation. The noise-reflection correction was taken as +1.5 dB(A), as the buildings were continuously located along the roads [50]. When considering the absorption of noise by the grass-covered ground, the noise-absorption coefficient was taken as 1; for hard grounds, this was 0, and for the lawn prawns, this was 0.3 [51]. The equation of noise absorption (Equation (2)) was compiled for this investigation to determine the traffic-noise absorption of the trees. By incorporating Equations (1) and (2) into Equation (3), the final noise levels of the sample observation points were calculated. To validate the final noise levels (F_{dB}), real-time noise levels were observed using a sound-level meter (accuracy ±0.1 dB(A)) [52].

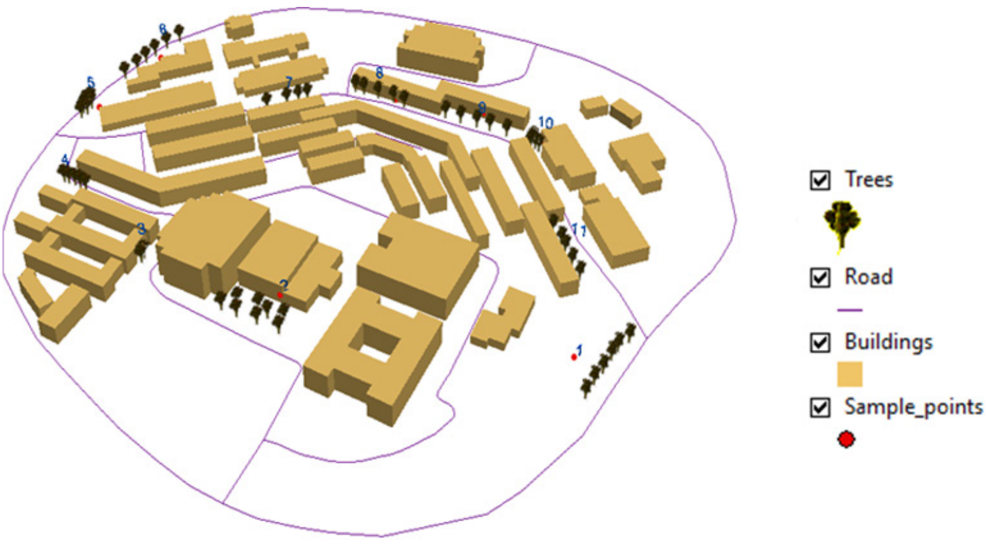

Fig. 4. Sets of trees

According to Equation (2), the frequency-absorption coefficient (G) of the leaves should be calculated; the impedance tube method is widely used for identifying G. The size, texture, and thickness of the leaves affect this coefficient [29]. First, the noise-absorption coefficient of the leaves should be calculated to determine the coefficient G. Equation (4) can be used to calculate G:

$$\alpha_m = G \cdot f^{0.5} \tag{4}$$

where:

f – frequency of traffic noise,
α_m – noise-absorption coefficient of leaves [29].

The traffic-noise frequency ranged from 500 to 1000 Hz [53]; thus, the frequency of the traffic noise was considered to be 1000 Hz in this study. Generally, the average noise-absorption coefficient (α_m) is about 0.5 for leaves [19]. Thus, α_m was assumed to be 0.5 in this case study. Moreover, a laser-scanning survey was conducted to identify the surface area of the leaves in unit of volume (F) and the depth of the trees (L).

To accurately detect the tree canopies, three or four laser scanning were used for each tree set. The Topcon GLS-2000 terrestrial laser-scanning instrument was used to measure the tree canopies in 3D. For this survey, the cloud-to-cloud method was used to register the whole project. Around the trees, the laser scanner was positioned three or four times. During the LiDAR data-processing, each position was scanned, and these scans were registered together to create a representation of a 3D point cloud. MAGNET College software was used for the LiDAR data-processing. After generating the 3D point clouds, the trees were extracted from the point clouds, and then the 3D convex hull method was used by the MeshLab software to visualize the canopy of the trees to determine *F* and *L*.

The 3D building model of the research area was designed to show the locations of the noise points and the locations of the tree sets. The drone image point clouds were used to capture 3D buildings, and the Pix4dMapper software was used to process the drone images to SfM point clouds. Furthermore, ArcGIS Pro and Civil 3D software was used to design the 3D buildings of UTM's inner circle. The traffic-noise levels, canopy noise absorption, and actual noise values (measured by using a DEKKO SL-130 noise-level meter) on each sample point were considered for comparison. As precautions, the complete canopy of a tree was considered between the noise source and the sample noise points to determine its noise absorption.

4. Results and Discussion

According to Figure 4, sets of trees (1–11) were selected to measure how effective trees were at reducing traffic-noise pollution. Tree Set 1 was located as a tree belt (see Fig. 5). A tree was selected that corresponded to the sample noise observation points in order to examine the noise absorption.

Fig. 5. Tree Set 1

The noise observation point was selected under the canopy of the tree. The noise absorption of Tree 1 according to the equation of noise absorption equals 1.5 dB(A). The weighted decibels (dB(A)) level of Point 1 (value from the Kluijver noise model) equals 57.4 dB(A). The weighted decibels level of Point 1 (value from the noise meter) equals 57.1 dB(A). However, there were no changes in noise mitigation when the noise-observation point was under the canopy of the tree.

According to Figure 6, the whole group of trees was taken as one unit. Furthermore, the trees were placed as belts with different rows from the road's edge; this meant that one tree was covered by another tree that indicated that two trees were growing over one another perpendicular to the road's edge. The noise absorption of Tree 2 equals 1.2 dB(A). The weighted decibels level of Point 2 (value of the Kluijver noise model) equals 63.9 dB(A). The weighted decibels level of Point 2 (value from the noise meter) equals 61.3 dB(A). Thus, 1.2 dB(A) < 63.9 dB(A) − 61.3 dB(A) (tree belts) = 2.6 dB(A). Point 2 was on the facades of the building. There was an impact to mitigate the traffic-noise levels due to the tree belt and grouped trees; however, there was a reasonable difference between the noise-absorption value (1.2 dB(A)) and the difference of 2.6 dB(A)). This meant that this proposed method was not more effective in identifying noise mitigation from grouped trees.

Fig. 6. Tree Set 2

According to Figure 7, this was an isolated tree. The noise absorption of Tree 3 equals 1.6 dB(A). The weighted decibels level of Point 3 (value from the Kluijver noise model) equals 67.6 dB(A). The weighted decibels level of Point 3 (value from the noise meter) equals 64.3 dB(A). Thus, 1.6 dB(A) < 67.6 dB(A) – 64.3 dB(A) = 3.3 dB(A). Point 3 was on the facades of the building. Since 1.6 dB(A) < 3.3 dB(A), this proposed model was effective in reducing the noise mitigation from the isolated trees. This canopy of the tree consisted of a greater number of leaves.

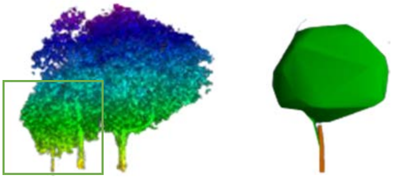

Fig. 7. Tree Set 3

Similar to the above process, one tree of the tree belt was selected to examine its traffic-noise absorption. The noise absorption of Tree 4 equals 2.6 dB(A). The weighted decibels level of Point 4 (value from the Kluijver noise model) equals 63.8 dB(A). The weighted decibels level of Point 3 (value from the noise meter) equals 60.1 dB(A). Thus, 2.6 dB(A) < 63.8 dB(A) – 60.1 dB(A) (tree belts) = 3.7 dB(A). This meant that there was a positive impact to minimizing the traffic-noise levels through the tree belts.

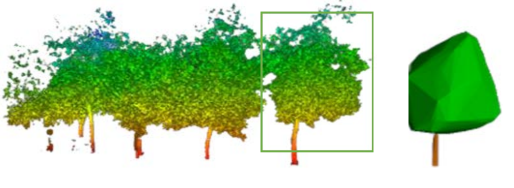

Fig. 8. Tree Set 4

According to Figure 9, a corresponding tree with noise-observation points in the tree belt was selected to identify the absorption of the traffic noise. However, the noise-observation point was below the canopy of the tree. According to the results, the noise absorption of Tree 5 equals 2.3 dB(A). The weighted decibels level of Point 5 (value from the Kluijver noise model) equals 60.1 dB(A). The weighted decibels level of Point 5 (value of the noise meter) equals 63.3 dB(A). However, there was no traffic-noise mitigation under the canopy.

Fig. 9. Tree Set 5

The noise-observation point was located below the canopy of the trees. A tree was selected to identify the noise absorption by canopies. As a result, the noise absorption of Tree 6 equals 2.8 dB(A). The weighted decibels level of Point 6 (value from the Klujiver noise model) equals 67.8 dB(A). The weighted decibels level of Point 6 (value of the noise meter) equals 69.1 dB(A). However, there was no noise mitigation under the canopy.

Fig. 10. Tree Set 6

According to Figure 11, a tree was selected that corresponded to the noise-observation point to identify the performance of its noise absorption. However, there were fewer leaves on this tree. The noise absorption of Tree 7 equals 2.8 dB(A). The weighted decibels level of Point 7 (value from the Kluijver noise model) equals 68.8 dB(A). The weighted decibels level of Point 7 (value of the noise meter) equals 67.3 dB(A). Thus, 2.8 dB(A) > 68.8 dB(A) − 67.3 dB(A) = 1.5 dB(A). The leaves the main role of absorbing the noise. There was a considerable difference between 2.8 dB(A) and 1.5 dB(A).

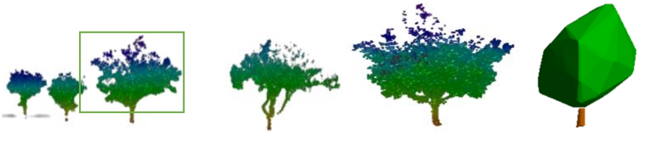

Fig. 11. Tree Set 7

According to Figure 12, a tree was selected in the tree belt. However, the sizes of the leaves were slightly bigger. The noise absorption of Tree 8 equals 1.4 dB(A). The weighted decibels level of Point 8 (value from the Kluijver noise model) equals 70.2 dB(A). The weighted decibels level of Point 8 (value of the noise meter) equals 67.9 dB(A). Thus, 1.4 dB(A) < 70.2 dB(A) − 67.9 dB(A) = 2.3 dB(A). There was a positive impact on the mitigation of the traffic-noise absorption by the canopy.

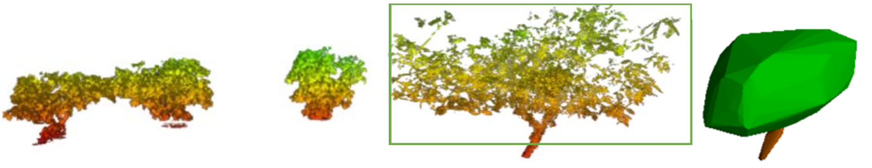

Fig. 12. Tree Set 8

According to Figure 13, a tree was selected in the tree belt. The noise absorption of Tree 9 equals 1.6 dB(A). The weighted decibels level of Point 9 (value from the Kluijver noise model) equals 67.4 dB(A). The weighted decibels level of Point 9 (value of the noise meter) equals 65.3 dB(A). Thus, 1.6 dB(A) < 67.4 dB(A) − 65.3 dB(A) = = 2.1 dB(A). There was a positive impact on the mitigation of the traffic-noise levels by the tree belt.

Fig. 13. Tree Set 9

According to Figure 14, two trees were selected from Set 10; Tree 2 was located behind Tree 1. Here, Trees 1 and 2 were taken as separate canopies to examine their respective noise absorption. The noise absorption of Tree 10(1) equals 2.2 dB(A), while the noise absorption of Tree 10(2) equals 1.7 dB(A). The weighted decibels level of Point 10 (value of the Kluijver noise model) equals 71.6 dB(A). The weighted decibels level of Point 10 (value from the noise meter) equals 68.9 dB(A). Thus, 2.2 dB < 71.6 dB(A) − 68.9 dB(A) (tree belts) = 2.7 dB(A). For the Tree 10(2), it is 1.7 dB(A) < 71.6 dB(A) − 68.9 dB(A). However, the total noise reduction of the trees (2.2 dB(A) + 1.7 dB(A)) was not equal to the noise reduction of Point 10 (71.6 dB(A) − 68.9 dB(A)).

Fig. 14. Tree Set 10

According to Figure 15, a tree was selected in tree belts. The noise absorption of Tree 11 equals 1.8 dB(A). The weighted decibels level of Point 11 (value from the Klujiver noise model) equals 65.1 dB(A). The weighted decibels level of Point 11 (value from the noise meter) equals 61.9 dB(A). Thus, 1.8 dB(A) < 65.1 dB(A) − 61.9 dB(A) = = 3.2 dB(A). There was a positive impact on the mitigation of the traffic-noise levels by the tree belt.

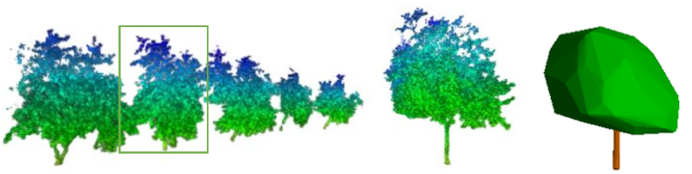

Fig. 15. Tree Set 11

The impact of trees to mitigate traffic-noise pollution is vital (according to the results from Figures 5–15). In particular, the leaves of trees are vital for absorbing traffic noise according to the results of Figures 7, 11, and 12. Thus, increasing the numbers of trees along roads is a less-expensive and more-effective method for managing and controlling traffic-noise pollution. The characteristics of leaves (such as their size, thickness, and texture) are vital for absorbing noise; this means that the noise-absorption coefficient of leaves depends on these elements. Because leaves spread across a wider area than bark and branches, the canopy of a tree impacts noise absorption. However, there is no reduction in traffic noise below the canopies of trees according to the results from Figures 5, 9, and 10. Compiling the Kluijver noise model and the equation of noise absorption (the proposed method) provided a significant approach to calculating the final traffic-noise levels after absorption. In addition, embedding a convex hull visualization of the canopies provided the facilities to extract parameters like the depths and surface areas of the leaves, which were needed to calculate the traffic-noise absorption. Tree belts are more effective in minimizing traffic-noise pollution (according to the results from Figures 8, 13, and 15). An arrangement of trees, say, that are parallel to the edge of the road, as one behind another may be affected when mitigating traffic-noise pollution. However, this proposed method does not provide accurate results for these incidents. Isolated trees are less effective for noise absorption than tree belts are. The accuracy of elements such as the depths of trees and the surface areas of leaves are major influences in calculating noise absorption. Identifying the depths of canopies by LiDAR is an easy process; however, 3D tree visualization is a must for determining the surface areas of leaves. Traffic-noise frequency affects noise absorption; however, the frequency of traffic noise is not constant and varies from time to time. Therefore, the application of the maximum frequency of traffic noise is vital for determining the maximum absorption of traffic noise by leaves.

5. Conclusions

Road-traffic noise pollution is a major problem in urban areas and can have negative effects on human health, including sleep disturbance, stress, and cardiovascular disease. Trees can act as natural sound barriers, and their leaves play a significant role in absorbing traffic noise. There are various tree structures that can be used to reduce traffic noise, including tree belts, tree groups, and isolated trees. The only objective of this study was to determine how well the tree structures reduced traffic noise. On the other hand, it could be developed when determining the height, width, and spacing between trees in a tree belt so as to absorb noise better (according to the findings of this current study).

However, accurate calculation of the noise-absorption coefficient of leaves is essential for effective noise mitigation. The depths of trees, the surface areas of leaves (in unit volume), and the noise-absorption coefficients of leaves are also critical factors that affect noise absorption. Furthermore, the size, thickness, age, moisture content, dryness, and greenness of leaves all affect how much noise they can absorb. Furthermore, the noise-absorption coefficient of leaves is altered in response to these conditions. Instead of using a single value, the noise-absorption coefficient of each leaf should be determined (if possible). It is possible to accurately identify the noise absorption of trees; therefore, it is possible to determine which trees best absorb road noise. In addition to their surface area, the noise-absorption coefficient of leaves is also an essential factor that affects noise mitigation. The frequency of a sound plays a crucial role in the noise-absorption coefficient of leaves. According to the equation of noise absorption, examining the noise-absorption coefficient of leaves under different frequencies in an impedance tube and taking an average value is important. However, it has been suggested that examining the actual noise-absorption coefficient of leaves for each tree may enhance the accuracy of the noise absorption rather than taking an average value.

In recent years, 3D trees visualization has emerged as a promising technique to for accurately determining the depths of trees and the surface areas of leaves. Tree-modeling applications based on terrestrial laser scanning (TLS) have been shown to be effective in obtaining detailed information about the properties of trees, such as the depths of trees, the areas of canopies, and the volume of canopies. Moreover, 3D visualization can enhance the accuracy of the details of the canopies, making it a significant solution for determining the surface areas of leaves. To detect 3D trees, this study employed the TLS method; however, it is more efficient to combine the TLS and ALS approaches for 3D tree detection to precisely detect all of the information.

Unfortunately, the accurate measurement of the actual surface areas of leaves is still a challenge. One approach is to embed LiDAR point clouds to a surface-fitting method (such as a convex hull) to create surfaces from point clouds. This method has been shown to be more accurate than other surface-fitting methods such as the triangular irregular network (TIN) or voxel methods. Nevertheless, more research is needed to improve the accuracy of surface-area calculation for leaves. Because of this surface fit with the outer points of point clouds, however, the 3D convex hull method overestimates 3D tree canopies. As a result, a tiny point cloud gap is removed from this. As a precaution, the 3D concave hull approach can be recommended. However, designing a 3D concave hull surface for 3D point clouds poses issues. The method of convex hull and concave hull surface-fitting for 3D tree point clouds is shown in Figure 16 [34].

a) b)

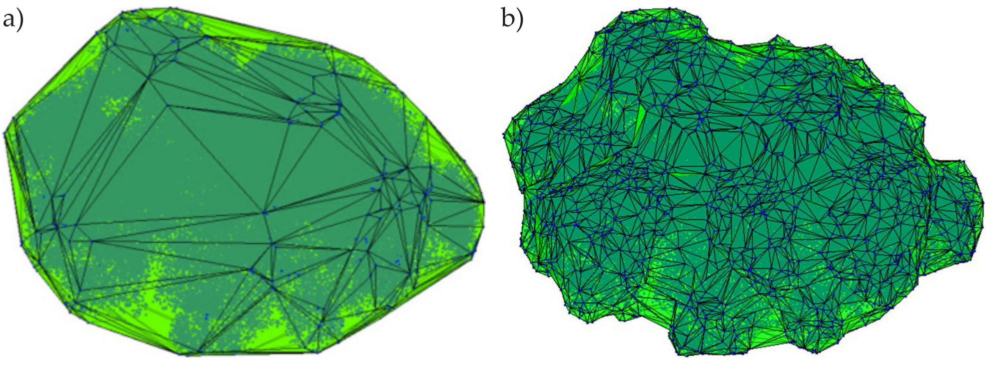

Fig. 16. Convex hull canopy (a); concave hull canopy (b)

In the current study, a tree in a tree belt that is situated between a noise source and a noise receiver (noise observation) was chosen to examine noise absorption. Therefore, this study was meant to compare the ability of a tree to absorb noise when it is located in a tree belt versus when it is isolated. It was found that a tree absorbs more noise when it can locate a tree belt. This technique can also be extended to find the characteristics of tree belts that absorb noise. In addition to this, the methods of this study may be developed to identify the noise absorption by groups of trees.

As a future research direction, 3D traffic-noise visualization could be embedded with 3D tree visualization to enable the 3D visualization of traffic-noise levels on building facades with traffic-noise absorption by trees. This would provide a more comprehensive understanding of the effectiveness of noise-mitigation measures in urban areas. In conclusion, the accurate measurement of the depths of trees, the surface areas of leaves in unit volumes, and the noise-absorption coefficients of leaves are critical for effective noise mitigation in urban areas. Three-dimensional tree visualization and impedance tube measurements are promising techniques for accurately determining these parameters. Future research should focus on improving the accuracy of calculating the surface areas of leaves and exploring new approaches for combining 3D tree and traffic-noise visualizations.

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3D GIS Research Lab at Universiti Teknologi Malaysia.

CRediT Author Contribution

N. W.: method, software, design analysis, model, writing, conceptualization and identification, 3D visualization, and validation.

U. U.: oversight, planning, validation, verification of research gaps, editing and review, project management, and obtaining funding.

S. A.: oversight, project administration, writing–review and editing and funding acquisition.

Declaration of Competing Interest

The corresponding author attests, on behalf of all authors, that no involvements exist that could give rise to concerns about bias in the work reported, or in the conclusions, implications, or viewpoints expressed.

Data Availability

Requests for access to the datasets generated and/or analyzed in this research will be considered upon inquiry to the corresponding authors.

Use of Generative AI and AI-assisted Technologies

This research did not involve the generation of AI-generated results.

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