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Traffic Noise Absorption and Propagation in A Three-Dimensional Spatial Environment

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Abstract

The impact of noise barriers on noise propagation is vital for traffic noise calculations and visualizations. Noise barriers create a major noise reduction. Green belts are the most common type of noise barrier to mitigate road traffic noise. The width, height, and surface area of leaves a green belt, as well as the noise absorption coefficient of leaves, are vital for noise absorption. This review aims to compare the characteristics and performance of green belts barriers built for traffic noise reduction. Individual tree canopies play the main role in absorbing noise in green belts. Therefore, identifying the canopy's properties is important. The side scan and nadir scan from the LiDAR survey were used to detect the tree canopy points cloud. The voxel-based, convex hull, and concave hull methods are used to visualize tree canopies in three-dimensional (3D). Concave hull provides an extract fitting surface than convex hull visualization. However, these hull surfaces do not provide accurate estimation of surface area of leaves. Further, voxel-based horizontal layers through the voxel-based profiling describes a significant method to calculate surface area of leaves in tree canopies. Establishing green belts as barriers is more cost-effective, making the former better for developing countries.

1. Introduction

Road traffic noise is a major contributor to overall noise pollution (Subramani et al., 2012) and traffic noise creates 90% of urban noise pollution (Gilani & Mir, 2021; Halim et al., 2018; Islam et al., 2021; Kurakula & Kuffer, 2008). Noise barriers are the major form of noise reduction in sound propagation areas (Can et al., 2008; Guarnaccia et al., 2012). Traffic noise travels in all directions from the source point, so it affects a 360-degree range (Almansi et al., 2024; Huang et al., 2018; Wickramathilaka et al., 2023). Therefore, the three-dimensional visualization of noise barriers is vital for predicting the performance of noise barriers (Dubey et al., 2022; Pamanikabud & Tansatcha, 2009). Recently, traffic noise visualization scenarios have been implemented using noise-reduction barriers in urban areas (Jamrah et al., 2006; Murthy et al., 1970; Peng et al., 2021; Tobollik et al., 2019; Yang et al., 2020). Trees can be used as noise barriers along roads. Especially tree leaves absorb road traffic noise (Wickramathilaka et al., 2024).

The structures of trees such as group of trees, isolated trees and tree belts act as different ways to block the noise (Wickramathilaka et al., 2024). Tree belts along roads have long been identified as having noise reduction potential than other tree structures (Van Renterghem, 2014; Wickramathilaka et al., 2024). The width and height of a tree belts are impact to reduce noise (Wickramathilaka et al., 2024). However, the performance of individual trees in tree belts is significant in terms of noise mitigation. In particular, tree leaves absorb road traffic noise (Karbalaei et al., 2015; Kowalska-Koczwara et al., 2021; Samara & Tsitsoni, 2011; Tang & Ong, 1988), and the amount of noise absorption depends on the noise absorption coefficient of the leaves, their surface area of leaves, and the depth of tree (Watanabe & Yamada, 1996). The noise absorption coefficient of the leaves varies with the size, texture, and thickness of the leaves. In addition, as the leaves become wider and thicker, so does the amount of noise absorption (Joshi et al., 2013). The amount of greenery in a leaf improves its capacity to absorb sound (Jang, 2023). Because they usually have dense foliage all year round, evergreen trees are better suited to serve as a continuous sound barrier than trees with dried leaves (Jang, 2023; Samara & Tsitsoni, 2011). When the leaves dry out, some of their flexibility and density are lost. However, compared to evergreen foliage, dry leaves might not be as successful at reducing noise (Jang, 2023). Younger leaves often have higher moisture content, are softer, and are more flexible than older leaves. Compared to older leaves, younger leaves are often softer, more flexible, and have higher moisture content. Thus, the noise absorption coefficient depends on several factors of the leaves. Therefore, several studies have suggested an experimental method of impedance tube to identify noise absorption coefficient of leaves. This review paper shows more information about identifying noise absorption coefficient of leaves.

Furthermore, the surface area of the leaves is vital to absorb noise. It means that the canopy of the tree is prominent. The road traffic noise absorption equation describes the depth of tree is vital to absorb noise (Watanabe & Yamada, 1996), Identifying surface area of leaves is not an easy process. Because leaves spread in a 3D space. Thus, this study tries to convey information about finding the surface area of leaves to identify noise absorption. To identify the noise-mitigation performance of tree belts, it is vital to construct individual trees in a three-dimensional space using their actual dimensions. 3D visualization of a canopy is essential to identify surface area of leaves, and depth of trees accurately. Therefore, this study demonstrates the visualization of the 3D tree and their accuracy comparison for traffic noise absorption. But the visualization of trees is still an issue. Recently, 3D points clouds have been widely used for the visualization of tree canopies (Itakura & Hosoi, 2018; Parmehr & Amati, 2021), and a combination of terrestrial laser scanning and drone survey techniques are vital for the detection of tree canopies (Shimizu et al., 2022). Furthermore, developments of terrestrial scanning survey to identify the surface area of leaves are described in this review. The depth of the tree can be found directly from the 3D point clouds. However, there are several methods to calculate the surface area of leaves through the surface generation of the point clouds.

Furthermore, finding an exactly fitting surface with canopy point clouds enhances the accuracy of the canopy properties (Suwardhi et al., 2022). Recently, the convex hull, concave hull (Kempf et al., 2021)and voxel-based methods have been widely used for surface fitting for point clouds (Suwardhi et al., 2022). Somehow, several studies have demonstrated the convex using the slice method to identify canopy properties. The visualization of a tree canopy using a convex hull and concave hull forms a surface mesh, and a cartographic generalization of the mesh demands that a tree canopy has a real three-dimensional appearance (Li & Nan, 2021). Although several noise studies are available on mitigating traffic noise pollution in urban areas, the problem remains the same. Green areas are vital for reducing traffic noise levels through their absorption properties. In particular, tree belts are more effective in terms of noise reduction than isolated trees. If green spaces are manipulated for noise mitigation, it is essential to extract the properties of trees into 3D space. Further, the detection of tree canopies using modern survey techniques and their visualization in a three-dimensional environment are important to identify the noise reduction by trees. The main objectives of this review are to address the problems mentioned above and find applicable solutions by reviewing previous research.

2. Methodology

For this paper, two hundred (200) research papers were collected to review traffic noise absorption of trees and 3D tree visualization to identify traffic noise absorption. One hundred (100) of the best research papers were selected to review under the subtopics; Traffic noise absorption and trees, Noise absorption coefficient of trees, Tree canopy detection and visualization, Tree canopy 3D visualization, concave hull and convex hull, 3D tree visualization developments, and 3D Tree visualization object modeling. Figure 1 shows the flow chart of the methodology used in this review paper.

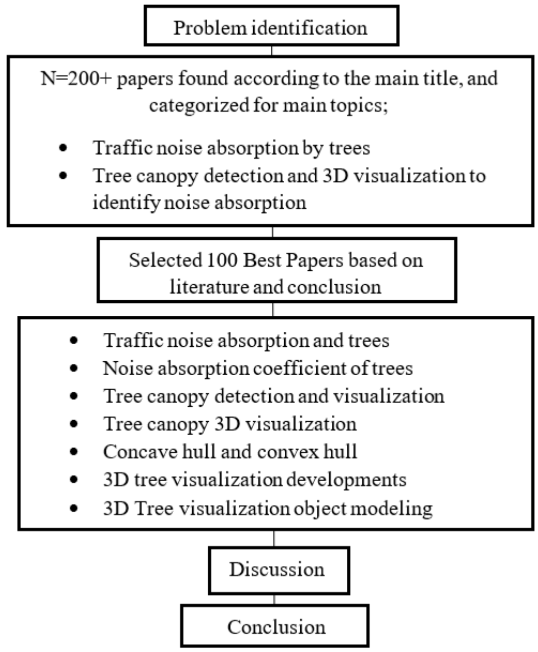


Figure 1. Flow Chart of the Methodology

3. Results and Discussion

3.1 Traffic Noise Absorption and Trees

Well-grown vegetation belts are an effective part of the mitigation of road traffic noise levels (Maleki et al., 2010). Therefore, the identification and recommendation of suitable plants for vegetation belts are vital (Pathak et al., 2011). Traffic noise is reduced by 50% when vegetation is improved from minimum to moderate vegetation density, and when vegetation barriers increase from moderate to dense, this can reduce noise by 9 dB(A)-11 dB(A). A 5 m deep vegetation belt was identified to be the general depth needed to mitigate of traffic noise (Ow & Ghosh, 2017). Previous research has shown that trees can absorb 5 to 10 dB(A) of road noise, which 10–24% of the pollution caused by traffic noise (Li & Xie, 2021). To determine the trees' ability to absorb traffic noise, comprehensive data about the trees is required (Kalansuriya et al., 2009). Furthermore, several studies have shown that road noise is reduced by tree belts.

This study measured traffic noise levels at 5, 10, and 20 meters away from moving cars using three different planting schemes: minimal, medium, and dense. Table 1 shows the research findings. The findings showed how much noise reduction along the roadsides with and without trees. At 5 m, the width of the tree belt, the noise reduction was 2, 3, and 2 dB(A) in relation to the site. Furthermore, at a tree belt width of 10 m, the reduction in noise was 1, 2, and 2 dB(A) with respect to the site. Furthermore, at 20 m tree belt width, the site noise reduction was 4, 8, and 6 dB(A) (Ow & Ghosh, 2017) Table 1 shows the noise absorption of trees.

In this paper, the identification of tree-based noise absorption is discussed. However, determining noise absorption remains a challenge. Noise levels were measured in this investigation using a sound level meter. But there is no proper formula for figuring out whether trees in tree belts absorb noise or not from these kinds of investigation. Standard noise formulae should be used to measure noise levels from road traffic to ensure study accuracy. For leaves to absorb road noise, their noise absorption coefficient is essential. The sizes, thicknesses, and textures of leaves are the main components that absorb noise (Joshi et al., 2013; Watanabe & Yamada, 1996). In addition, the depth of a tree's canopy and the surface area of its leaves are ideal for absorbing noise. Furthermore, compared to dry leaves, green leaves are more effective in absorbing noise (Safikhani et al., 2014). Surface area, depth, noise-absorption coefficient, and traffic noise frequency have an impact on the ability to absorb noise. An equation has been developed to determine the amount of noise absorption by trees. Equation 1 shows the noise absorption of leaves.

$$A = -10\log\left(1 - \left(\frac{G \times F \times L \times f^{0.5}}{8}\right)\right) \ldots\ldots\ldots\ldots\ldots (Eq.1)$$

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

Table 1. Noise Absorption based on Different Sites

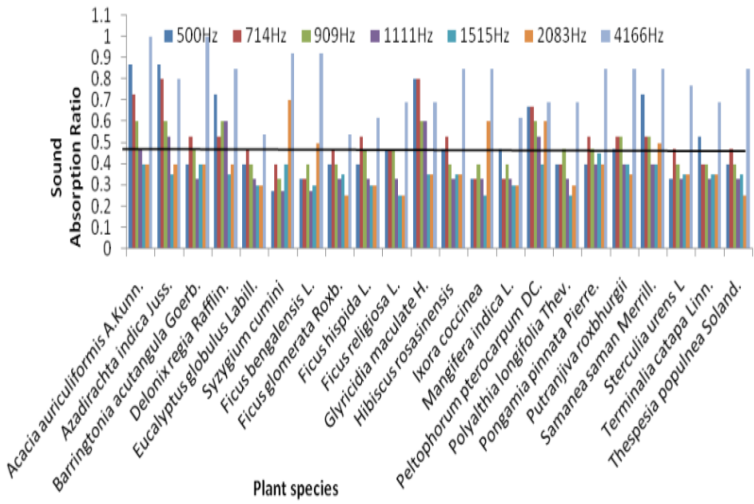
Site	At Source dB(A)	Difference between source & at 5m	5 m from source dB(A)	Difference between 5 and 10m	10m from source dB(A)	Difference between I0 and 20 m	20 m from source dB(A)	Total reduction dB(A)
Minimal planting scheme	78	1	77	2	75	1	74	4
Sparse to medium planting scheme	73	3	70	3	67	2	65	8
Dense planting scheme	67	2	65	2	63	2	61	6

The size, thickness and texture of leaves are important factors in the absorption of noise; therefore, the noise absorption coefficient of the leaves depends on these attributes. The canopy of a tree affects noise absorption because the leaves cover a larger area than the bark and branches. Tree belts are a more effective way to absorb noise than isolated trees. When measuring noise absorption, factors such as leaf surface area and tree depth accuracy have a significant impact. The findings indicate that a tree belt's depth, width, and tree-to-tree spacing of a tree belt are the main determinants of how much road noise it blocks (Ow & Ghosh, 2017; Peng et al., 2014). Furthermore, tree structures such as tree belts and groupings of trees reduce traffic noise pollution better than single, isolated trees (Ow & Ghosh, 2017; Wickramathilaka et al., 2022). 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 (Dobson & Ryan, 2000). This means that the canopy of a tree is vital for absorbing noise.

Furthermore, traffic noise attenuation through 10 m to 20 m width of tree belts was found to be 2 dB to 3 dB (with a tree spacing of less than 0.5 m), while it was up to 7 dB through 120 m tree belts of eucalyptus vegetation (with a tree spacing greater than 0.5 m) (Huddart, 1990; Ow & Ghosh, 2017; Peng et al., 2014). Moreover, researchers have found that a narrow belt of dense conifer vegetation reduced noise by 5 dB through 3m (Kragh, 1981; Ow & Ghosh, 2017). The height, width and density of a tree belt are the most important factors for noise reduction, rather than characteristics of leaf sizes and branches. A confirmed width (at least 30 m) has a positive impact on noise reduction, while height provides greater opportunities for noise reduction because high tree belts consist of a greater surface area (Fang & Ling, 2003). Research by Fang & Ling (2003), found that shrubs offered greater noise reduction. Therefore, both trees and shrubs should be taken advantage of in the context of noise mitigation.

3.2 Noise Absorption Coefficient of Trees

The sound absorption coefficient refers to the acoustical effectiveness of a material and the incident sound energy absorption (Bohatkiewicz, 2016). A sound absorption coefficient value closer to zero means poor noise absorption (Joshi et al., 2013). Thicker, denser, and heavier materials are the main factors for noise absorption (Karlinasari et al., 2012; Tudor et al., 2020). The leaves of trees are more effective for noise absorption than their trunks. Leaves have several acoustic properties like absorption, scattering and reflection, but noise absorption is a more effective acoustic property of leaves. The size, shape, thickness and texture of leaves are the factors affecting their noise absorption coefficient (Watanabe & Yamada, 1996). A study was carried out to estimate the noise absorption coefficient of leaves. Various leaf thicknesses (1 cm, 1.75 cm and 2 cm) and sizes (0.5 × 0.5 cm2, 1.0 × 1.0 cm2 and 2.0 × 2.0 cm2) were used under different frequencies in the impedance tube (Jung et al., 2020). As a result of this study, the noise absorption coefficient of twenty-two (22) leaves is shown in Figure 2. Moreover, the acoustic properties of leaves depend on the frequency of the noise, and the noise absorption coefficient varies with different noise frequencies (Joshi et al., 2013).

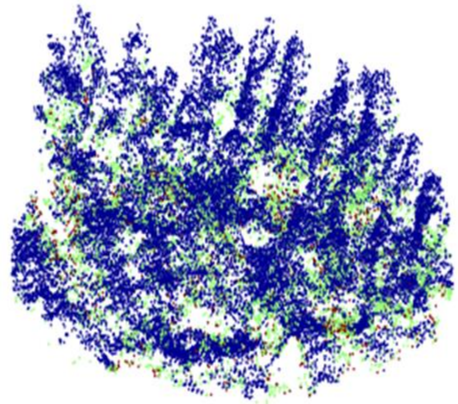


Source: Joshi et al., 2013

Figure 2. Noise Absorption Coefficient of Leaves

3.3 Tree Canopy Detection and Visualization

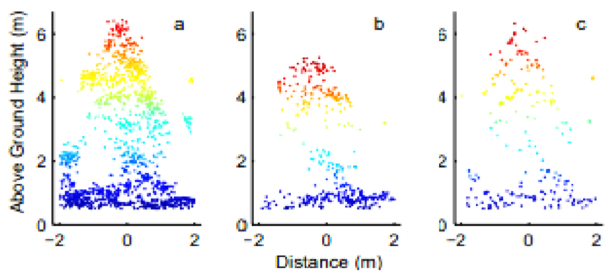
Well-grown trees are vital for the mitigation of road traffic noise levels (Margaritis et al., 2018). The canopy of a tree is an effective biomass for noise absorption because it consists of leaves (Pathak et al., 2008). Therefore, detecting the tree canopy (Jichen et al., 2017) is very important for identifying the amount of noise absorption using the parameters of the surface area of leaves and tree depth (Watanabe & Yamada, 1996). LiDAR point clouds are widely used for decision-making processes in vegetation operations (Wulder et al., 2008). The distribution of LiDAR points in the canopy provides reliable information, based on individual trees (Wallace et al., 2012). Mini-Unmanned Aerial Vehicles (UAV) are a platform to use when conducting high spatial resolution surveys for tree canopy height detection (Wallace et al., 2012). In order to assess canopy height, a set of quantitative statistics was used for each point cloud (Donoghue et al., 2007; Lim & Treitz, 2004). However, the effect of flight conditions on measuring vegetation is still being examined. It is recommended to use a lower flying height, a small survey area and high point densities for mini-UAV surveying (Disney et al., 2010; Goodwin et al., 2006; Lovell et al., 2005). These studies described using the beam divergence, point density, scan angle and internal properties of scanners for the detection of individual trees. Lovell et al. (2005), found that the measurements of tree heights were formulated using a higher point density. Furthermore, this study described how the use of a large scan angle reduced the number of lower canopy returns and helped with a large canopy cover (Hao et al., 2021). The results obtained by Wallace et al. (2012), showed the points cloud of a tree canopy generated at an average flying height of 48.3 m; the first (blue), second (green), and third (red) return signal points were shown in point clouds. The multi-rotor drone with an Ibeo LUX laser scanner was used for this study. The histograms of the above-ground level of the LiDAR return signals from the point clouds were captured at different flight heights (30 m, 50 m, 70 m and 90 m). The point cloud density for an individual tree was significantly different from different flying heights (Wallace et al., 2012). Figure 3 shows an example of the point clouds of a tree canopy.



Source: Wallace et al., 2012

Figure 3. An Example of the Point Clouds of a Tree Canopy

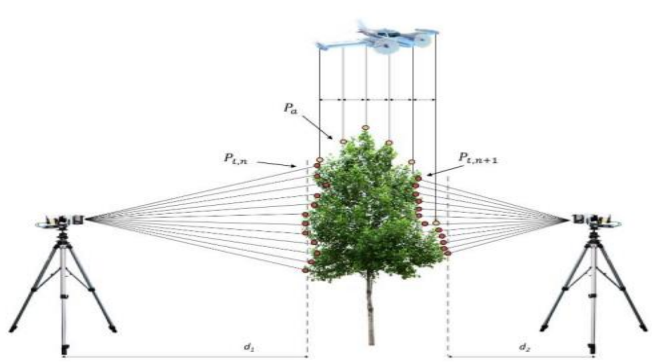
The vegetation heights returned over a single plot for point clouds were captured at above-ground flying heights of a) 30 m, b) 50 m and c) 70 m. There were an obvious attenuation of the upper canopy returns due to the flight altitude. Figure 4 shows the canopy point clouds at various flying heights.



Source: Wallace et al., 2012

Figure 4. An Example of the Point Clouds of a Tree Canopy

Terrestrial laser scanning (TLS) is used to obtain precise information about trees (Zhong et al., 2016). It enables the extraction of tree information - such as the crown size, tree height and crown base height - more easily than a UAV survey (Hillman et al., 2021). TLS systems can be adapted to measure the actual shape of a tree canopy accurately, and TLS data can be used to delineate the boundaries of the canopy. Typically, TLS does not measure the horizontal top view of the canopy or the top view of the canopy due to its side scanning. Therefore, embedding the nadir perspective and TLS approaches are vital for capturing tree canopy details (Paris et al., 2017). Figure 5 shows the side scanning and nadir scanning of a tree canopy.



Source: Paris et al., 2017

Figure 5. Side and nadir scanning of tree canopies

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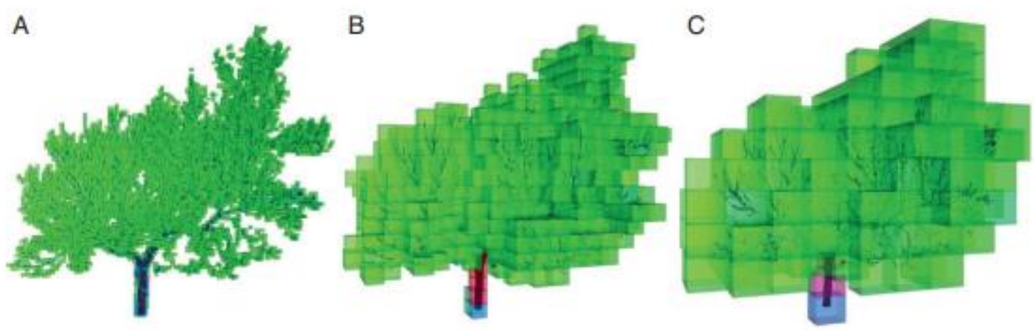
3.4 Tree Canopy 3D Visualization

The voxel-based method, the convex hull by slices and the 3D convex hull are the methods usually used for the 3D visualization of a tree canopy (Yan et al., 2019). Three-dimensional tree modelling is an indispensable part of real-world visualization (Zhang et al., 2022). However, due to the irregular and intricate structure of trees, large-scale 3D modelling is impossible (Xu et al., 2021). Nevertheless, to identify the traffic noise absorption of trees, accurate visualization is essential. A mesh surface is often used for vegetation modelling and this leads to a time-consuming modelling process (Tang et al., 2013). Unlike the triangular mesh model, the voxel model consists of a voxel grid model. Recently, voxel grid modelling has been used for individual tree modelling, and the voxel size is important for 3D modelling (Li et al., 2017). The voxel size can be defined according to the density of the point clouds and the user requirements (Hancock et al., 2017). However, researchers are searching for standardised modelling methods for voxels (Chakraborty et al., 2019; Zhang et al., 2022).

The study by Park et al. (2010) used K-Dimensional tree (KD-tree) algorithms for the voxelisation of point clouds. Traditionally, to estimate the canopy properties, the boundary box was used, which was a simpler method. Gaps in the canopy structure are not considered in the boundary box model (Smart & Robinson, 1991). Voxelization algorithms are usually based on classifying points into three-dimensional grid voxels (Fernández-Sarría et al., 2013), and all analysis vox functions are provided in the VoxR package (Béland et al., 2014). A simple voxelisation can be fully filled by rounding the point coordinates of the three-dimensional Cartesian system: (coord (x, y and z) *res)/res, where res is the voxel resolution. The vox function output is discrete, and the centre of each voxel and the number of points is represented within each voxel (Fernández-Sarría et al., 2013; Lecigne et al., 2018). Figure 6 shows a voxel representation of tree canopies using voxel, resolutions of 0.1 m (A), 0.5 m (B), and 1 m (C).



Source: Lecigne et al., 2018

Figure 6. Voxel Representation and Resolution of a Tree Canopy

In the convex hull by slices method, the point clouds are divided into several irregular planes. All the point clouds are formulated in the direction of the Z-axis, according to a certain interval. This interval depends on the density of the point clouds. If the interval is too large, the volume estimation is not accurate. However, if the interval is too small, the calculation may be too complicated. In processing, the interval is given as one to five times the point density. Finally, the overall canopy volume can be estimated by summing the volume of each slice (Li et al., 2016). Figure 7 illustrates the use of the convex hull by slices method for the volume estimation of a tree canopy. The 3D convex hull method is a mesh method used to visualise the canopy of a tree in 3D, including the creation of minimal vertex and points enclosed by external planes. The convex hull volume is calculated using the boundaries of planes, which consist of many Delaunay triangles (Yan et al., 2019). Figure 8 illustrates the volume estimation using the 3D convex hull method.

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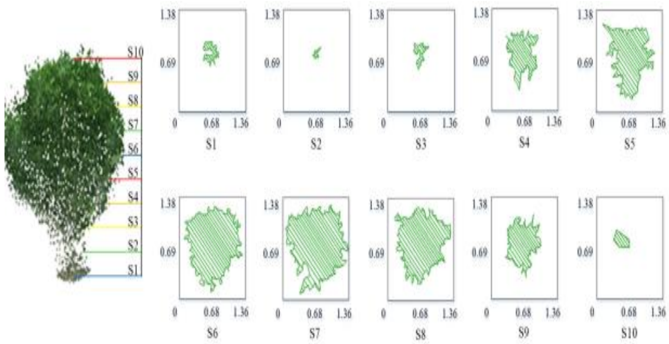


Source: Lecigne et al., 2018

Figure 7. Volume Estimation from the 3D Convex Hull, the Convex Hull by Slices

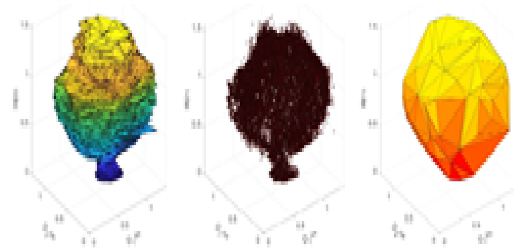
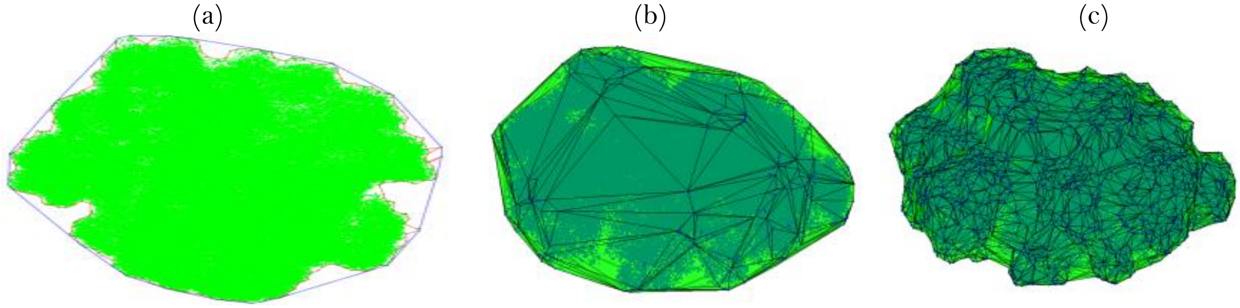


Figure 8. Volume Estimation from the 3D Convex Hull

3.5 Concave Hull and Convex Hull

The estimation of tree canopy measurements depends on the raster and vector visualization (Dunbar et al., 2004). The raster visualization of point clouds depends on the voxel, but the canopy parameters may vary with the voxel size. By contrast, tree canopy point clouds from vectors use networks of irregular triangles with a higher level of accuracy (Soma et al., 2021). The well-known convex and concave hull methods, in particular, are used for tree canopy estimation (Colaço et al., 2017; Yan et al., 2019). Parmehr & Amati (2021), compared the convex hull and concave hull representations of tree canopy point clouds. The canopy visualization was projected onto a two-dimensional plane to calculate the maximum diameter and area of a tree canopy. Figure 9(a) describes the surface fitting of a tree canopy convex hull in red and a concave hull in blue. Whereas a convex hull provides an overestimated volume, a concave hull provides an extract-fitting surface to the point clouds while managing accuracy and reliability (Parmehr & Amati, 2021). Figure 9(b) illustrates the 3D visualization of a tree canopy from a convex hull, and Figure 9(c) illustrates the 3D visualization of a tree canopy from a concave hull.

(a) (b) (c)



Source: Parmehr & Amati, 2021

Figure 9. a) Describes the surface fitting of a tree canopy convex hull in red and a concave hull in blue; b) Illustrates a 3D visualization of a tree canopy from a convex hull; c) illustrates a 3D visualization of a tree canopy from a concave hull

3.6 3D Tree Visualization Developments

Convex hull, concave hull, and voxel-based are the methods to create a surface for the tree canopy. However, these methods are not shown a clear identification of the total surface area of leaves in the tree canopy. Therefore, tree visualization development is vital. Several studies have developed mathematical methods to identify the Leaf area density (LAD) of a tree canopy. The surface area of leaves in unit volume is prime to calculate, traffic noise absorption from the tree canopies. The studies of Hosoi & Omasa (2006), Kargar et al. (2019), and Gu et al. (2022) and, have conducted studies to identify the LAD of a tree canopy using Lidar point

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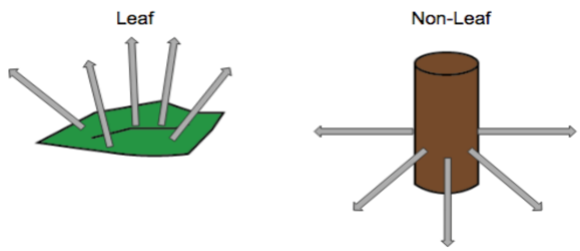
clouds. Points cloud segmentation is required to select leaves' points cloud separately. Normal of returns associate the surface structure in unorganized point clouds. Figure 10 is illustrated the difference between normal distributions of leaves and branches.



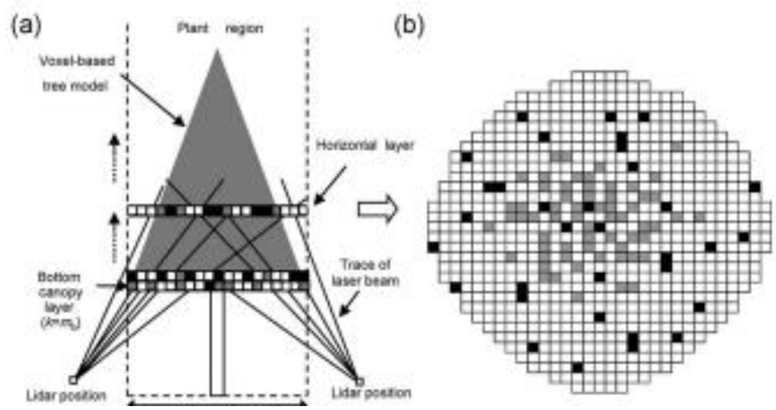
Source: Gu et al., 2022

Figure 10. Difference between the Normal Distribution of Leaves and Branches

The normal changing difference is small in the leaf points cloud. According to Equation (2), n (p) is the normal of the point cloud in p^{th} point. r is the average distance between two leaves. The leaves points cloud can be extracted using the amount of Δn.

$$\Delta n\ (p, r) = \left(\frac{1}{N}\right) \sum_{i=1}^{N} (n(p) - n(p_i)) \quad \text{.......... (Eq. 2)}$$

Moreover, the points cloud is segmented into layers on the horizontal direction (x-axis), and LAD is calculated using voxel-based canopy profiling (VCP). VCP describes voxel-based profiling (see figure 11) between two horizontal layers in a points cloud.



Source: Gu et al, 2022

Figure 11. Horizontal Voxel Layer of Leaf Point Clouds

$$LAD(h, \Delta h) = \alpha(\theta) \left(\frac{1}{\Delta h}\right) \sum_{k=m_h}^{m_{h+\Delta h}} \frac{n_1(k)}{n_1(k) + n_p(k)'} \quad \text{.......... (Eq. 3)}$$

According to equation (3), where Δh is the thickness of the layer, and mh and mh+Δh indicate the voxel coordinates on the vertical direction (y-axis), θ is the zenith angle of the lidar beam. The heights h and h + Δh, and n1(k) and np(k) represent a number of voxels consisting of leaf points and excluding. Respectively, n1(k) + np(k) denotes the total number of incident laser beams in the k-th layer. The α(θ) is a correction factor of the leaf inclination angle.

3.7 3D Tree Visualization Object Modeling

The concept of object modeling for a tree canopy is not widely used to estimate the volume of the canopy. Object modeling does not represent an extract fitting surface to canopy points cloud. But it derives some

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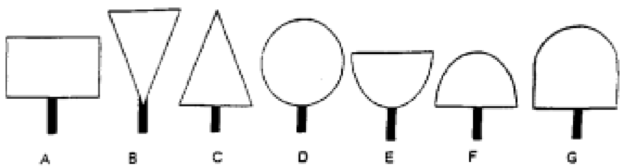
geometric shapes from tree canopies. Therefore, volume estimation of tree canopies from object modeling is not an accurate method. But Object modeling is vital for enhancing the visual quality (geometric shapes). Computer programing methods are inserted to identify the area of the canopy. Canopy volume calculation is vital to find noise absorption by trees. Tree height, canopy diameter, and canopy height are the parameters for object modeling. Biomass Estimates from Canopy Volume (BECVOL), and Arbour Structure (ARBORSTRUQ) are the methods of corresponding object modeling for tree canopies (Melville et al., 1999). ARBORSTRUQ is a more user-friendly method than BECVOL, and a complex algorithm is used in BECVOL. There are several geometric shapes have been derived in the ARBORSTRUQ method (see figure 12), and corresponding equations of geometric shapes to find the volume is described in figure 13. Where, X is the total tree height in centimeters, Y is the height of the lowest leaves in centimeters, R is the greatest canopy diameter in centimeters, and H is the variable height.



Source: Melville et al., 1999

Figure 12. Geometric Shapes of the Tree Canopy

Shape A: volume to H= $\pi R^2(H–Y)$
Shape B: volume to H= $0.333\pi R^2(H–Y)^3(X–Y)^{-2}$
Shape C: volume to H= $0.333\pi R^2[(X–Y)–(X–H)^3(X–Y)^{-2}]$
Shape D: volume to H= $0.333\pi(H–Y)^2(3R–H+Y)$
Shape E: volume to H= $0.333\pi(H–Y)^2(3R–H+Y)$
Shape F: volume to H= $0.333\pi[2R^3–(X–H)^2(3R–X+H)]$
Shape G: volume to H= $\pi R^2(X–R–Y)+0.333\pi[2R^3–(X–H)^2(3R–X+H)]$

Figure 13. Equation to Find the Volume of Geometric Shapes

3.8 Discussion

Increasing green spaces is a cost-effective method of mitigateing noise pollution from road traffic noise. According to the recent study of Gharibi & Shayesteh (2024), noise reduction of green areas is done by two approaches. The study has found the variation of traffic noise with and without tree noise barriers. According to the result of this study, green sound barriers reduce noise by 0 to 4.5 dB. On average, the mean noise reduction by green barriers is 0.1–6.4 dB which is 9–11 dB in the study of Ow and Ghosh. However, this study does not describe the impact of green spaces for noise reduction in a 3D space. In particular, moderate and high-thickness green belts along roads are more effective than isolated trees in introducing traffic noise. The study by Sultan et al. (2024), has found the quantity of sound absorption by a vegetation barrier is related to the width and height of the vegetation barrier.

Although several studies have discussed the exact general depth (5 m) needed for minimizing traffic noise, the mitigation depends on the width and height of the tree belt and the type of tree. Accurately determining the width and height of a tree belt to mitigate highway noise pollution is challenging in practical scenarios. However, a suitable height and width for the tree belt can be determined after visualizing the trees in a 3D environment. According to the study of Wickramathilaka et al. (2024), a method has been demonstrated and developed to identify noise absorption by tree belts through a 3D visualization of trees. In addition, tree spacing and surface areas are vital for noise reduction. It is not possible to identify the impact of tree spacing for road traffic noise reductions, the study of variety of trees for sound attenuation, and it was succeeded in minimizing traffic noise pollution in urban cities (Martínez-Sala et al., 2006). The study of Yofianti & Usman (2021) has mentioned that not only trees but also shrubs offer greater noise reduction, so a combination of both trees and shrubs should be employed to achieve the maximum noise reduction through green areas.

When considering individual tree properties, the size, thickness, and texture of the leaves are important for noise absorption. In particular, the noise absorption coefficient of the leaves directly relates to the noise absorption. A leaf will vibrate at a particular (resonant) frequency when the sound's wavelength is comparable to that of the leaf. Sound energy is converted to heat during this process. This means that the sound energy is reduced (Romanova et al., 2019). In conclusion, the optimal noise reduction effect would probably be achieved by combining large, textured, and fairly thick leaves. For real-world uses, think about how these elements could be used into sound barriers or landscape architecture. Furthermore, compared to dry leaves, wet leaves often have a higher sound absorption coefficient. The density of the leaf material can increase due to the dampness, increasing its capacity to absorb sound energy (Ali et al., 2020).

In general, the frequency of traffic noise is not constant and varies with the speed, amount, and composition of traffic. It indicates that in an urban setting, the frequency of road traffic noise is dynamic. The noise absorption coefficient of the leaves varies with the frequency of the noise. Therefore, different noise frequencies are needed to identify the average noise absorption coefficient of leaves (Adhika et al., 2023). Therefore, identifying the noise absorption coefficient of leaves using an impedance tube is important to determine the noise absorption of trees. In general, varied leaf thicknesses)1 cm, 1.75 cm, and 2 cm) and sizes (0.5 × 0.5 cm^2, 1.0 × 1.0 cm^2, and 2.0 × 2.0 cm^2) are used in impedance tube tests. However, to calculate the noise absorption of leaves, the frequency absorption factor of leaves is vital. Therefore, the standard noise equation can be used to identify the frequency absorption factor of leaves through the noise absorption coefficient of leaves.

To identify the performance of trees as noise barriers, detecting and visualizing the tree canopy are crucial because the tree canopy consists of leaves. The surface area of leaves is vital for noise absorption. When considering individual trees, the surface area of the leaves and the depth of the trees are vital to noise absorption. A combination of terrestrial laser scanning (TLS) for side scanning and Mini-Unmanned Aerial Vehicles (UAV) for nadir scanning provides a high spatial resolution survey for tree canopy detection. TLS is better for detecting the point clouds of a tree. UAVs (using first-and last-return signals) are better for detecting the depth of a tree. For that identification of the surface area of leaves is vital. The voxel-based, convex hull by slices and 3D convex hull methods are usually used to visualize a tree canopy in 3D. Recently, voxel grid modelling has been used for individual tree modelling, and the voxel size is important for 3D modelling. However, gaps in the tree canopy structure are not visualised in this voxel-based method (Ross et al., 2022). Decreasing the voxel size enables accuracy of visualization. To avoid voxel complications, the convex hull- slice method is one solution (Dong et al., 2021). In this method, all the point clouds are formulated in the direction of the Z-axis according to a certain interval. In processing, the interval is taken as one to five times the point density. Due to the inaccurate volume estimation of the convex hull using the slices method, the minimal vertex visualization (3D convex hull) method is the solution required to eliminate this inaccurate volume estimation. Not only the convex hull method, the concave hull method can also be used for tree canopy estimation. However, a convex hull provides an overestimated volume, while a concave hull provides an extract-fitting surface to the point clouds while managing accuracy and reliability. As a development of tree canopy visualization, a modern approach has been developed to find the surface area of leaves using horizontal voxel-based layers. Here, the size of the voxel is the average surface area of a leaf. Furthermore, this approach describes the surface area of the leaves instead of the total canopy area. However, simple geometric object modelling for tree canopies alone can be used to visualize tree canopies. Geometric object modelling provides inaccurate calculation of the surface area of leaves. However, it is mentioned in this review paper, the 3D Tree Visualization Developments provide higher accuracy to identify the surface area of leaves. The laser scanning proceedings of this method is prime to detect leaves of a canopy.

4. Conclusion

Recently, road traffic noise pollution has become a major social issue in both developed and developing cities. Although developed cities have addressed these problems robustly, developing countries are not focusing on noise pollution issues due to the economic pressure they are facing. The leaves of trees act as natural sound barriers, absorbing a significant amount of noise. Tree belts, tree groupings, and lone trees are some of the tree structures that can be used to muffle traffic noise. Tree belts are more effective to noise reduction than group of trees and isolated trees. Establishing green belts as barriers is more cost-effective. Moreover, a combination of grass areas and shrubs among trees inside tree belts improves the noise absorption ability of green belts and is vital for noise reduction. When detecting the noise absorption performance of green belts, the individual tree properties are crucial and the tree canopy in particular impacts noise reduction.

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In addition to these benefits, the leaves on the trees are very effective in blocking out road noise. It is crucial to understand how well plants absorb noise for this reason. Well-manicured vegetation belts are a useful tool for reducing noise pollution from moving vehicles. Consequently, it is critical to identify and suggest appropriate pants for vegetation belts. Important variables influencing noise absorption are tree depths, leaf surface areas (per unit volume), and leaf noise absorption coefficients. Furthermore, the ability of a leaf to absorb noise is influenced by its size, thickness, age, moisture content, dryness, and greenness. But for effective noise reduction, the noise absorption coefficient of leaves must be calculated precisely. Moreover, these circumstances modify the noise absorption coefficient of leaves. Determine each leaf's noise absorption coefficient (if possible) rather than relying on only one figure. It is feasible to precisely distinguish which trees absorb traffic noise, and consequently, which trees are the greatest at doing so. Apart from their surface area, the noise absorption coefficient is a crucial element that influences noise reduction. The noise-absorption coefficient of leaves is significantly influenced by the frequency of sounds. The noise-absorption coefficient of leaves under various frequencies in an impedance tube should be examined, and an average value should be taken, according to the noise absorption equation. Alternatively, instead of choosing an average value, it has been recommended that studying the actual noise absorption coefficient of the leaves for each tree may improve the accuracy of the noise absorption.

The visualization of 3D trees has become a viable method for precisely measuring leaf surface areas and tree depths in recent years. Tree modelling programs utilizing terrestrial laser scanning (TLS) have been shown to be successful in gathering comprehensive data on tree attributes, including tree depths, canopy areas, and canopy volumes. Furthermore, 3D visualization is a crucial tool for figuring out leaf surface areas because it can improve the accuracy of the canopies' details. This work used the TLS method to detect 3D trees; however, to accurately detect all of the information, it is more effective to combine the TLS and ALS approaches for 3D tree detection.

It is still difficult to estimate the true surface areas accurately. Creating surfaces from point clouds can be accomplished in part by embedding LiDAR point clouds into a surface fitting technique (such a convex one). It has been demonstrated that this approach is more accurate than other surface fitting techniques such as voxel or the triangular irregular network (TIN). However, more investigation is required to increase the accuracy of the leaf surface area computation. However, the 3D convex hull approach overestimates 3D tree canopies due to this surface fit with the outside points of point clouds. This removes a little point cloud gap from this. The 3D concave hull method can be advised as a precautionary measure. It is uncommon to estimate the volume of a tree canopy using the idea of object modelling. A canopy points cloud extract fitting surface is not represented by object modelling. However, it takes some geometric shapes from the canopies of trees. Consequently, the estimation of the volume of tree canopies using object modelling is an imprecise technique. Techniques to generate a surface for the tree canopy are voxel-based, convex, and concave hull. However, the entire leaf surface area within the tree canopy cannot be clearly identified using these methods. Therefore, the development of tree visualization is essential. The leaf area density (LAD) of a tree canopy can be found using mathematical techniques that have been developed in several studies.

As future suggestions; planting trees along the roads is vital to reduce noise pollution. To identify the suitable height and width of the tree belts, the 3D visualization of tree is vital. Due to the individual performance of a tree in a tree bel being vital, the noise absorption coefficient of leaves should be taken into account. This means that the type of tree is a considerable factor in the absorption of noise from road traffic. To identify the properties of the trees such surface area of the leaves and depth of the trees, the 3D tree detection and 3D tree visualization is vital accurately.

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