Plant Species Selection Based on Leaf Vibration Experiments

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Abstract. Noise pollution is exacerbated by the rapid urban development. Noise has a serious impact on both people's life and cities' ecological environment. Noise should be controlled immediately. Plants are one of the natural noise-reducing materials, which becomes increasingly important and popular. In urban landscape design, it is very important to select the plant species which have good noise reduction effect. The aim of this paper is to find out the characteristics of the plants with good noise reduction effect and apply it in urban landscape design. In this study, an experiment of sound attenuation by plants focusing on leaf vibration is carried out. This study investigates the vibration of leaves of 6 plant species in a sound field using a Keyence (IG-1000/CCD) Laser Micrometre. The results show that the vibration amplitudes of plant leaves increase significantly by about 4-12 $\mu$m after being stimulated by sound. In addition, driven by the same sound, the amplitudes of all leaves varied with the difference of leaf thickness, leaf area and leaf mass. The amplitudes of all leaves increase with the increase of leaf area and leaf mass, while decrease with the increase of leaf thickness.

1. Introduction
With the rapid development of urbanization, city gray infrastructure has increased significantly, and urban green space has become less and less. This triggers a series of rapid urbanization problems: the urban ecological environment is severely damaged, the various environmental elements necessary for people's well-being are also seriously polluted and destroyed, resulting in the deterioration of people's life quality [1]. At the same time, urban noise pollution is serious. An analysis of noise over the past few decades has found that traffic noise has become the major source of noise pollution [2]. In order to reduce the impact of traffic noise on residents living along the traffic lines, it is an effective way to set sound absorption barriers on both sides of roads. Urban green space can be used as a sound barrier to control traffic noise. By using plants to attenuate traffic noise, traffic noise can be effectively controlled and urban ecological environment can be improved. Renterhem et al. found that plant crowns had a better effect on noise attenuation at higher frequencies. Tree trunks did not attenuate low-frequency noise significantly, while the effect of intermediate-frequency noise attenuation was significant [3]. Yang et al. analysed the factors influencing plant noise reduction by studying the propagation path of sound through a tree [4]. Fan found that plant leaf types affected noise attenuation by plants, and the leaves with oval shape had more significant effects than long and narrow leaves [5]. Fang and Ling found that vegetation belts of different width, height and visibility had different effects on noise reduction [6]. Plants are one of the natural noise-reducing materials, which have become more and more important and popular. In urban landscape design, it is very important to select the plant species with good noise reduction effect for the sustainable development of urban ecology.
In the current study, an experiment of leaf vibration is carried out with leaves on the plants. 6 typical plant species are considered. In order to enhance the effect of traffic noise attenuation, this paper is based on the leaf vibration of plants, considering the leaf characteristics of tree species with better noise reduction effect, and provides the fundamental for the selection of plant species in urban landscape.

2. Methods and materials

2.1. Materials

Six species of common plants are selected for experiment. The sound source is point sound source which is low-frequency pulse sound (93.5 dB), and the vibration tester is a Keyence laser micrometre (IG-1000/CCD). Table 1 shows some of the basic physical properties of the leaves of the 6 common plants tested.

| Plant                     | Leaf area (mm²) | Leaf thickness (mm) | Petiole length (mm) | Petiole width (mm) | Petiole thickness (mm) | Mass (g) |
|---------------------------|-----------------|---------------------|---------------------|-------------------|------------------------|----------|
| Anthurium andraeanum      | 7156.94         | 0.60                | 120.00              | 3.54              | 4.56                   | 3.8392   |
| Gardenia jasminoides      | 3115.17         | 0.74                | 95.50               | 2.76              | 3.00                   | 1.5635   |
| Zamioculcas zamiifolia    | 3544.02         | 0.66                | 145.00              | 2.92              | 3.64                   | 1.9649   |
| Echeveria pulvinata.      | 931.91          | 0.80                | 4.00                | 2.00              | 1.86                   | 0.2696   |
| Plectranthus scutellarioi | 619.77          | 0.58                | 2.00                | 1.50              | 1.58                   | 0.1466   |
| Hibiscus syriacus         | 625.23          | 0.56                | 3.00                | 3.50              | 1.54                   | 0.1215   |

2.2. Development of a noise source

Noise reduction by plant is mainly through two ways [5]-[14]. One is changing the sound energy into the kinetic energy by leaf vibration. The other is changing the sound energy into the thermal energy by leaf friction. The vibration of plant leaves mainly attenuates the low-frequency noise, so this experimental sound source chooses the low-frequency pulse sound. Four kinds of sound sources are selected during the experiment, as shown in Table 2, and the sound source 1 is finally selected.
### Table 2. Sound source selection.

| Spectrum |
|----------|
| ![Spectrum](image) |

### 2.3. Experimental design

In order to prevent the impact of human activity on the experimental results, the experiment is carried out on a hermetically sealed wind-free vibration isolation table. The experimental process is shown in Figure 1 and Figure 2 (h is the vertical distance between the sound source and the plant leaf measuring point, h= 14-22 cm). In order to obtain the changes of amplitude of plant leaves after being stimulated by sound, the vibration of plant leaves is recorded for 24 s in each experiment, totalling 1.2 million measuring points. During the first 8-12 s, the self-vibration of leaves is recorded under no-sound excitation. Then the changes of the amplitude of plant leaves under the excitation of the sound are recorded. In this experiment, 3 leaves per plant are selected and tested, and each leaf is tested 5 times for analysis.

![Figure 1. Top view of the plant leaf vibration.](image)

![Figure 2. Side view of the plant leaf vibration.](image)

### 3. Results

The results show that the self-vibration amplitude of plant leaves is 1 μm under no-sound. After stimulated by sound, the amplitude of plant leaf significantly increases about 4-12 μm, which is shown in Table 3. The amplitude of different leaves is significantly different under the same excitation. By analysing the influencing factors, it is found that the influence of physical factors such as mass, area and thickness of different plant leaves on amplitude is significantly different. Further analysis of these factors shows that plant leaf mass, area and thickness are the main factors that affect the increase of plant leaf amplitude. The amplitudes of all leaves increase with the increase of leaf area and leaf mass, while decrease with the increase of leaf thickness.
Table 3. Vibration amplitude of plant leaves.

| Plant                                               | Vibration amplitude of the leaf |
|-----------------------------------------------------|--------------------------------|
| Anthurium andraeanum Linden. (leaf 1)               |                                |
| Anthurium andraeanum Linden. (leaf 2)               |                                |
| Echeveria pulvinata. (leaf 2)                       |                                |
| Echeveria pulvinata. (leaf 3)                       |                                |
| Hibiscus syriacus Linn. (leaf 1)                    |                                |
| Hibiscus syriacus Linn. (leaf 3)                    |                                |

4. Discussion
Leaf mass and leaf area are the two most important factors affecting plant leaf vibration. It is also found that whether plant leaves contain petioles or not, and the length and thickness of petioles are the factors affecting the increase of plant leaf vibration.
The results show that there is a significant positive correlation between leaf mass, leaf area and leaf amplitude, while leaf thickness and leaf amplitude are negatively correlated. And the influence of leaf mass and area on amplitude is greater than the thickness. Therefore, in the future the plant species selection in landscape, in order to achieve better noise reduction effect, should focus on the selection of leaf weight, large area and thin plant species. In addition, in order to promote the sustainable development of urban ecology, other principles should also be followed in the selection of plant species: (1) Local species should be used. According to the criteria of suitable tree planting and local
conditions, the local dominant tree species can better adapt to the local climatic conditions and soil conditions. (2) Ecologically-beneficial plants should be used to assist. Many plants have special ecological functions. Some plants can absorb the harmful gases which the traffic exhausts and enhance the overall ecological environment of the city.

5. Conclusion
In this study, 6 species of plants were tested on a sealed, wind-free platform to examine leaf amplitude, by considering various factors including leaf mass, leaf area and leaf thickness. When driven by the same sound, the amplitudes of all leaves varied with the difference of leaf thickness, leaf area and leaf mass. The vibration amplitudes of plant leaves increase significantly by about 4-12 μm after being stimulated by sound. The mass and area of plant leaves have a positive correlation with the amplitude, and the leaf thickness has a negative correlation with the amplitude. The influence of leaf mass and area on amplitude is greater than leaf thickness. In addition, many of physical properties of plant leaves have an impact on the amplitude of vibration. These findings can be used to guide urban landscape design and planting design. This is worthy of investigation which focuses on the other factors affecting leaf vibration. Further studies will be conducted on the other factors of plant leaf which can influence leaf vibration.

6. References
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