Can Architectural Surfaces Capture Atmospheric Particulate Matter Like Trees? A Design Strategy to Mimic Leaf Traits

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Abstract: Trees’ ability to capture atmospheric Particular Matter (PM) is related to morphological traits (shape, size, and micro-morphology) of the leaves. The objectives of this study were (1) to find out whether cluster pattern of the leaves is also a parameter that affects trees’ PM capturing performance and (2) to apply the cluster patterns of the leaves on architectural surfaces to confirm its impact on PM capturing performance. Two series of chamber experiments were designed to observe the impact of cluster patterns on PM capturing performance whilst other influential variables were controlled. First, we exposed synthetic leaf structures of different cluster patterns (a large and sparsely arranged cluster pattern and a small and densely arranged cluster pattern) to artificially generated PM in a chamber for 60 min and recorded the changing levels of PM_{2.5} and PM_{10} every minute. The results confirmed that the small and densely arranged cluster pattern has more significant effect on reducing PM_{2.5} and PM_{10} than the large and sparsely arranged cluster pattern. Secondly, we created three different types of architectural surfaces mimicking the cluster patterns of the leaves: a base surface, a folded surface, and a folded and porous surface. The surfaces were also exposed to artificially generated PM in the chamber and the levels of PM_{2.5} and PM_{10} were recorded. The results confirmed that the folded and porous surface has a more significant effect on reducing PM_{2.5} and PM_{10} than other surfaces. The study has confirmed that the PM capturing performance of architectural surfaces can be improved by mimicking cluster pattern of the leaves.

Keywords: leaf cluster pattern; green infrastructure; bio-mimicry

1. Introduction

Atmospheric particulate matter (PM) has recently emerged as a significant environmental problem. Major cities worldwide recognize its seriousness, identify the impact of PM on the human body, and aim to lower the particulate levels in the air. Smaller particles are more likely to invade the body’s respiratory system and cause serious health problems [1,2]. If the amount of PM in the air (PM_{10} (D_p < 10 µm) or PM_{2.5} (D_p < 2.5 µm)) increases by 10 µg/m³, the probability of asthma in children aged 1–3 y rises by 1.06% and 1.12% [3,4].

Trees are known to play an essential role in reducing PM pollution in the city [5,6]. Previous studies have shown that trees are more effective in reducing PM than buildings or surfaces because of the high air turbulence created by their complex morphology and large surface area [7–10]. There are two main mechanisms for trees to remove PM in the air. The first one is when PM is captured on the leaf surface and washed away by rainwater [11–15]. The second is the mechanism by which PM is absorbed into the leaves’ stomata, transferred to the roots, and broken down by bacteria in the soil. The first mechanism involves trees’ physical characteristics, and it is known to be more efficient [12]. Furthermore, previous studies reveal that the shape and size of leaves significantly affect PM reduction [10,16,17]. Therefore, we began our study by describing the structural fea-
tures of leaves that can be applied to various surfaces that make up the urban infrastructure so that urban infrastructure could affect PM reduction in the same manner as trees.

Previous studies have investigated various parameters of the leaves that affect the capturing efficiency of PM. The shape, size, orientation, and micro-morphology of the surface are found to be the effective parameters [10,12,14]. It has been acknowledged that the smaller the individual leaf is, and the more complex the leaf shape is, the higher the PM capturing performance [10,12,18]. Also, the more complex the micro-morphological surface of the leaf is, such as hair, trichome, and ridges, the higher PM capturing performance [11–13,19,20]. Interestingly, the needle-like leaves of conifers have significantly higher PM capturing performance per unit area than the leaves of broadleaf tree species [10,13,18]. The re-suspension rate of captured PM is also lower [12]. This could be due to the differences in the patterns of coniferous trees’ leaves and how they are clustered. However, no experimental study has been conducted to see how PM capturing performance depends on the leaves’ arrangement patterns when the surface area is the same.

This study focuses on the leaf cluster pattern in which individual leaves are gathered to form the whole. When the total surface area is the same, a large, broad, flat-sided, and sparsely arranged cluster pattern and a small, dense, and volumetric cluster pattern were created to investigate how these differences affect PM capturing performance. After exposing two tree-like structures with synthetic leaves arranged in different cluster patterns to artificially generated PM in a chamber for 60 min, we recorded the levels of PM in the chamber every minute. The results confirmed that the small, dense, and volumetric cluster pattern has a more significant effect on reducing PM than the large, broad, flat-sided, and sparsely arranged cluster pattern.

Green infrastructure in the built environment has been considered as one potential urban planning solution for improving air quality as well as enhancing the sustainability of cities [21,22]. The aim of this study is to find a way to improve the absorption performance of architectural surfaces that form the urban infrastructure. The term architectural surfaces, in this research, refers to the surfaces that can be applied to buildings and infrastructures. Therefore, we conducted experiments to answer whether applying the physical properties of leaf cluster patterns derived from the experiments with a tree-like structure mentioned above can achieve the same results for architectural surfaces.

Different architectural surfaces were created based on morphological features of the sparsely arranged cluster pattern of large flat-sided leaves and the densely arranged cluster pattern of small leaves forming a three-dimensional mass. Based on the main morphological features of leaf cluster patterns as related to the volumetric degree of PM capturing and surface gaps, a base surface (B), a folded surface (F), and a folded and porous surface (P) were created. These three types of surfaces had different shapes but the same overall surface areas. We produced samples for the experiment by printing out the generated surfaces using SLA 3D printers. Chamber experiments using the samples produced were conducted in the same way as leaf experiments. Architectural surface experimental trials also yielded results in relation to leaf cluster pattern experimental trials. As a result, it was confirmed that the PM capturing performance would improve if the surfaces with the same area are split into small pieces to create more gaps (pores) and are made into three-dimensional surfaces.

2. Materials and Methods

Two series of chamber experiments were designed for this study. First, to find out whether the cluster pattern of leaves is a parameter that affect trees’ PM capturing performance or not, we created synthetic leaf structures with two different cluster patterns (a large and sparsely arranged cluster pattern and a small and densely arranged cluster pattern). Other influential variables—total surface area, and micro-morphology—were kept the same. Each synthetic leaf structure was placed in a chamber and exposed to artificially generated PM for 60 min. Changing levels of PM$_{2.5}$ and PM$_{10}$ inside the chamber were recorded every minute and the experiment was repeated 5 times per pattern.
The experiment answers the question whether there will be difference in PM capturing performance depending on the cluster patterns.

The second series of experiments were designed to confirm, if the cluster patterns of the leaves are applied to the architectural surfaces, whether they will show the same PM capturing performance or not. Will the cluster pattern that showed superior PM capturing performance in synthetic leaf structure experiment also show superior PM capturing performance when applied to the architectural surfaces? Architectural surfaces mimicking the two different leaf cluster patterns and a base surface for comparison purpose were created whilst other variables—total surface area and micro-morphology—were kept the same. Each surface sample was placed in a chamber and exposed to artificially generated PM for 80 min. Changing levels of PM$_{2.5}$ and PM$_{10}$ inside the chamber were recorded every minute and the experiment was repeated 5 times per surface pattern. The changes in PM$_{2.5}$ and PM$_{10}$ levels of each sample were graphed, and 10 min interval records were compared with each other.

2.1. Creation of Leaf Cluster Patterns

In this article, to experiment, we created two groups: tree-like structures, with identical surface areas and individual leaf shapes, and micro-morphology, but with differences in leaf sizes and clustering patterns. We created a group of 4 sparsely arranged large leaves and a group of 96 closely arranged small leaves. The overall surface areas, individual leaf shapes, and leaf micro-morphology were the same. The size and number of individual leaves differed, forming a large sparse pattern (hereafter L pattern) and a small and dense pattern (hereafter S pattern). For both patterns, the total area of the leaves was 38,552 mm$^2$. In the L pattern, the surface area of a single leaf was 9638 mm$^2$. There were four leaves per stem, and the pattern consisted of one stem with four leaves. In the S pattern, one leaf had an area of 401.583 mm$^2$. There were eight leaves per stem, and one pattern consisted of 12 stems. The S pattern had 96 leaves in total. Figure 1 demonstrates the area of the L pattern and S pattern samples, and Figure 2 demonstrates the shapes of L pattern and S pattern samples when fabricated into the tree like structures.

![Figure 1. Leaves of the L pattern and S pattern.](image-url)
Figure 2. Three-dimensional schematic diagram of the L pattern and S pattern.

2.2. Synthetic Leaf Structure Fabrication Method

Previous research on the method of fabrication of synthetic leaves was surveyed for the experiment [10]. The method used is outlined below. First, a glutinous rice glue solution (boiled with 10 g of glutinous rice powder in 1 L of water) was applied to cotton poplin to make it stiff, prevent wrinkles or folds, and the cotton poplin was cut in a shape of a leaf. Second, a commercially manufactured artificial stem (wrapped in green paper) was attached to one side of each leaf with instant glue. Small holes were made in wood dowel stems, and the leaves were inserted and secured in the stems. Third, the leaves made before the experiment were immersed in deionized water and shaken to remove the remaining particles. Finally, the leaves were dried at 35 °C for 30 min using an enclosed drying chamber to prevent contamination with the indoor particles. All the materials used in this experiment are selected to control the influence of additional variables. Using the same fabric, without any pleats or folds, produced artificial leaves with exactly the same surface characteristics and roughness [10]. The cotton poplin stiffened with rice glue reflects the characteristics of leaves well. There was no shape deformation during the pre-treatment process, and the synthetic leaf withstood well without damage throughout the experiment. For the accuracy of the experiment, the synthetic leaves were used only once.

2.3. Chamber Experiment

The chamber experiment was conducted by putting the produced synthetic leaf structures into the chamber, artificially generating PM, and measuring the level of PM$_{2.5}$ and PM$_{10}$ inside the chamber for a particular time to compare the rates at which PM levels decreased. The experimental apparatus is shown in Figure 3.
Experiments were conducted five times for each pattern (L pattern and S pattern) and, for the sake of comparison, for an empty chamber. The chamber was made of acrylic material with the size of 500 mm (w) × 500 mm (d) × 700 mm (h). A particle generating unit, particle mixing unit, and dehumidification unit were placed in the upstream of the main chamber, where PM tests were conducted [16].

The PM flow was generated by burning commercially available mosquito repellents inside the particle mixing unit and using compressors and flow meters. It was then injected into the chamber at a constant rate through air mixing and dehumidification units. The main experimental chamber contained samples to be tested, PM measuring devices, and a wireless fan. Humidity, temperature, and wind speed were maintained constant in the chamber: humidity was maintained at the level of 30–35%, temperature at 18 °C–22 °C, and wind speed at about 1 m/s.

The process of the experiment was as follows. First, PM was artificially generated, and air containing PM was injected into the enclosed chamber at constant pressure. As soon as the level of PM$_{2.5}$ indicated by the measuring device exceeded 450 µg/m$^3$, the injection stopped. The PM levels inside the chamber were recorded for 60 min after the injection stopped.

To measure PM$_{2.5}$ and PM$_{10}$, we used the Dylos DC1700 device. The device measures the number of particles per 0.01 cubic foot using the light scattering method (>0.5 µm, >2.5 µm) and converts them to PM$_{2.5}$ and PM$_{10}$ (µg/m$^3$). The device records the data by averaging the levels measured for one minute.

2.4. Creating Architectural Surfaces with Different Complexity

We found a noteworthy difference in PM capturing performance between the large and sparse pattern and a small and dense pattern. Based on these results, we established a hypothesis that if a specific area is divided into small sections to create gaps and volumetric surfaces, there will be a difference in PM capturing performance compared to the flat surface area.

Using the 3D modeling software Rhinoceros 3D, three types of surface models with the same area were created: base (B surface), folded (F surface), and folded and porous (P surface). The origami method (Japanese paper folding method) was used to make the flat base surface (B) into a more volumetric folded surface (F). The same method was used to create the folded and porous surface (P). The three surfaces were about 240 mm × 240 mm in size and had the same surface areas of 119,040 mm$^2$ (Figure 4). When a planar surface is folded to form a volumetric surface, its size seems smaller from a plan view. However, all three surfaces have the same overall surface area. The samples for conducting chamber experiments were made from reinforced resin by utilizing an SLA-style 3D printer.

![Figure 4. Architectural surfaces with different complexity.](image-url)
Figure 4. Architectural surfaces with different complexity.

3. Results
3.1. Effect of Leaf Cluster Patterns on PM Capturing Performance

When the PM$_{2.5}$ level measured by the measuring device inside the chamber exceeded 450 μg/m$^3$, the PM injection stopped. Even after the injection stopped, the level of PM inside the chamber continued to increase slightly. The PM level peaked within a minute or two and then gradually decreased. Even after the injection was stopped, the increase in the PM level is believed to be due to the time shift between the area where PM was generated and the area where PM was measured.

Experiments were conducted five times for each pattern, and the mean values were graphed (Figures 5 and 6). For comparison, we also measured how PM levels were naturally reduced by gravity in the empty chambers without samples.

Figure 5. Changes in the PM$_{2.5}$ levels inside the chamber by cluster patterns.
Comparing the mean values of the five experiments for the L pattern, S pattern, and the empty chamber shows the difference in the rate of PM reduction according to the pattern. Compared with the empty chamber, PM inside the chamber with the L pattern structure decreased faster. PM decreased faster when the S pattern structure was in the chamber compared with the L pattern structure. Both PM$_{2.5}$ and PM$_{10}$ showed similar patterns. Considering the limitations of the experimental setting, the maximum values of PM levels varied slightly in each experiment. Table 1 demonstrates the comparison of PM$_{2.5}$ reduction levels in 10-min intervals inside the chamber for the three experimental conditions by considering the level of reduction from the maximum level.

Table 1. PM$_{2.5}$ reduction mean values compared to the maximum level (Unit: $\mu$g/m$^3$).

|       | S     | L     | E     |
|-------|-------|-------|-------|
| 10 min| 17.5% | 16.8% | 15.2% |
| 20 min| 26.0% | 24.5% | 21.0% |
| 30 min| 33.2% | 30.6% | 25.7% |
| 40 min| 40.0% | 36.6% | 29.9% |
| 50 min| 46.4% | 42.2% | 34.6% |
| 60 min| 52.0% | 46.9% | 39.1% |

Table 1 shows that the reduction is more significant when the S pattern is in the chamber than when it is empty. After 10 min, the average decrease rate of PM$_{2.5}$ compared to the maximum level was 17.5%, 16.8%, and 15.2%, for the S pattern, L pattern, and empty chamber, respectively. There was a 1% or 2% reduction rate difference between the S pattern and the L pattern and the S pattern and the empty chamber, respectively. After 30 min, the average decrease in PM$_{2.5}$ particles compared to the maximum level was 33.2% for the S pattern, 30.6% for the L pattern, and 25.7% for the empty chamber, indicating that the difference between the S pattern and the L pattern was about 3% and the S pattern and the empty chamber about 8%. Finally, after 60 min, the average decrease in PM$_{2.5}$ level compared to the maximum level was 52.0% for the S pattern, 46.9% for the L pattern, and 39.1% for the empty chamber, showing a difference of about 6% between the S pattern and the L pattern and about 13% between the S pattern and the empty chamber. In other words, the difference in PM$_{2.5}$ reduction rates between the S pattern, L pattern, and the empty chamber increased with time.
Table 2 demonstrates that the S pattern has a higher PM$_{10}$ reduction rate than the L pattern or the empty chamber. After 10 min, the average decrease in PM$_{10}$ from the maximum level was 26.6% for the S pattern, 25.8% for the L pattern, and 21.6% for the empty chamber. There was a 1% and 5% difference between the S pattern and the L pattern and the S pattern and the empty chamber, respectively. After 30 min, the average decrease in PM$_{10}$ compared to the maximum level was 45.6% for the S pattern, 43.2% for the L pattern, and 35.9% for the empty chamber. The reduction rate difference between the S pattern and the L pattern was about 2%, and between the S pattern and the empty chamber, about 10%. After 60 min, the average decrease in PM$_{10}$ compared to the maximum level was 62.8% for the S pattern, 58.6% for the L pattern, and 50.6% for the empty chamber. The rate difference between the S pattern and the L pattern was about 4%, and between the S pattern and the empty chamber, about 12%. As a result, the difference between the S pattern, L pattern, and empty chamber’s PM$_{2.5}$ and PM$_{10}$ reduction rates increased over time.

Table 2. PM$_{10}$ reduction mean values compared to the maximum level (Unit: µg/m$^3$).

|        | S   | L   | E   |
|--------|-----|-----|-----|
| 10 min | 26.6% | 25.8% | 21.6% |
| 20 min | 37.5% | 36.4% | 29.9% |
| 30 min | 45.6% | 43.2% | 35.9% |
| 40 min | 52.1% | 49.1% | 40.9% |
| 50 min | 57.9% | 54.4% | 45.8% |
| 60 min | 62.8% | 58.6% | 50.6% |

3.2. PM Capturing Performance of an Architectural Surface That Imitates the Clustering Patterns of Leaves

Five experimental trials in the chamber were conducted for each of these surfaces: a base surface (B), a folded surface (F), a folded and porous surface (P). The mean values resulted from the experimental trials were graphed (Figures 7 and 8).

![Figure 7](https://example.com/figure7.png)

Figure 7. Changes in the PM$_{2.5}$ levels in the chamber by surface type.
By comparing the graphs of the mean values of the five experimental trials for the base surface (B), folded surface (F), and folded and porous surface (P), the PM reduction rate can be determined for each type of surface. PM reduction rate inside the chamber was faster for the F surface than for the B surface. PM reduction rate was the highest for the P surface. Both PM$_{2.5}$ and PM$_{10}$ showed similar reduction patterns.

Table 3 shows that the PM reduction rate measured at 10-min intervals for the P surface was higher than that of the F and B surfaces. After 10 min, the average decrease in PM$_{2.5}$ compared to the maximum level was 12.84% for the P surface, 12.33% for the B surface, and 11.49% for the F surface. The P surface showed a slight difference of about 0.5% from the B surface and 1.3% from the F surface. After 30 min, the order of the PM$_{2.5}$ average reduction rates for different surfaces changed with the F surface moving to the second position after the P surface. The rates were 24.07% for the P surface, 22.63% for the F surface, and 22.5% for the B surface. The difference between the reduction rates for the P surface and the F and B surfaces was about 1.5%. After that, the reduction rate for the F surface was higher than that of the B surface. Finally, after 80 min, the average reduction in PM$_{2.5}$ compared to the maximum level was 52.90% for the P surface, 49.76% for the F surface, and 46.23% for the B surface. The difference between the P and F surfaces was about 3%, and between the P and B surfaces about 6%.

Table 4 demonstrates that the P surface had the highest PM$_{10}$ average reduction rate. After 10 min, the average reduction in PM$_{10}$ compared to the maximum level was 19.28% for the P surface, 19.20% for the B surface, and 18.75% for the F surface. The reduction rate for the P surface was about 0.08% higher than that for the B surface and 0.53% higher than...
that for the F surface. After 30 min, the order of the average reduction rate in PM$_{10}$ changed, with the F surface moving to the second position after the P surface. The reduction rates were as follows: 36.26% for the P surface, 35.17% for the F surface, and 35.10% for the B surface. The difference between the P surface and the F surface was about 1%. As with PM$_{2.5}$, the reduction rate for the F surface was higher than for the B surface after 30 min. Finally, after 80 min, the average reduction in PM$_{10}$ compared to the maximum level was 63.42% for the P surface, 61.21% for the F surface, and 58.64% for the B surface. The difference between the P and F surfaces was about 3%, and between the P and B surfaces about 5%.

**Table 4.** PM$_{10}$ reduction mean values compared to the maximum level.

|                   | Base Surface (B) | Folded Surface (F) | Folded and Porous Surface (P) |
|-------------------|-----------------|--------------------|-------------------------------|
| 10 min            | 19.20%          | 18.75%             | 19.28%                        |
| 20 min            | 27.99%          | 27.94%             | 28.84%                        |
| 30 min            | 35.10%          | 35.17%             | 36.26%                        |
| 40 min            | 40.56%          | 41.27%             | 42.84%                        |
| 50 min            | 45.47%          | 47.09%             | 48.48%                        |
| 60 min            | 49.99%          | 52.10%             | 53.56%                        |
| 70 min            | 54.19%          | 56.34%             | 58.68%                        |
| 80 min            | 58.64%          | 61.21%             | 63.42%                        |

### 4. Discussion

#### 4.1. Experiment’s Results of PM Capturing Performance of Different Leaf Cluster Patterns

Experiments on the effect of leaf cluster patterns on the PM capturing performance confirmed that both PM$_{2.5}$ and PM$_{10}$ levels decreased the fastest in the case of the S pattern 60 min after the injection of PM in the chamber stopped. The results confirmed that the S pattern has a higher PM$_{2.5}$ and PM$_{10}$ reduction capacity than the L pattern, even for the same surface area. The difference in PM$_{2.5}$ reduction rates between the patterns increased over time. When comparing the mean values of PM$_{2.5}$ reduction rate 10 min after the injection of PM stopped, the difference between the S pattern and the L pattern was 0.7%, and between the L pattern and empty chamber 1.6%. After 30 min, the average reduction rate for the S pattern was 2.6% higher than for the L pattern, and the average reduction rate for the L pattern was 4.9% higher than for the empty chamber. After 60 min, the average PM reduction rate for the S pattern was 5.1% higher than for the L pattern, and the average reduction rate for the L pattern was 7.8% higher than for the empty chamber. The difference between the empty chamber and the L patterns increased steadily over time, and the difference between the L pattern and the S patterns also increased steadily.

We found that the difference in PM$_{10}$ reduction rates between the patterns also grew over time. The S pattern and the L pattern recorded a 0.7% difference when the average PM$_{10}$ reduction rates after 10 min were compared. The difference between the L pattern and the empty chamber was 4.2%. After 30 min, the average reduction rate for the S pattern was 2.4% higher than for the L pattern, and the average reduction rate for the L pattern was 7.3% higher than for the empty chamber. After 60 min, the average PM reduction rate for the S pattern was 4.3% higher than that for the L pattern, and the average reduction rate for the L pattern was 7.9% higher than that for the empty chamber. The reduction in PM$_{10}$ also shows that the difference between the empty chamber and the L pattern increased steadily. The difference between the L and S patterns also grew steadily over time. Even for the same surface areas, the small and dense cluster pattern had a more significant effect on reducing PM$_{2.5}$ and PM$_{10}$ levels.

In this experimental study, PM was injected from the upper part of the chamber. The empty chamber experiment results showed a natural reduction rate in PM inside the chamber due to gravity.

Along with the shape and size of the leaves, leaf cluster patterns also affected PM capturing performance. This can be the basis for explaining the results of previous studies.
on coniferous trees demonstrating excellent results in capturing PM in the air. In other words, even for the surfaces with the same areas, small leaves with many small gaps between them capture PM more effectively than other leaf cluster patterns that are not three-dimensional and porous patterns.

4.2. Experiment Results of PM Capturing Performance of Architectural Surfaces with Leaf Cluster Patterns

By comparing the graphs of the mean values of PM levels for the B surface, F surface, and P surface, we can see the differences based on the volumetric quality of the surface and the degree of gap formation. PM$_{2.5}$ and PM$_{10}$ reduction rates were the fastest in a chamber with the P surface—folded and porous surface. Both PM$_{2.5}$ and PM$_{10}$ demonstrated similar patterns. During the first 30 min, there was little difference between the three surfaces, and the PM$_{2.5}$ and PM$_{10}$ reduction rates for the B surface were more significant than those for the F surface. After 30 min, the F surface demonstrated a higher reduction rate than the B surface, and the difference between the surfaces increased. We confirmed that the degree to which the surface is volumetric and porous affected PM$_{2.5}$ and PM$_{10}$ reduction through the chamber experiments with the three surfaces.

Experiments on architectural surfaces with morphological principles derived from artificial leaf experiments also showed that volumetric surfaces had higher reductions in PM$_{2.5}$ and PM$_{10}$ than planar ones. In addition, it was confirmed that folded and porous surfaces showed high PM reduction rates for both PM$_{2.5}$ and PM$_{10}$. However, it should be noted that any deviation during the experiments with the same surface structure was negligible compared to the differences in the reduction rates between surfaces with different structures. Additional experiments are needed to clarify further the fact that the folded and porous surface has the best PM reduction performance compared to other surfaces when the surface areas are the same.

5. Conclusions

The atmospheric PM is a significant environmental problem, and previous studies have investigated the effectiveness of trees in reducing PM in the city. This study aims to define morphological traits of trees that affect their PM capturing performance and to show the possibility of architecture adopting the traits of the trees to improve its PM capturing performance.

In this study, two series of chamber experiments were conducted. The synthetic leaf structure experiments confirmed that the leaf cluster pattern, along with the shape and size of leaves, affects the PM capturing performance. Experiments with a fixed total surface area but different leaf cluster patterns showed that cluster patterns with smaller leaves and smaller gaps between them were more suitable for PM capturing than the patterns made up of large leaves and with large gaps between them. That is presumably due to small gaps between the leaves and the leaves forming microscopic currents, increasing the probability that dust particles hit the leaves and are captured by them.

The second part of the study is to apply the morphological principles derived from the synthetic leaf structure experiments to architectural surfaces and to confirm that PM capturing performance of architectural surfaces can be improved. The experiments confirmed that the folded surface is more advantageous for capturing PM, and the folded and porous surface is the most advantageous for capturing PM. Findings from this study can be summarized as follows:

1. Cluster pattern of leaves affect PM capturing performance of the trees.
2. Smaller leaves with smaller gaps show superior PM capturing performance than the large leaves with larger gaps when the total surface area are same.
3. Architectural surfaces mimicking the leaf cluster pattern that showed superior PM capturing performance also show superior PM capturing performance.
4. The folded and porous architectural surface is the most advantageous for capturing PM when the total surface area is the same.
(5) The PM capturing performance of architectural surfaces can be improved by mimicking the cluster pattern of the leaves.

The results of this study have confirmed that it is possible to improve the PM capturing performance of the architectural surfaces by changing their morphological characteristics. This study shows the possibility to develop durable PM capturing materials and surfaces applicable to the buildings and infrastructures in urban environments. This study can initiate developing design strategies for urban infrastructure to lower the PM levels in cities. It calls for further research to investigate the traits of the trees which can be adopted for green infrastructure designs.

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