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MORE THAN JUST A GREEN FACADE: VERTICAL GARDENS FOR SOUND ABSORPTION AND ARCHITECTURAL ACOUSTICS

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Noise can become uncomfortable for us in many situations both indoors and outdoors. External noise consists of activities (airplanes flying overhead, traffic on the road, etc.) that are either loud enough to be considered uncomfortable when outdoors, or are of an elevated volume to the extent that they infiltrate buildings at levels considered uncomfortable. In the case of internal uncomfortable noise, this can either stem from noisy activities that occur inside the building (people speaking loudly, printers, etc.), or when an unexpected sound suddenly permeates an area that has a very low level of background noise. The most common manner by which to mitigate excess noise is through the use of certain materials, which either insulate against noise passing through the material, or absorb the noise wavelengths. In the case of the latter, vertical gardens present themselves as not only an aesthetic element in architecture, but also as a potential acoustic control tool in building design. For this work 10 m^2 of vertical garden substrate modules was tested in a full size reverberation chamber. The objective was to open the doors for vertical gardens to be used in architectural acoustic design.

Keywords: Green wall, Sustainable design, Architecture, Sound engineering.

1 INTRODUCTION

Renterghem and Botteldooren (2008) found that in 2000 up to 44% of residents of the EU were exposed to noise levels that were detrimental to health. Typically noise pollution in cities comes from traffic, in addition to indoor mechanical installations such as HVAC systems. It is also argued that sustainable building design should incorporate noise control systems (Khaleghi *et al.* 2008; Field 2008). There are numerous benefits in the widespread application of green roofs and vertical gardens in cities, where advantages are related to water retention, urban heat island effect reduction, insulation and biodiversity. Wong *et al*. (2010) have put forward that vegetation is also important in fighting acoustic contamination in urban environments. For example, Connelly and Hodgson (2008) put forward that green roofs could be designed for sound absorption in relation to their mass, density and moisture content. In Posada *et al.*'s research (2009), vertical gardens were found to have a beneficial effect in mitigating traffic noise. Furthermore, Restrepo and González (2009) found vertical gardens able to significantly reduce sound levels. More recently, Asdrubali and Mencarelli (2014) sought to determine the absorption coefficient of tropical plants in a porous substrate used in hydroponics cultivation. First an impedance tube was used to determine the normal incidence absorption coefficient. Second, a reverberation chamber was used to determine the diffuse field absorption coefficient. Unfortunately, the chamber dimensions were smaller than those required. Both experiments showed that the main absorber material was the substrate soil, where plants only had a beneficial effect when a large number were planted. Overall, most research to date has been in outdoor vegetation to mitigate the infiltration of uncomfortable sounds into the building interior. However, this paper seeks to build on Asdrubali and Mencarelli's work (2014), where a vertical garden design developed at the *Pontificia Universidad Católica of Ecuador* (PUCE) was tested for interior acoustic design.

2 METHODOLOGY

The main research question of this study was: "Which values does the random incidence sound absorption coefficient of the vertical garden modules filled with substrate have over the frequency range from 100 to 5000 Hz?". These vertical garden modules can be applied in different configurations: connected to form one big garden, or dispersed to form patches of smaller gardens, and directly connected to a wall versus placed in front of a wall. As such, two sub-research questions were formulated:

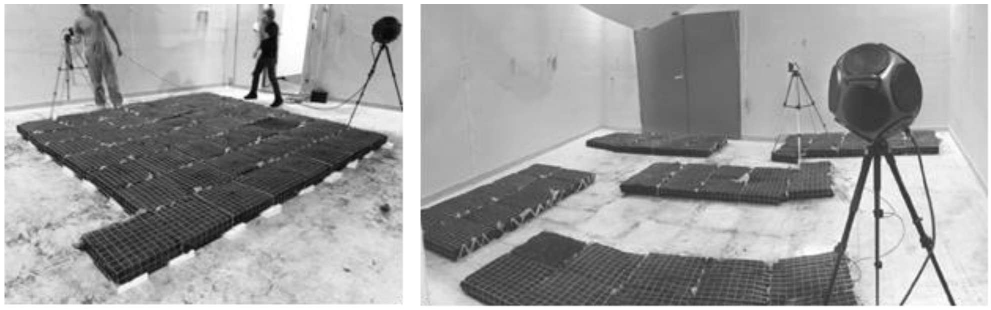
(1) To what extent will the random incidence sound absorption coefficient of the garden modules be different between a connected and dispersed configuration?

(2) To what extent will the random incidence sound absorption coefficient of the garden modules be different when the modules are directly connected to a wall, placed in front of a wall with a 5 cm air cavity or with a 10 cm air cavity?

In order to answer these questions, measurements were conducted in the reverberation chamber of the Delft University of Technology (TUDelft), which has a size of 200 m^3 and complies with the requirements of ISO 354: 2003. The research followed the procedures of the interrupted noise measurement, as described in this same standard using white noise as sound. The vertical garden modules each had a size of 0.45x0.45 m^2 with a thickness of 10 cm. The modules consisted of a steel mesh with 5 cm apertures, filled with a substrate mixture of potting soil, coco chips and sphagnum moss. The substrate was covered in a fine mesh inside the steel mesh, to avoid loss of fine grains. A total of 50 modules were used, covering a total surface area of 10.125 m^2. The modules were placed in two basic configurations on the floor of the reverberation room: connected and dispersed.

Connected: The modules were connected forming a grid of 7x7 modules plus one module attached to one of the sides (Figure 1a). The total area of the sides in this configuration was 30x0.45x0.1 = 1.35 m^2.

Dispersed: The configuration formed five groups of 2x5 modules (Figure 1b). These five groups of modules were distributed over the floor of the reverberation room. The total area of the sides in this configuration was 70x0.45x0.1 = 3.15 m^2.



(a) (b)

Figure 1. a) Modules in connected configuration, b) Modules in dispersed configuration.

Besides, these two configurations were tested in three different positions in relation to the floor: directly on top of the floor, and with a 5 or 10 cm air cavity between the floor and the modules. To create these cavities, the modules were placed on blocks of 5 cm thick Styrofoam (1 or 2 layers) with dimensions of 10x20 cm. In all cases, the sides of the configuration of modules were open, meaning that the air cavities and the sides of the panel were accessible for the sound. The main reason for choosing the sides to be open was because this more closely resembles the way the modules are used in practice.

Measurements were performed in one-third octave bands with center frequencies starting from 100 Hz up until 5000 Hz. For calculating the random incidence sound absorption coefficient of the modules, the total exposed surface area of the modules was considered, including the top and side surface area. For assessing the sound absorption by the air in the reverberation chamber ISO 9613-1: 1993 was used.

Six positions were marked on the floor of the reverberation chamber. These six positions were used for positioning the microphone. The height of the microphone was roughly 1.3 m above the floor. Positions 5 and 6, also denoted B and A, were also used for positioning the sound source. The center of the sound source was 1.5 m above the floor. As a result, a total of 10 source-microphone positions were used. Besides, each measurement was repeated at least three times.

The equipment used for the measurements was: (1) A Norsonic Nor140 class 1 calibrated sound analyzer; (2) A Norsonic Nor276 dodecahedron omni-directional loudspeaker; (3) A Norsonic Nor280 power amplifier, connected to the Nor276.

Table 1. Weighted (α_w), low frequency (α_L; average of 100 – 315 Hz), mid frequency (α_M; average of 400 – 1250 Hz) and high frequency (α_H; average of 1600 – 5000 Hz) random incidence sound absorption coefficient of the measured configurations.

Configuration	α_w	α_L	α_M	α_H
Connected - on floor	1.00	0.76	1.00	0.94
Connected - 5 cm air gap	1.00	0.82	1.00	0.98
Connected - 10 cm air gap	1.00	0.80	1.00	0.99
Dispersed - on floor	1.00	0.73	1.00	0.93
Dispersed - 5 cm air gap	1.00	0.74	1.00	0.95
Dispersed - 10 cm air gap	1.00	0.73	1.00	0.93

3 RESULTS

Table 1 and Figures 2 (a and b) present the results of the measurement for all of the configurations. The error bars shown in the figure represent the imprecision or uncertainty of the measurements based on the recommendations of ISO 354: 2003. A result of edge scattering yields values of the absorption coefficient higher than 1.

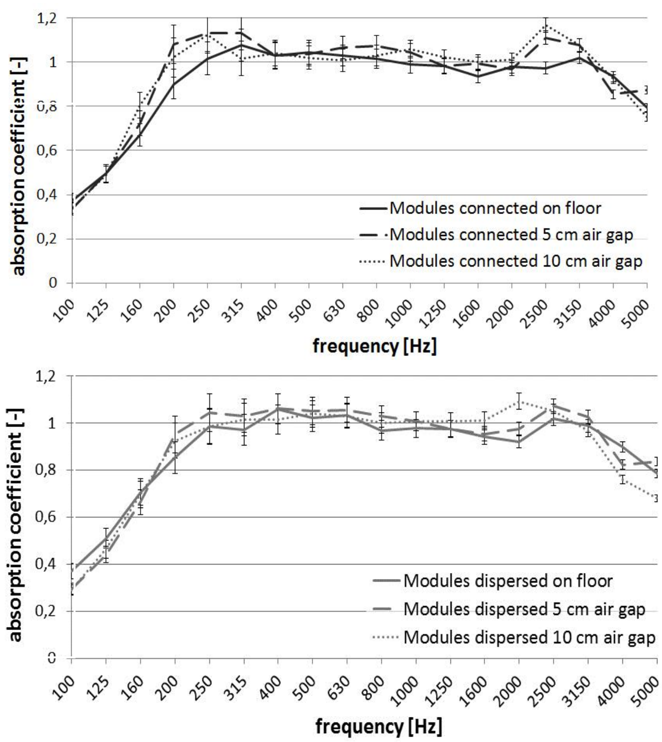


Figure 2. Random incidence sound absorption coefficient, α_s, of the a) connected configurations, b) of the dispersed configurations.

4 DISCUSSION OF RESULTS

4.1 On Floor versus Raised

As can be seen from Figure 2, the substrate follows the behavior of porous absorbers: low sound absorption in the lower frequencies, and high absorption in the higher frequencies. Between 250 Hz and 3150 Hz, the sound absorption coefficient is around 1 (the slightly larger than 1 value is a result of edge scattering). Above 3150 Hz a slight decrease in the sound absorption is visible. This decrease generally is attributable to the measuring equipment and not so much to the material under investigation. Moreover, the difference between the modules directly on top of the floor and the raised modules (5 and 10 cm air gap) is negligible. A peak around 2500 Hz may be attributed to the onset of standing waves inside the modules. Such standing waves arise when the thickness of the material under investigation corresponds to (a random integer times) half a wavelength of the sound. The first frequency where this is expected to happen is

343/2/0.1 = 1715 Hz. Assuming that the thickness of the substrate in many places was less than 10 cm as a result raising this frequency, this value is fairly close to 2500 Hz.

4.2 Connected versus Dispersed

Figure 3 shows the sound absorption coefficient of the modules placed directly on the ground, both in connected and in dispersed configuration. These coefficients are based on the assumption that all exposed surface areas are considered in the calculation. As can be seen, there is no significant difference between the connected and dispersed configuration. The difference between these configurations can be found if not the total exposed surface area is used for computing the absorption coefficient (Figure 3a) but only the top surface area (Figure 3b). In that case, the total absorption is normalized on the top surface area only. Since the exposed surface area of the dispersed configuration is bigger – there is more side area – the total sound absorption is higher, and as a result, the absorption coefficient is higher. However, for characterizing the substrate as a material, it is important to consider the total area exposed to sound.

(a)

(b)

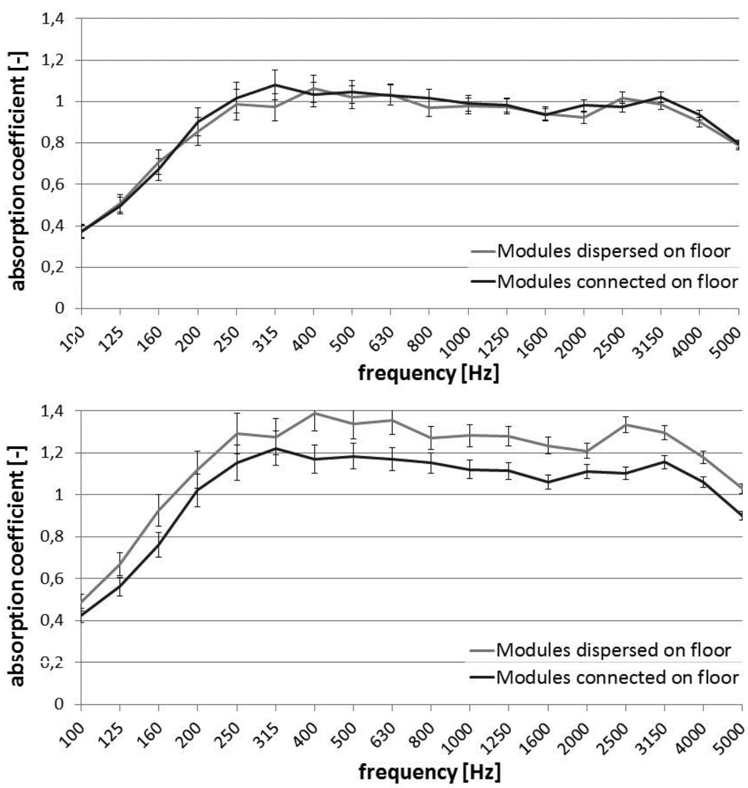


Figure 3. Random incidence sound absorption coefficient, α_s, of the 'on the floor' configurations in case the total exposed surface area (top and side area) (Figure 3a) or only the top area (Figure 3b) is used for calculating the absorption coefficient.

5 CONCLUSION

During this study the random incidence sound absorption coefficient of the vertical garden modules developed at the PUCE were measured in the reverberation room of the TUDelft. A total of 50 modules making up a total floor area of 10.125 m^2 was used for the measurements. Six configurations were measured: connected versus dispersed and directly on the floor versus with an air cavity of 5 or 10 cm. In general, no difference was found between the six configurations: neither air gaps, nor dispersing the modules had an effect on the absorption coefficient. In general, the sound absorption follows the pattern of porous absorbers: low absorption in the lower frequencies, high absorption in the higher frequencies. The weighted sound absorption coefficient of the modules with substrate, for all configurations tested, equals 1.00. This makes this type of substrate highly suitable for applications were sound needs to be attenuated, paving the way for applying vertical gardens for the acoustics of indoor spaces or urban squares.

6 RECOMMENDATIONS FOR FURTHER RESEARCH

First, it is recommended to repeat the study with the same modules, filled with the same substrate, but heavily populated with plants such as ferns or baby tears. Second, certain other characteristics of the substrate, like flow resistivity, porosity and density, were not measured. As a result, a comparison of the measured results to theory is difficult.

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