

Sustainable Materials for Sound Absorption and Insulation: Paper ICA2016-695

Acoustic properties of green walls: Absorption and insulation

Rodolfo Thomazelli^(a), Fernando Caetano^(b), Stelamaris Bertoli^(c)

^(a) Universidade Estadual de Campinas, Brasil, rodolfo.thomazelli@gmail.com

^(b) Universidade Paranaense, Brasil, durso.arq@gmail.com

^(c) Universidade Estadual de Campinas, Brasil, rolla@fec.unicamp.br

Abstract

In the past few decades, the issue of environmental quality in the urban environment is a recurring theme. Green walls and roofs have demonstrated great efficiency in the attenuation of adverse effects such as heat islands. The thermal characterization of these systems are well studied, however few studies have been carried out on their acoustic potential. The characterization of the acoustic performance of green walls may provide better results for the acoustic simulation of urban environments where such elements are employed. This paper presents experimental results of the sound absorption and insulation tests for a modular system of vegetable panels. Each module was composed of a baseplate made of laminated plywood, equipped with 9 geotextile bags in which was inserted a highly porous substrate, and grown a specie of plant with high leaf density. Absorption tests were conducted in a reverberation room, where sound absorption coefficient over frequency was measured. The sound absorption of the panels were analysed in three different situations, in order to better characterize the contribution of each part of the system: (I) baseplate + geotextile bags, (II) baseplate + geotextile bags + substrate, and (III) plate base + geotextile bags + substrate + vegetation. Façade insulation tests were performed with the same types of sample placed on a concrete block façade of a small building. Results showed a significant increase of sound absorption coefficients at the whole spectrum when substrate and vegetation were inserted on the baseplates in each situation. Both the standardized level difference and the weighted standardized level difference showed a small improvement in the insulation for the sample with vegetation.

Keywords: sound absorption; sound insulation; green walls.

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1 Introduction

The recent spread of vegetal skins in urban buildings in many parts of the world integrates the trend to use low impact friendly environmental technologies in order to achieve mitigation and passive environmental comfort. One of the major advantages in the use of these systems, mainly those with vertical configuration (green walls), lies in its ability to create green urban areas without struggle over the land use [1] [2].

It has been a long time that the scientific community knows about the role of vegetation in the balance of many natural cycles and the environmental quality. However, often the plants benefit the buildings in indirect ways, a fact that can be changed by its incorporation directly to the surfaces of buildings [3] [4].

Several studies in Brazil and worldwide have addressed the potential for thermal mitigation of green walls, but little has been published about its ability to mitigate the urban noise. Thus, the understanding the system acoustic behaviour is still poor and inconsistent, and partly it is due to the lack of standardization in the methodology used in different studies [5].

According to the World Health Organization [6] the noise is a major source of environmental pollution in urban centres, affecting directly their quality of life. Many studies have shown that, apart from hearing loss by aging, urban noise can still bring sleep disturbances, low performance in daily activities, and even changes in blood pressure, increasing the risk of cardiovascular diseases [7] [8] [9].

The ability of vegetation in lowering urban noise, especially noise of vehicular traffic, has been addressed since the 1970s, demonstrating that trees and shrubs barriers attenuate noise according to its width and density. [10] indicate that a conifer barrier 15 meters wide is able to attenuate up to 8 dBA, a moderate value for this dimension.

The foliage of the vegetation itself has a very low mass to perform substantially as an insulating material; however, through reflection and sound scattering the foliage and branches make possible to obtain a significant attenuation. Moreover, a part of the incident noise is absorbed by the thermoviscous layer of air that surrounds the leaves, and by converting sound energy into mechanical vibrations, so dissipated as heat. [11]

In fact the vegetation alone is capable of attenuate acoustic vibrations mainly at high frequencies, but considering the combined effect of the soft ground with dead leaves and roots both the level of attenuation as the frequency range increases [10]. [12] emphasize that the use of a lightweight and porous substrate dramatically increases the capacity of sound absorption by plants, even reaching the acoustic performance of materials such as glass wool.

In addition, other vegetation settings such as creepers, vines and shrubs can enhance the sound absorption of the surfaces compared to arboreal vegetation [12] [13]. Given that these conditions

are found in green wall systems (lightweight and porous substrate layer associated with trailing foliage), there is an interest in analysing its acoustic behaviour relative to the noise absorption, and potential for improve the sound insulation in masonry elements.

[5] point out that prior knowledge about the acoustic properties of different materials and coatings provides an advantage to the architectural design stage of buildings. In this sense, this article aims to present the results of two experimental analyzes with a modular living wall system: 1) sound absorption capacity, and 2) air sound insulation capacity, thus creating a basis for future acoustic simulations in the urban environment and indoors with the use of the system.

2 Methodology

2.1 Selection and assembly of the green wall system

The living wall system analyzed in this study consisted of modular sealed plywood boards, upon which geotextile bags were fixed. Inside the bags were then placed the growth medium (substrate) and plants (FIGURE 1).



Source: (Authors, 2015)

Figure 1: Modular panel and assembly scheme of the system

Generally the system was designed to bring a low increment of load to the wall, and operate in a self-sustaining way through semi-hydroponic irrigation. For this was used a coconut fibre based growth medium (granular and fibrous portions of the coconut mesocarp) associated with the mineral perlite. Thus, it was possible to obtain a very lightweight substrate, with a porosity of 87 %, apparent density of 71 kg/m³, and liquid retention capacity of 400 ml per litre of substrate.

At first, the selection of plants to the system considered environmental resistance and maintenance need criteria. On the other hand, the sound absorption could be enhanced with the use of high density good coverage plants [14] [15], as indicated by another studies on the noise attenuation of green belts [11]. Therefore, taking into account all these factors was chosen the species *Callisia repens* to perform this experiment, which in adulthood has the above features.

2.2 Acoustic measurements: Absorption

To obtain the sound absorption coefficients of the system, tests were performed in a reverberation room. The experimental procedure was based on ISO 354 [16], which provides instructions for absorption coefficient evaluations. Reverberation time of the room both with and without the sample (20 panels placed in the centre of the room, covering a total area of 7.2 m²) were measured.

For this, four microphone and two source positions were chosen. For each one of the eight combinations, three measurements were made, and the averaged values were used for the absorption coefficient calculation. The measurements were carried out in 1/3 octave band among 100 and 5000 Hz. The *Building Acoustics* system from *Bruel & Kjaer*, composed of an omnidirectional source (BK 4296), a signal amplifier (BK 2716) and a real-time frequency analyzer (BK 2260 *Investigator*) was used as experimental setup.

In order to characterize the acoustic contribution of each part of the assembly, the modular system was analyzed in three different configurations. The settings chosen were: (I) baseplate + geotextile bags, (II) baseplate + geotextile bags + substrate, and (III) baseplate + geotextile bags + substrate + vegetation. In the three configurations described, the set of panels were positioned directly in the room floor. To simulate a situation closer to reality (in which the panels should be installed over steel bars fixed on the facade), tests in configuration II were also conducted with the panels supported on wooden slats (FIGURE 2).



Source: (Authors, 2016)

Figure 2: Pictures of the reverberation room with (a) the modular system in configuration III and (b) the modular system in configuration II supported on wooden slats

2.3 Acoustic measurements: Insulation

The sound insulation tests were carried out on the facade of a building made of concrete blocks masonry and concrete slab. For the panels installation, 5 steel bars of 2 x 5 x 300 cm were vertically fixed on the facade under analysis. The tests were conducted for three different conditions: (a) facade without panels (with steel bars already installed); (b) facade with 20 panels of configuration I (baseplate + geotextile bags); and (c) facade with 20 panels of configuration III (base plate + geotextile bags + substrate + vegetation). Figure 3 shows the pictures of the building in the three conditions.



Source: (Authors, 2016)

Figure 3: Pictures of the three insulation test conditions

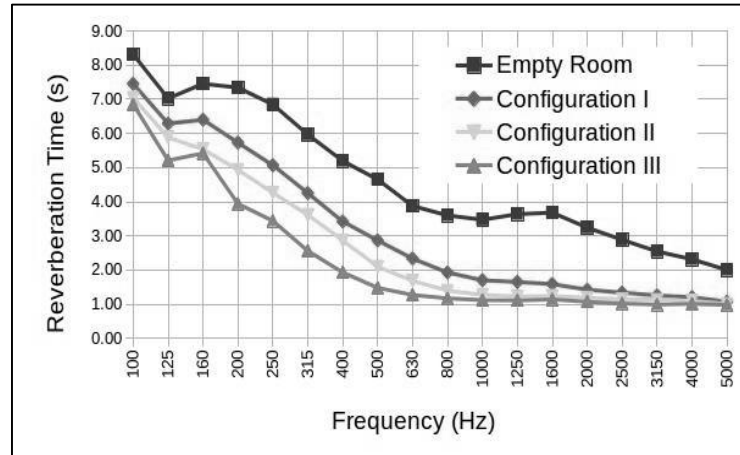
The experimental procedure was based on the global method of ISO 140-5 [17], which provides instructions for sound insulation measurements in facades and of facade elements. The sound pressure levels were collected for a fixed source and 8 microphone positions (3 external and 5 internal to the building). The reverberation time of the building (which values are necessary for the standardized level difference ($D_{2m,nT}$) calculations) was obtained from one source and 3 microphone positions due the reduced internal space of the building. For each situation the measurements were repeated three times and the averages over the frequency range were calculated. The measures were executed in 1/3 octave bands among 100 and 5000 Hz. The experimental setup used on this stage was the same as used for testing sound absorption.

3 Results and discussion

3.1 Sound absorption

The curves in the Figure 4 graphic shows a comparison between the reverberation time (RT) in function of frequency obtained in trials with the empty reverberation room and then filled with the panels in the three configurations described above. It is possible to note that the presence of the panels caused a reduction in the measured reverberation time over the entire analyzed frequency band, having greater influence the more complete the system configuration was. This behaviour shows that the sound absorption of the samples increased successively. It is also observed that from 2 kHz the substrate contribution to the RT reduction decreases considerably. The same behaviour occurs for the setting with plants, in this case from 1 kHz.

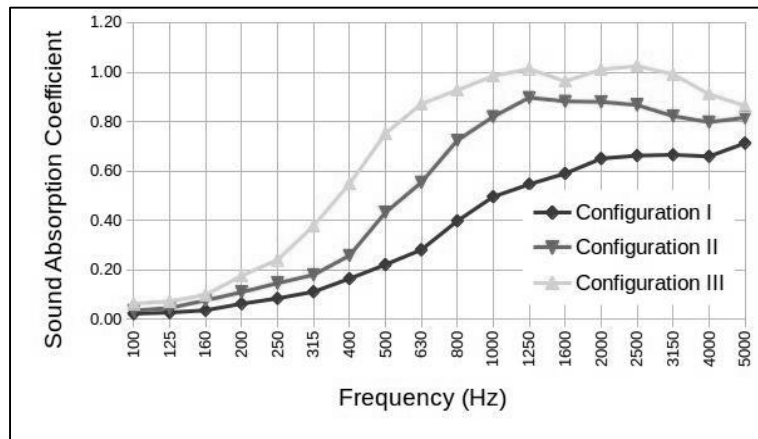
The analysis of Figure 4 also let state that the main agent for the RT reduction along the analyzed frequency range are the geotextile bags, whereas the plasticized surface of the plywood does not behave as a good absorber material. However, the behaviour obtained for frequencies below 200 Hz cannot be accurately analyzed, since in this region the modal features of the room may have compromised the results.



Source: (Authors, 2016)

Figure 4: Reverberation time in function of frequency to the room empty and filled with panels in configurations (I), (II) and (III)

In Figure 5 the curves at the graph represent the sound absorption coefficient in function of frequency obtained for the three panels configurations analyzed. It is observed an increase in the absorption coefficients at all frequencies by inserting, respectively, the substrate and the plants in the bags of the plywood base. This behaviour is a reflection of reverberation times shown in Figure 4.

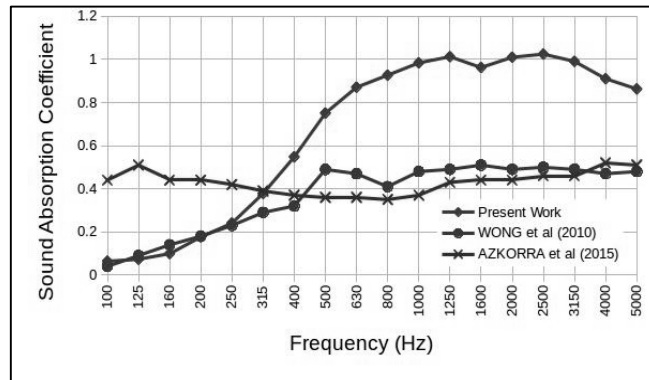


Source: (Authors, 2016)

Figure 5: Absorption coefficients in function of frequency to the configurations (I), (II) and (III)

Specifically in the Configuration III (complete panel), the sound absorption coefficients obtained show that the system has a great potential for use as sound absorption element, even performing similarly to materials developed specifically for acoustic conditioning, especially above 500 Hz.

In the Figure 6 are shown comparative results between the sound absorption coefficient in function of frequency obtained in this study and in two another similar works, which assays were too carried out in reverberation room according ISO 354 [16].



Source: Adapted from [15] and [5] by the authors

Figure 6: Comparison of the sound absorption coefficients by vegetal panels in 3 different works

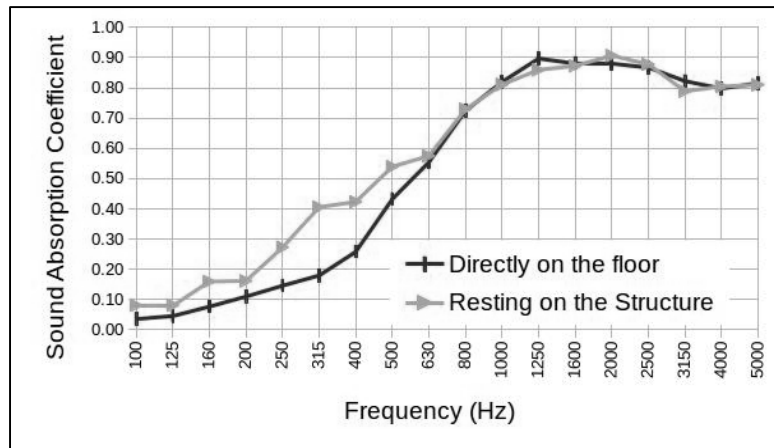
In the work of [15] the studied panels were composed of a wooden frame in which were inserted vessels with the vegetation. The authors evaluated the influence vegetation cover on the absorption coefficient, comparing results obtained from coated panels at 43 %, 71 % and 100 % of the area. According to the authors, the substrate was the main responsible for the efficiency of the panels at sound absorption of low frequencies; meanwhile, the vegetation acted acoustically at high frequencies, but more like a spreading mechanism, which did not produce a significant effect in reducing the reverberation time. The authors concluded that the area covered by vegetation affects the sound absorption for frequencies between 250 and 1 kHz. In the graph of Figure 6 is shown the curve of sound absorption coefficient for panels 100 % covered by vegetation in that work.

Meanwhile, in the working of [5] the panels were composed of plastic modules in which the substrate and the plants were inserted. The authors compared their results of sound absorption coefficient with other works, concluding that the plant panels have potential as sound absorbers, and that the variation in the acoustic performance is consequence of the various configuration possibilities of the panels and materials that compose them.

In the Figure 6 it is also noted the difference between the sound absorption coefficients from this study and the other two, for frequencies above 400 Hz. The many variations among the presented configurations are noticeable, but the use of geotextile bags seems to be the main factor responsible for the higher behaviour here. This happens because besides the good sound absorption of the geotextile in the range in question (as can be seen by the graph analysis of Figure 5), it is not a rigid and reflective barrier like the plastic and the vessel, as pointed [5].

Another important detail seen in the Figure 6 graph relates to the better sound absorption performance presented for the panels in the work of [5], for frequencies below 315 Hz. Apparently this behaviour arises from the configuration of its wood substructure, which due to the distance of 120 mm from the room floor generated an air box under the panels. It is known that this type of arrangement allows materials to act as vibrant panels system with high performance of absorption at low frequencies. For the other two papers the assays were performed with the panels positioned directly on the surfaces of the room (floor for this work and wall for the work of [15]).

The comparison of the sound absorption tests with configuration II (baseplate + geotextile bags + substrate) mounted directly on the floor and later resting on a wooden structure confirm the hypothesis of the plates functioning as vibrant panels, improving absorption in low frequencies. This result is shown in the graphic of Figure 7, which shows that the presence of a substructure of wooden laths (in this case forming a 20 mm air gap) increased the sound absorption coefficient compared to the panels placed directly on the floor of the camera, for frequencies below 630 Hz.



Source: (Authors, 2016)

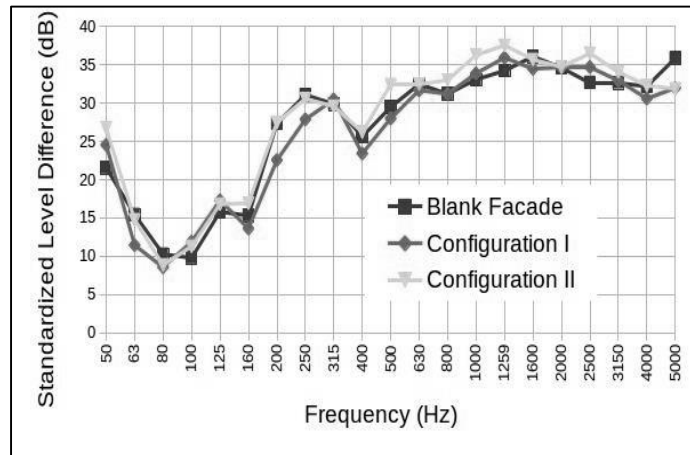
Figure 7: Influence of the gap formed by the laths substructure in the sound absorption coefficient of configuration II

3.2 Sound insulation

Sound insulation tests were performed on three situations: (a) blank facade, (b) facade covered with modular panels of configuration I (base plate + geotextile bags) and (c) facade covered with modular panels of configuration III (baseplate + geotextile bags + substrate + vegetation). The curves presented in Figure 8 show the standard level differences from the three situations analyzed. In general, the contribution of the modular system for the sound insulation shows to be minimal. The presence of panels of configuration I results in lower values for standardized level difference in some regions of the spectrum. For configuration III, this effect occurs only between 4 and 5 kHz.

From the measured standardized level difference ($D_{2m,nT}$), single-number values of sound insulation were calculated (weighted standardized level difference - $D_{2m,nT,w}$). The results were 31 dB, 31 dB and 33 dB for the three tested situations, respectively. The complete modular panel improved the sound insulation in 2 dB.

Verifying the minimal contribution of vegetation green walls for soundproofing, [18] who conducted similar studies to this work, suggests that the optimization of a panel system should take into account the mass (thickness of panels and substrate composition), impenetrability (sealing between parts of the system) and structural insulation (panel-facade coupling) - *i.e.*, all extra-vegetation factors. In fact, for the system studied in this paper, these factors can be improved, especially the impenetrability: the coupling between plates and the coupling between the plates and the installation frame weren't sealed, which is essential for sound insulation.



Source: (Authors, 2016)

Figure 8: Standardized level difference for blank facade, facade covered with modular panels of configuration I, and facade covered with modular panels of configuration III.

4 Conclusions

This article presents the results of sound absorption and sound insulation tests performed on a modular system of green wall. The values can provide input for computer simulations of urban sound environment and internal quality of buildings with green walls. The system tested consisted of modular plasticized plywood panels, on which geotextile bags were applied. Inside the bags were inserted the growth medium (substrate) and the plants (*Callisia repens*).

The sound absorption coefficients were obtained in three different configurations, in order to characterize the acoustic contribution of each part of the assembly. The chosen settings were: (I) baseplate + geotextile bags, (II) baseplate + geotextile bags + substrate, and (III) baseplate + geotextile bags + substrate + vegetation. For frequencies above 1000 Hz the absorption coefficients are practically constant and greater than 0.5. Specifically for setting III (full panel), the sound absorption coefficients reached 1.0, demonstrating the great potential of this system to use as sound absorbing solution. For configuration II, the results for the panels supported by wooden battens has shown an increase in sound absorption coefficient in the range between 200 and 630 Hz.

Sound insulation tests were performed considering three situations: (a) facade without modular panels, (b) facade covered with modular panels in configuration I (base plate + geotextile bags) and (c) facade covered with modular panels in Configuration III (baseplate + geotextile bags + substrate + vegetation). The differences between the results for tests with and without panels (in both settings) showed that, in general, the contribution of the modular system for sound insulation is not expressive. Note that in certain regions the presence of panels of configuration I results in lower values for standardized level differences in various regions of the spectrum.

The calculated values of the weighted standardized level difference ($D_{2m,nT,w}$) for the three test situations were 31 dB, 31 dB and 33 dB, respectively. The full panel conferred a 2 dB rise in air insulation of the facade.

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