EXTENDED ABSTRACT

MARTA BRUNO

1. INTRODUCTION

The benefits of green roofs and walls have been a subject of study and incentive to their use. One of such benefits is sound attenuation, even though the efficiency of using these infrastructures as noise reduction solutions is still an underexplored issue.

This dissertation focuses on the potential of green coating systems for acoustic absorption and insulation within the context of a building.

In order to do so, a research on green coating systems' characteristics that can be most influential in acoustic performance has been performed. The research methodology consists of consulting acoustic experimental test methods applied by other bibliographical references and gathering the respective results, according to the characteristics of the tested samples. It is also presented a proposal of two experimental procedures adapted to green roofs and walls, along with a test of influence parameters studied.

2. ACOUSTICAL CONCEPTS

When a sound wave strikes the surface of a material, part of the sound energy is reflected back, another part is transmitted through the material and the remaining percentage is absorbed through conversion to heat energy. To reduce reverberation within a space, strategies are applied to decrease the percentage of sound energy reflected on the surfaces surrounding it. Thus, sound absorption is a fundamental property in the study of acoustic conditions indoors.

A material's sound absorbing properties are expressed by the sound absorption coefficient, α, as a function of the frequency. α expresses the ratio between the amount of sound energy that is not reflected by a surface and the incident sound energy. It ranges from 0 (total reflection) to 1 (total absorption).

There are several standard methodologies for determining the noise absorption coefficient of a building element. ISO (International Organization for Standardization) standards describe three procedures that may be applicable: reverberant chamber tests, for diffuse sound field testing (ISO 354: 2003); impedance tube tests, for normal incidence (ISO 10534-2: 1996); or *in-situ* tests, for free sound field testing (ISO 13472-1: 2002).

There are some statistical parameters, such as the noise reduction coefficient (NRC), that enable to calculate a weighted value of the material's noise absorption coefficient. The NRC can be calculated by the formula:

$$NRC = \frac{\alpha\ (250\ Hz) + \alpha\ (500\ Hz) + \alpha\ (1000\ Hz) + \alpha\ (2000\ Hz)}{4} \quad . \tag{1}$$

Since part of the sound energy can be transmitted through constructive elements, the sound produced in a space may be listened in another adjacent compartment. The quantification of the airborne sound insulation provided by constructive elements tested in the laboratory is carried out using the sound reduction index R (dB), according to the expression:

$$R = L_1 - L_2 + 10 \log\left(\frac{S}{A_2}\right) \quad , \tag{2}$$

where L_1 is the average sound pressure level in the room where the sound source is (dB); L_2 is the average level of sound pressure in the receiving room (dB); A_2 is the sound absorption equivalent area of the receiver room (m^2); and S is the area of the separation wall (m^2). R is expressed in decibels (dB) and also varies with frequency.

There are standards available for measuring insulation to airborne sounds on facades and facade elements (ISO 10140-2:2010; ISO 140-4:1998; ISO 140-5:1998), but not on roofs. For these tests, it would be required at least one sound source and one microphone in the emitter room and at least one microphone in the receiving room.

In order to compare R of different buildind elements, this index can also be simplified to a weighted sound reduction index, R_w, which can be determined by adjusting the insulation curve to a conventional reference description according to the procedure of ISO 717-1:2013. In this adjusted curve, R_w corresponds to the ordinate value for the 500 Hz frequency band.

3. Green coating types and characteristics

3.1 Green roofs

The traditional (and most common) construction system of a green roof is the multilayer system, which consists of different layered components (Figure 1). As an alternative to the multilayer system, there are modular systems, which are pre-planted blocks that facilitate the installation process.

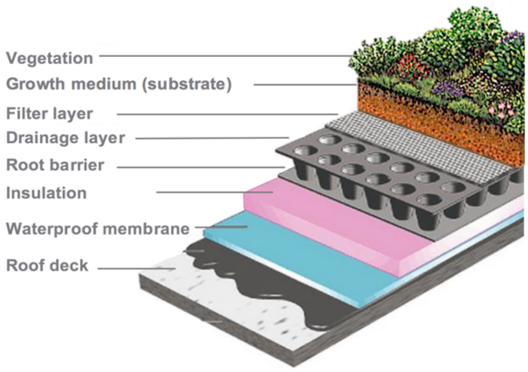

Figure 1 – Green roof layer components (traditional system).

Four types of green roof can be distinguished by varying the characteristics of the layers (FLL, 2008; IGRA, 2017):

- Intensive - in which the substrate layer is thicker than 15 cm. There is a wide range of plant species that can be chosen, including those with higher dimensions and water needs. It's accessible to people, like a garden. It requires higher maintenance and costs.

- Extensive – In contrast to the intensive type, the extensive type requires less maintenance, costs and water needs. These green roofs are not accessible. Their substrate layer's thickness is lower than 20 cm and the vegetation should meet the requirements of little irrigation and fertilization (sedum plants are typically used).

- Semi-intensive – It's a combination of the characteristics of both intensive and extensive types. The substrate's thicknesses range from 12 to 25 cm and support grasses, shrubs and perennial plants. These green roofs may be moderately accessible and their maintenance requirements are between the previous described types.

- Brown roofs - The characteristics of this type are similar to those of the extensive type, distinguished by the fact that the vegetation is not installed by humans. Instead, spontaneous plants germinate in the substrate layer of the roof over time.

3.2 Green walls

The construction's system of vertical green coatings varies with different type of green wall.

Two main green wall types are considered: green façades and living walls (Figure 2). The first type requires climbing or hanging plant species to cover the vertical surface. The majority of green façades' vegetation climb directly on wall (direct green façades) or cling to trellises, which give plants a framework to grow (indirect green facades).

Living walls are vertical systems attached to a structural wall that use geotextile panels (continuous type) or modules of different materials (modular type) to support the vegetation. The continuous systems have a metal structure fixed to the wall, on which is installed a waterproof membrane and then the geotextile panels, which have pockets for the vegetation to be placed. Modular systems are usually tray or pot holders fixed onto the wall.

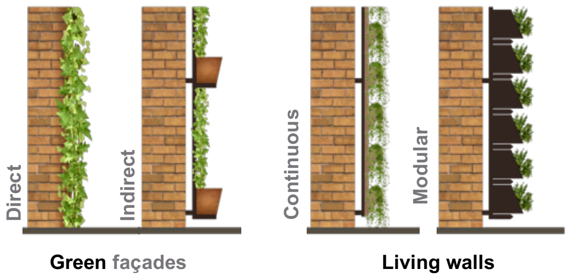

Figure 2 – Green wall main types.

4. Sound absorption of green coating systems

The research on the green coatings' sound absorption has been carried out in three scales: building, street and urban areas.

On the urban area scale (Ismail, 2013; Margaritis and Kang, 2016) and the street scale (Van Renterghem and Botteldooren, 2008a; 2008b; 2009; Jang *et al.*, 2015; Guillaume *et al.*, 2015; Lunain *et al.*, 2016), most studies use numerical simulation models to estimate the potential absorption effect of green coatings on the urban sound landscape. However, there are few studies in these contexts since a reliable basis of experimental data is needed to predict the potential acoustic impact of green coatings on smaller scales.

The current dissertation focuses on green roofs and walls' acoustical performance on a building scale. In order to investigate the sound absorption potential of these infrastructures, experimental data from the literature review was analyzed and compiled, as well as the laboratory and *in-situ* assay methods used (Table 1). Different results were found depending on the type of green coating tested and its constructive characteristics and materials.

Table 1 – Bibliographic references consulted to study the sound absorption potential of green roofs and walls.

Author(s)	Year	Tests		
		Used method	Sound incidence	Standard
Costa and James	1995	Reverberation chamber	Random	-
Londhe *et al.*	2009	*In-situ*	Normal	ISO 13472-1
Smyrnova *et al.*	2010	Reverberation chamber Sonda PU	Random	ISO 354
Wong *et al.*	2010	Reverberation chamber	Random	(a) ISO 354
Connelly	2011	Impedance tube Anechoic chamber *In-situ*	Normal Random	ASTM E1050-98
Benkreira *et al.*	2011	Impedance tube	Normal	ISO 10534-2
Horoshenkov *et al.*	2011	Impedance tube	Normal	ISO 10534-3
Mandon *et al.*	2011	Impedance tube	Normal	ISO 10534-2
Pittaluga *et al.*	2011	Impedance tube	Normal	ASTM C 384-04
Praag	2011	Reverberation chamber	Random	(a) ISO 354
Van Renterghem and Botteldooren	2011	*In-situ*	Random	-
Horoshenkov *et al.*	2012	Impedance tube	Normal	ISO 10534
Yang *et al.*	2012	Semi-anechoic chamber Impedance tube	Random Normal	-
Ding *et al.*	2013	Impedance tube	Normal	ISO 10534-2
Horoshenkov *et al.*	2013	Impedance tube	Normal	ISO 10534-4
Piovesan	2013	Reverberation chamber	Random	ISO 354
Yang	2013	Reverberation chamber	Random	ISO 354
Yang *et al.*				
Asdrubali *et al.*	2014	Reverberation chamber Impedance tube	Random Normal	ISO 354 ISO 10534-2
Van Renterghem and Botteldooren	2014	*In-situ*	Random	(a) ISO 9613-1
Azkorra *et al.*	2015	Reverberation chamber	Random	ISO 354
Connelly and Hodsgon	2015	Câm.A *In-situ* Impedance tube	Random Normal	ASTM E1050-98
Lacasta *et al.*	2016	*In-situ*	Random	-
Thomazelli *et al.*	2016	Reverberation chamber	Random	ISO 354
Davis *et al.*	2017	Reverberation chamber	Random	ISO 354
Prisutova *et al.*	2017	Impedance tube	Normal	(a) ISO 10534-2

Legend: (a) Standard adapted to the available conditions.

The majority of the collected results show that the substrate is the layer which may have the greatest impact on sound absorption of green coating systems. Sound absorption also increases with substrate porosity and decreases in higher levels of compaction.

The influence of vegetation on the sound absorption depended on its sample coverage area, its foliage area and the sound incidence angle, noting significant variations for different plant species.

An increase on the distances between the green coating and a support surface generally contributed to improve its acoustic performance.

Despite these main and general conclusions, the results of all the analyzed studies were scattered. To facilitate the analysis of the collected results set, histograms with weighted values of sound absorption coefficients are presented. In Figure 3, histograms based on noise reduction coefficients (NRC) determined from random-incidence test results are presented on the left. On the right side, the same statistical graphics are represented for normal incidence test results, but instead of NRC, another weighted value is considered: an average of the sound absorption coefficients at 250, 500, 1000 and 1600 Hz, since there were no results for the absorption coefficient at 2000 Hz. It was found that NRC values are higher than 0,50 in most cases. However, there were some lower NRC values. The NRC values higher than 1 correspond to a test error due to the underestimation of the exposed coating area in random-incidence sound tests.

5. Sound insulation of green coating systems

The authors who tested the sound insulation potential of green roofs and walls are shown on Table 2.

Table 2 – Bibliographic references consulted in order to study the sound insulation potential of green roofs and walls.

Author(s)	Year	Tests performed inside (I), outside (O) or inside and outside (O-I)	Standard
Connelly e Hodgson	2008	O-I O	(a) ISO 15186-1
Connelly	2011	O-I O	(a) ISO 15186-1
Galbrun e Scerri	2017	I	ISO 10140-2 ; ISO 3382-2
Wong *et al.*	2010	O	-
Connelly e Hodgson	2013	O-I O	(a) ISO 15186-1
Lagström	2004	O-I	-
Pérez *et al.*	2016	I	ISO 140-5
Azkorra *et al.*	2015	I	ISO 10140-2

Legend: (a) Standard adapted to the available conditions.

The substrate's mass increase implies a total system's mass increase, which favors sound insulation of the green coatings. The vegetation does not seem to make a significant contribution to the sound insulation. Increasing the distance between the green coating and the support surface, in particular with air gaps, has contributed to improve the systems' acoustic performance.

The influence of green roofs and walls' characteristics on the systems' acoustical performance is qualitatively represented on Table 3. The green filling of the bars represents a good acoustic performance potential with the influence or the increase of the respective property, while the red filling has the opposite meaning.

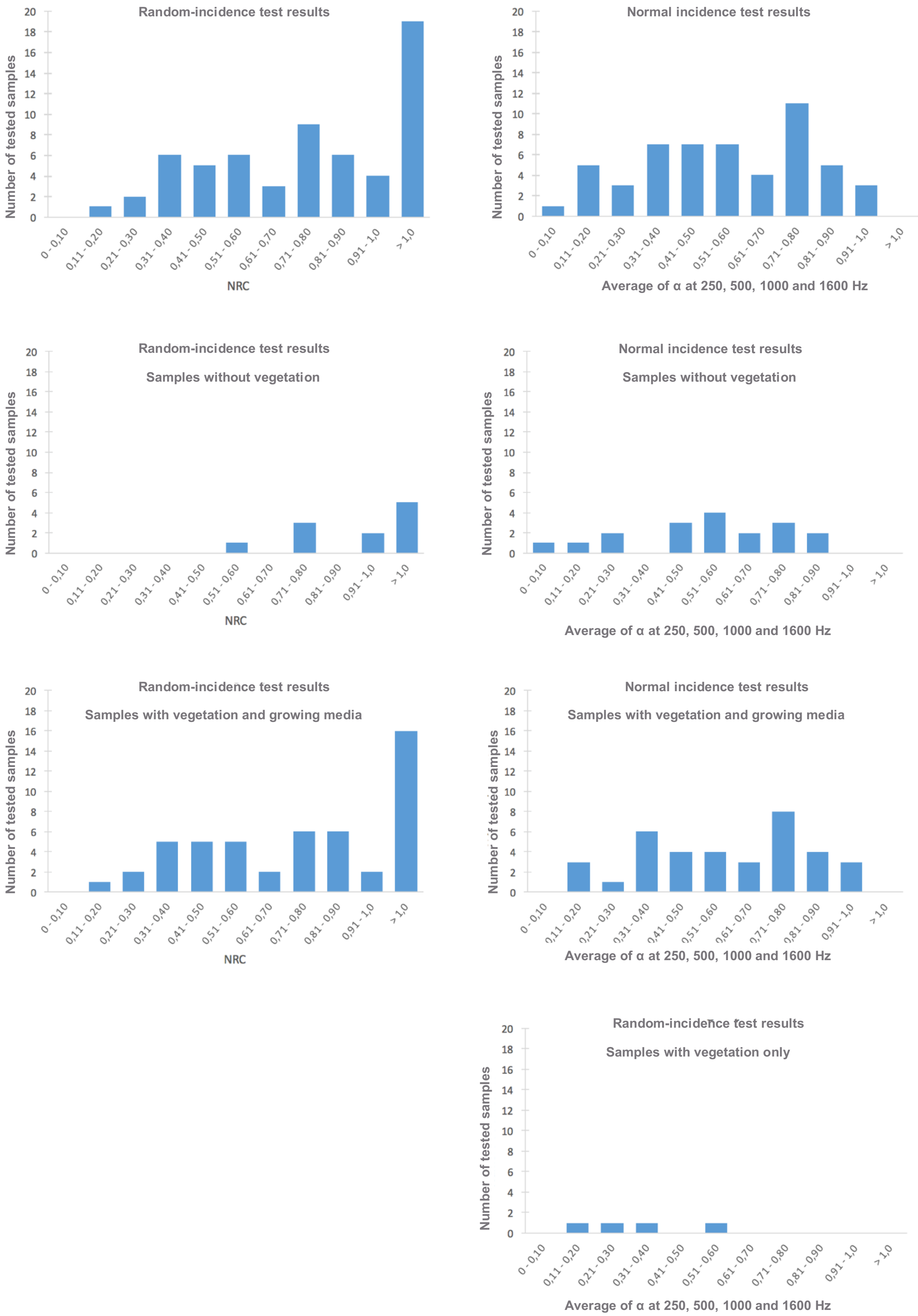

Figure 3 – Weighted values of sound absorption coefficients.

Table 3 – Qualitative influence of the green coating's characteristics on the system sound absorption and on the system sound insulation.

Study parameters (characteristics)		Sound absorption – Green roofs	Sound absorption – Green walls	Sound insulation – Green roofs	Sound insulation – Green walls
	Presence of the substrate layer	■■■■◧		■■■■◧	
	Substrate thickness	■□□□□		◧□□□□	
	Substrate porosity	■■■◧□		◧□□□□	
	% Organic matter	■■□□□	-	-	
	Water content	■■■□□ (red)		◧□□□□ (red)	
	Presence of vegetation	■■□□□		■□□□□	
	% Vegetation coverage area	-	■■◧□□	-	
	Different species	■■◧□□		◧□□□□	
	Presence of substrate and vegetation	■■■■□		■■■■□	
	Other layers	■■◧□□	■■■◧□	■■■□□	
Other systems' characteristics	Distance between modules	■□□□□		-	
Other systems' characteristics	Air gap	■■■□□		■■■■◧	

6. METHODOLOGY PROPOSALS TO TEST SOUND ABSORPTION AND SOUND INSULATION OF GREEN COATING SAMPLES

In order to test a representative sample of different green coating types, it was defined that a set of pots or containers with a minimum medium growing thickness of 8,5 cm, for example, would be used. Organic substrate, water and vegetation will be added in the pots. If possible, continuous living wall (geotextile panel) is also recommended to be tested to complement the few literature results available on these green walls. Light substrate (a mixture of coconut fiber, for example), suitable vegetation and water should be added in the pockets of the geotextile panel.

The design of these methodologies addresses some difficulties related to the samples and to the test sites. Examples of these difficulties are the amount of material required to cover different green coating types and the respective costs involved, or the simple risk of substrate being poured when testing substrate modules vertically.

To test samples' sound absorption, it is proposed to follow the standard procedure ISO 354: 2003 (reverberation chamber test). Aplying standard laboratory methodology facilitates the comparison of experimental results with those taken from other references which have used the same methodology. In addition, laboratory conditions allow testing a greater variety of parameters than if an *in-situ* test would be performed.

In order to study the sound insulation of the same samples, it is proposed that the similar pots with substrate and plants are disposed on the top surface of a chamber. As well as the pots, the sound source and a microphone are put on the chamber's roof. Inside the chamber, there will be at least two microphones to measure the differences of inside and outside sound levels. The procedure is described in more detail in chapter 5 of the current dissertation.

7. Conclusions and future work

Green coating systems are solutions with wide environmental benefits. One of these benefits is sound attenuation.

The adopted research methodology allowed to achieve the goals set at the beginning. Although the consulted case-studies use different methods of measurement and analysis of results, it was possible to highlight some of the characteristics of the green coatings that are most influent on their acoustic performance.

The substrate is one of the most important layers in the test records. As an acoustic absorber, it is noted that: its high porosity benefits the absorption of sound waves; high water content disadvantages the sound absorption, especially in dense substrates; and the variation of the layer thickness appears to be less influent. As an element of acoustic insulation, the presence of substrate and its thickness are significant only if it represents a significant system mass.

The larger mass green infrastructures provided, higher values on sound insulation were recorded. However, references such as Connelly and Hodgson (2008, 2013) state that sound reduction index spectrum does not follow the mass law in these cases.

The choice of vegetation species may influence green coverings' sound absorption, with incidence sound angle on the foliage and the leaf area being the most determinant factors. Plants' role is less significant for the system sound absorption than the substrates' role. It's important to ensure a certain percentage of vegetated coverage area in order to notice an increase in system's sound absorption. In the sound insulation context, it is expected that both substrate and vegetation layers don't play a significant role on sound insulation, because of the open air spaces between modules and the reduced systems mass. It should also be noted that the existence of an air gap in the green coating systems improved the sound absorption and sound insulation in the experimental campaigns carried out by most of the bibliographical references that tested this parameter.

In a generalized scale analysis of the building, it can be concluded that the green roofs have sound absorption and insulation capacity, while the green walls tend to present a higher attenuation potential only by absorbing the sound waves.

The literature review on different experimental test procedures contributed to formulate two experimental procedures to be studied and executed in the follow-up of the present work, in the near future. Consulting different investigation methods from the references also helped to predict test errors, difficulties and the performance expectations for each green coating type.

The obtained results with these experiments will complement the gathered information in the bibliographic review about the following influence parameters on the acoustic performance of green coatings: presence of substrate; substrate type, thickness and water content; presence of vegetation; vegetation coverage area and plant species; green coating types; distance between modules; and gap air beetween green coating and the support surface.

In the near future, it would be interesting to carry out an *in-situ* assay during winter and summer seasons, in order to compare the acoustic performance between higher dryness and temperatures conditions and higher humidity and lower temperatures conditions.

From a medium-term perspective, it will be useful to carry out further laboratory and *in-situ* tests that examine other parameters of influence on sound attenuation. In this way, there is room for acoustical improvement in green coating systems.

8. References

8.1 Articles and other Publications

Asdrubali, F., Mencarelli, N., Horoshenkov, K.V., & D'Alessandro, F. (2014). Sound absorption properties of tropical plants for indoor applications. In Proceedings of the 21st International Congress on Sound and Vibration (pp. 1-8). Beijing, China.

Azkorra, Z., Pérez, G., Coma, J., Cabeza, L. F., Bures, S., Álvaro, J. E., Erkoreka, A., & Urrestarazu, M. (2015). Evaluation of green walls as a passive acoustic insulation system for buildings. Applied Acoustics, 89, 46–56. https://doi.org/10.1016/j.apacoust.2014.09.010

Benkreira, H., Horoshenkov, K. V., Khan, A., Mandon, A., & Rohr, R. (2011). Acoustic characterization of porous substratum used in green noise control elements. In Inter.noise 2011 (pp. 1–6). Osaka.

Connelly, M. R. (2011). Acoustical characteristics of vegetated roofs - contributions to the ecological performance of buildings and the urban soundscape (thesis submitted in parcial fulfillment of the requirements for the degree of Doctor of Philosophy). Faculty of Graduate Studies, University of British Columbia, Vancouver.

Connelly, M., & Hodgson, M. (2008). Thermal and Acoustical Performance of Green Roofs: Sound Transmission Loss of Green Roofs. In Sixth Annual Greening Rooftops for Sustainable Communities - Conference, Awards & Trade Show, 1-11, Baltimore, USA.

Connelly, M., & Hodgson, M. (2013). Experimental investigation of the sound transmission of vegetated roofs. Applied Acoustics, 74(10), 1136–1143. https://doi.org/10.1016/j.apacoust.2013.04.003

Connelly, M., & Hodgson, M. (2015). Experimental investigation of the sound absorption characteristics of vegetated roofs. Building and Environment, 92, 335–346. https://doi.org/10.1016/j.buildenv.2015.04.023

Costa, P., & James, R. W. (1995). Constructive use of vegetation in office buildings. In Plants for People Symposium (pp. 1–25). Hague, Holland.

Davis, M. J. M., Tenpierik, M. J., Ramírez, F. R., & Pérez, M. E. (2017). More than just a Green Façade: The sound absorption properties of a vertical garden with and without plants. Building and Environment. https://doi.org/10.1016/j.buildenv.2017.01.010

Ding, L., Van Renterghem, T., Botteldooren, D., Horoshenkov, K., & Khan, A. (2013). Sound absorption of porous substrates covered by foliage: Experimental results and numerical predictions. The Journal of the Acoustical Society of America, https://doi.org/10.1121/1.4824830

Galbrun, L., & Scerri, L. (2017). Sound insulation of lightweight extensive green roofs. Building and Environment, 116, 130–139. https://doi.org/10.1016/j.buildenv.2017.02.008

Guillaume, G., Gauvreau, B., & L'Hermite, P. (2015). Numerical study of the impact of vegetation coverings on sound levels and time decays in a canyon street model. Science of the Total Environment, 502, 22–30. https://doi.org/10.1016/j.scitotenv.2014.08.111

Horoshenkov, K. V, Khan, A., & Benkreira, H. (2013). Acoustic properties of low growing plants. The Journal of the Acoustical Society of America, 133, 2554–2565. https://doi.org/10.1121/1.4798671

Horoshenkov, K. V., Khan, A., Benkreira, H., & Mandon, A. (2011). The effect of moisture and soil type on the acoustical properties of green noise control elements. In Proceedings of Forum Acusticum 2011 (pp. 845–849). Aalborg.

Ismail, M. R. (2013). Quiet environment: Acoustics of vertical green wall systems of the Islamic urban form. Frontiers of Architectural Research, 2, 162–177. https://doi.org/10.1016/j.foar.2013.02.002

Jang, H. S., Kim, H. J., & Jeon, J. Y. (2015). Scale-model method for measuring noise reduction in residential buildings by vegetation. Building and Environment, 86, 81–88. https://doi.org/10.1016/j.buildenv.2014.12.020

Lacasta, A. M., Penaranda, A., Cantalapiedra, I. R., Auguet, C., Bures, S., & Urrestarazu, M. (2016). Acoustic evaluation of modular greenery noise barriers. Urban Forestry and Urban Greening, 20, 172 179. https://doi.org/10.1016/j.ufug.2016.08.010

Lagström, J. (2004). Do extensive green roofs reduce noise? (Examination Project in Environmental Science, Publication No 010). Malmö, Sweden: International Green Roof Institute.

Londhe, N., Rao, M. D., & Blough, J. R. (2009). Application of the ISO 13472-1 in situ technique for measuring the acoustic absorption coefficient of grass and artificial turf surfaces. Applied Acoustics, 70(1), 129–141. https://doi.org/10.1016/j.apacoust.2007.12.011

Lunain, D., Ecotiere, D., & Gauvreau, B. (2016). In-situ evaluation of the acoustic efficiency of a green wall in urban area. In Internoise. Hamburg.

Mandon, A., Benkreira, H., Horoshenkov, K. V., Khan, A., & Rohr, R. (2011). The effect of drying on the acoustic absorption of novel green noise insulation. In European Drying Conference - EuroDrying'2011 (pp. 26–28). Palma de Mallorca, Balearic Island, Spain.

Margaritis, E., & Kang, J. (2016). Relationship between urban green spaces and other features of urban morphology with traffic noise distribution. Urban Forestry and Urban Greening, 15, 174-185. https://doi.org/10.1016/j.ufug.2015.12.009

Pérez, G., Coma, J., Barreneche, C., De Gracia, A., Urrestarazu, M., Burés, S., & Cabeza, L. F. (2016). Acoustic insulation capacity of Vertical Greenery Systems for buildings. Applied Acoustics, 110, 218–226. https://doi.org/10.1016/j.apacoust.2016.03.040

Piovesan, T. (2013). Caracterização acústica de dois sistemas modulares de telhados verdes brasileiros (dissertação de mestrado em Engenharia Civil). Universidade Federal de Santa Maria, Santa Maria, RS, Brasil.

Pittaluga, I., Schenone, C., & Borelli, D. (2011). Sound absorption of different green roof systems. In Proceedings of Meetings on Acoustics - 162nd Meeting. San Diego, California. Acoustical Society of America, 14, 1-13. https://doi.org/10.1121/1.3654256

Praag, R. (2011). Akoestisch Onderzoek: de invloed van groen op de nagalmtijd (MSc-proefschrift). Aldus bouwinnovatie en Faculteit Bouwkunde, Technische Universiteit Delft, Delft.

Prisutova, J., Horoshenkov, K., Brouard, B., & Groby, J. P. (2017). An application of normal mode decomposition to measure the acoustical properties of low growing plants in a broad frequency range. Applied Acoustics, 117, 39–50. https://doi.org/10.1016/j.apacoust.2016.09.028

Smyrnova, Y., Kang, J., Cheal, C., Tijs, E., & Bree, H. (2010). Laboratory Test of Sound Absorption of Vegetation. In 1st European Acoustics Association – EuroRegio 2010, Congress on Sound and Vibration. Ljubljana, Slovenia: Alps Adria Acoustics Association, Slovenian Acoustical Society.

Thomazelli, R., Caetano, F., & Bertoli, S. (2016). Absorção sonora de painéis modulares para muros vivos. In XVI Encontro Nacional de Tecnologia do Ambiente Construído - Desafios e Perspectivas da Internacionalização da Construção (pp. 1795–1805). São Paulo.

Van Renterghem, T., & Botteldooren, D. (2008a). Numerical evaluation of sound propagating over green roofs. Journal of Sound and Vibration, 317(3–5), 781–799. https://doi.org/10.1016/j.jsv.2008.03.025

Van Renterghem, T., & Botteldooren, D. (2008b). Green roofs to enhance quiet sides. Journal of Sound and Vibration, 123(5), 3749–3751. https://doi.org/10.1121/1.2934487

Van Renterghem, T., & Botteldooren, D. (2009). Reducing the acoustical façade load from road traffic with green roofs. Building and Environment, 44(5), 1081–1087. https://doi.org/10.1016/j.buildenv.2008.07.013

Van Renterghem, T., & Botteldooren, D. (2011). In-situ measurements of sound propagating over extensive green roofs. Building and Environment, 46(3), 729–738. https://doi.org/10.1016/j.buildenv.2010.10.006

Van Renterghem, T., & Botteldooren, D. (2014). Influence of rainfall on the noise shielding by a green roof. Building and Environment, 82, 1–8. https://doi.org/10.1016/j.buildenv.2014.07.025

Wong, N. H., Tan, A. Y. K., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., Chiang, K., & Wong, N. C. (2010). Acoustics evaluation of vertical greenery systems for building walls. Building and Environment, 45(3), 663–672. https://doi.org/10.1016/j.buildenv.2009.08.005

Yang, H. (2013). Outdoor noise control by natural/sustainable materials in urban areas (thesis for the degree of Doctor of Philosophy). School of Architecture, The University of Sheffield, Sheffield, UK.

Yang, H. S., Kang, J., & Cheal, C. (2013). Random-incidence absorption and scattering coefficients of vegetation. Acta Acustica United with Acustica, 99(3), 379–388. https://doi.org/10.3813/AAA.918619

Yang, H. S., Kang, J., & Choi, M. S. (2012). Acoustic effects of green roof systems on a low-profiled structure at street level. Building and Environment, 50, 44–55. https://doi.org/10.1016/j.buildenv.2011.10.004

8.2 Standard documents

ASTM C423-17: 2017. Standard test method for sound absorption and sound absorption coefficients by the reverberation room method. ASTM International, West Conshohocken, PA.

ISO 10140-2: 2010. Acoustics - Laboratory measurement of sound insulation of building elements, part 2: Measurement of airborne sound insulation. International Organization for Standardization, Geneva, Switzerland.

ISO 10534-2: 1996. Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes, part 2: Transfer-function method. International Organization for Standardization, Geneva, Switzerland.

ISO 13472-1: 2002. Acoustic - Measurement of Sound Absorption Properties of Road Surfaces in-situ, part 1: Extended Surface Method. International Organization for Standardization, Geneva, Switzerland.

ISO 140-4: 1998. Acoustics - Measurement of sound insulation in buildings and of building elements, part 4: Field measurements of airborne sound insulation between rooms. International Organization for Standardization, Geneva, Switzerland.

ISO 140-5: 1998. Acoustics - Measurement of sound insulation in buildings and of building elements, part 5: Field measurements of airborne sound insulation of façade elements and façades. International Organization for Standardization, Geneva, Switzerland.

ISO 354: 2003. Acoustics - Measurement of sound absorption in a reverberation room. International Organization for Standardization, Geneva, Switzerland.

ISO 717-1: 2013. Acoustics - Rating of sound insulation in buildings and of building elements, part 1: Airborne sound insulation. International Organization for Standardization, Geneva, Switzerland.