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Sound Absorption of Vertical Greenery System: Systematic Literature Review

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ABSTRACT

The combination of the sound absorption produced by pavement, walls and sidewalks that compose urban environments is responsible for the sound reduction found in urban canyons. It is possible to reduce urban noise through the insertion of Vertical Greenery Systems (VGS) on buildings facades. This work presents a systematic literature review regarding the Acoustics of Vertical Greenery Systems. Consulted database were Compendex, Web of Science, Science Direct and Scopus. Seven variations of the combination of the term "Vertical Greenery Systems" with the terms "sound absorption", "acoustic absorption" and "acoustic impedance" were used in the database search. Results showed twenty-two articles on the subject and two articles added due to a snowball analysis. Analysis of results considered the sound absorption measuring method, the plants that were used and the composition of the substrate. The temporal history showed a peak of researches in 2016. Results also revealed that the most searched species was Hedera Helix and the most used substrate was coconut fibers. This literature review concluded that the substrate, leaf characteristics and foliage area are responsible for the sound absorption of the system.

Keywords: Acoustic, Performance, Plants
I-INCE Classification of Subject Number: 38

1. INTRODUCTION

A Systematic Literature Review (SLR) is a manner of identifying, describing and analysing the most relevant information concerning a research, topic or phenomena. The purpose of a SLR is to summarize the evidence regarding a certain method or technology, recognize a lack of acknowledgement and locate and position the study inside a larger panorama (KITCHENHAM, 2004). The SLR is a defined search strategy that consists on planning, conducting and reporting the review.

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The reduction of Sound Pressure Level (SPL) in city street canyons is achieved through the combination of an absorbing ground, absorbers on the walls and sidewalks (HOROSHENKOV; HOTHERSALL; MERCY, 1999). There are many ways to reduce transport noise through natural means. Planted substrate in walls is a useful technique to increase the abatement (VAN RENTERGHEM et al., 2015). Choosing to apply natural systems as a mean to achieve noise abatement depends on the characteristics of the noise, besides the placement of the application and the position of the receptor. The benefits of a vegetative barrier on road traffic noise in urban cities are also psychological, i.e. the noise reduction by a vegetative barrier could be perceived as being greater than the actual noise reduction (OW; GHOSH, 2017).

Vertical Greenery System (VGS) has also been identified as a possible noise reduction method for inner city environments. . Part of this reduction is due to sound absorption (HORNIKX, 2016). This paper seeks to present the systematic literature review on sound absorption of VGS and compare some characteristics of the studies.

2. SYSTEMATIC LITERATURE REVIEW PROTOCOL

In a Systematic Literature Review (SLR), a search protocol must be formulated to answer a fundamental question of the study. This protocol must exhibit all articles related to the subject. A SLR is conducted through a series of steps: identifying the research, defining the database to be searched, defining keywords, defining inclusion and exclusion criteria, extracting data and finally reporting the results (KITCHENHAM, 2004).

2.1 Research Identification

This research focuses on the VGS´s properties that influence the performance of sound absorption. Consequently, a possible way to state the fundamental question could be: "Which are the VGS variables that influence sound absorption of the system?". The answers point to the properties of the system which will be monitored in future works to produce a modelling of sound absorption in VGS.

2.2 Database

This research revolves around science and engineering. The four main databases concerning these areas are Compendex (www.engineeringvillage.com), Science Direct (www.sciencedirect.com), Web of Science (www.webofknowledge.com) and Scopus (www.scopus.com). Databases offer an "advanced search" option, where it is necessary to define a string. A string is formed by keywords related to the research, codes to search for the keywords in parts of the documents, boolean and proximity operators. In a string, a combination of words must be written between quotation marks, if an exact phrase is to be searched. Boolean operators work to add, exclude or select terms. The main operators are AND, OR, AND NOT (SCOPUS, 2019). The proximity operator is called "wildcard" and is represented by an asterisk (*), that can be used to replace any letter or group of letters.

2.3 Definition of string and inclusion criteria

The terms of this search were divide into two groups of words. The first group consists of synonyms of VGS which can vary from vertical garden (DAVIS et al., 2017) to green wall (ATTAL et al., 2017). The second group consists of terms related to sound absorption. Table 1 shows the groups of keywords separated by Booleans operators, forming a string.

Table 1: *Summary of terms plus a boolean operator (forming a string)*

<table>
<tr><th>Synonyms of VGS</th><th>Boolean operator to sum the terms of both groups</th><th>Terms related to sound absorption</th></tr>
<tr><td>Green Wall</td><td rowspan="6">AND</td><td rowspan="2">Sound absorption</td></tr>
<tr><td>Green Facade</td></tr>
<tr><td>Living Wall</td><td rowspan="2">Acoustic Absorption</td></tr>
<tr><td>Plant Facade</td></tr>
<tr><td>Vertical Garden</td><td rowspan="2">Impedance</td></tr>
<tr><td>Vertical Green</td></tr>
</table>

In Table 2, the wildcard was added to the terms found in Table 1, in order to form a string and include in the search the plural version of the words. Some databases have a specific code to search the terms in parts of an article. This systematic review searched the terms for matches in titles, keywords and abstracts. The Compendex databases' standard search already includes this feature, while the Science Direct has a specific field - "advanced search" - for users who want to perform this kind of broader searches. The string formed was inserted in the "advanced search field" of each database website, in order to perform the primary search. Table 2 shows each of the complete strings inserted in the databases. The search was updated in February of 2019.

Table 2: *Strings inserted in databases*

Database	String
Compendex	("Green* wall*" OR "Green* fa*ade*" OR "vertical garden*" OR "vertical green*" OR "liv* wall*" OR "plant fa*ade*") AND ("Sound absorption" OR "impedance*" OR "acoustic absorption")
Web of Science	TS= ("Green* wall*" OR "Green* fa*ade*" OR "vertical garden*" OR "vertical green*" OR "liv* wall*" OR "plant fa*ade*") AND TS=("Sound absorption" OR "impedance*" OR "acoustic absorption")
Science direct	("Green wall" OR "Green facade" OR "vertical garden" OR "vertical green" OR "living wall" OR "plant facade") AND ("Sound absorption" OR "impedance" OR "acoustic absorption")
Scopus	TITLE-ABS-KEY (("Green* wall*" OR "Green* fa*ade*" OR "vertical garden*" OR "vertical green*" OR "liv* wall*" OR "plant fa*ade*") AND ("Sound absorption" OR "impedance*" OR "acoustic absorption"))

A second search is formed by analysing the references present in articles of the primary search, a process named snowball. The snowball is an inclusion criteria that works to form a consistent review by including all articles related to the researched topic.

2.4 Exclusion criteria

The same articles can be found in different databases. The articles that appeared more than once were excluded from the analysis. Articles that did not present sound absorption coefficient data or that presented the same results of other works were also excluded from the analysys. Also, articles were excluded if they were not available for access through the CAPES' portal (www.periodicos.capes.gov.br) or Researchgate (www.researchgate.net).

2.5 Data extraction

A systematic review is a requirement for quantitative meta-analysis (KITCHENHAM, 2004). In the specific case of the analysis here discussed, the focus was placed specially on tracking the year of publication of the searched articles, the main authors responsible for publishing the papers, and the source - the conference or journal that published them. Together, these 3 pieces of information can provide a fairly good understanding of the development of the discussions and findings surrounding a certain theme, and can help researchers track down new and pertinent publications more easily as well as better identify relevant authors and sources of publications worth following on a more regular basis. In this case, in order for a data analysis to be performed, there was the need to collect the methods of determining sound absorption coefficient, the plants and the substrate of VGS, plus the main conclusions of the studies.

2.6 Report and analysis of results

The collected data was reported using graphics and tables, to make evident the correlation between the studies. The analysis and conclusions drawn from a SLR provide an overview of the whole subject, and help researchers plan future works.

3. RESULTS AND ANALYSIS

The primary search resulted in 49 articles. After the exclusion of duplicated articles, there were 24 articles left. The snowball process added another 2 articles. In total, the present SLR searched 26 articles.

Figure 1 shows the evolution of publications concerning sound absorption in VGS. A development of the subject starts in 2009, led by Ardila et al. (2009). More than that, the temporal history showed a peak in publication in 2016.

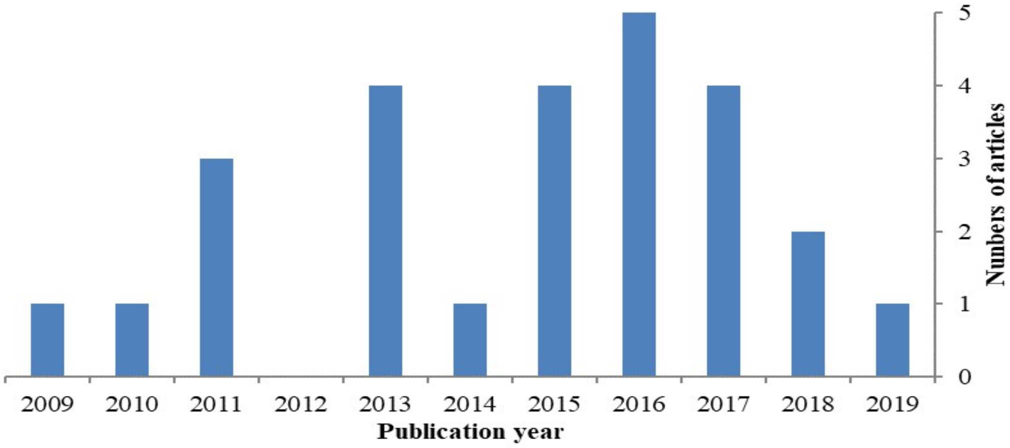

Figure 1: *History of publications on sound absorption in VGS*

Regarding the sources of the publications, 13 articles were published in 10 different journals. The journal that most published about the theme was Building Environment. Another 13 articles were published in 5 different Conferences. The INTERNOISE totals 8 publications. In the analysis of the SLR there were 120 different authors listed. Figure 2 shows the most published authors in the area.

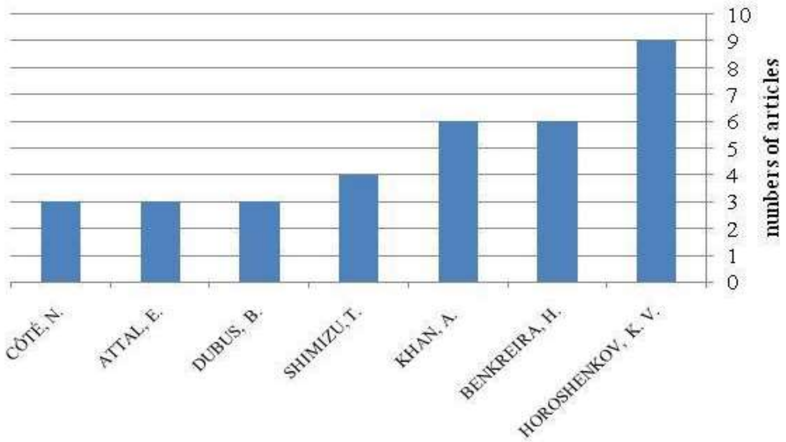

Figure 2: *The most published authors on sound absorption in VGS*

Considering the exclusion criteria in the analysis of the obtained articles, the works of Romanova and Horoshenkov (2018) were excluded for not being available. The articles by Ardila et al. (2009), Bahour and Ramakrishnan (2018) and Lunain and Gauvreau (2016) were excluded for not presenting a coefficient of sound absorption. Furthermore, the publications by Horoshenkov, Khan and Benkreira (2013a) and Shimizu et al. (2015) were excluded for presenting results that had already been previously published in other articles. After applying all exclusion criteria, there were 19 articles left. Table 3 presents the number of tested VGS configurations in each work.

Table 3: *Ranking according to the number of configurations tested to determine the sound absorption coefficient*

Article	Number of configurations
(YANG; KANG; CHEAL, 2013)	31
(HOROSHENKOV et al., 2011a)	24
(DAVIS et al., 2017)	18
(SERRA et al., 2017)	11
(ATTAL et al., 2017)	8
(HOROSHENKOV et al., 2011a)	6
(D'ALESSANDRO; ASDRUBALI; MENCARELLI, 2015)	6
(AZKORRA et al., 2015)	5
(MANSO et al., 2017)	5
(HOROSHENKOV; KHAN; BENKREIRA, 2013b)	5
(ROMANOVA; HOROSHENKOV; HURRELL, 2019)	5
(HOROSHENKOV et al., 2011b)	5
(SHIMIZU et al., 2016)	4
(WONG et al., 2010)	3
(ATTAL et al., 2016)	3
(PRISUTOVA et al., 2014)	2
(ATTAL et al., 2015)	1
(LACASTA et al., 2016)	1

The most complete study was conducted by Kang Yang, Kang and Cheal (2013), who considered 31 configurations (8 different mixes of soil, 6 different vegetal cover areas and 4 depths of soil with 3 different plants).

Considering all the analysed articles, the determination of the sound absorption coefficient, in general, follows two standards: ISO 354 (2003), which describes a reverberant chamber method, and ISO 10534-1 (1996), which describes an impedance tube method. Figure 3 shows equality in both methods. However, an in situ method was also observed in two articles. Lacasta et al. (2016) used an in-situ measurement adapted from ISO 13472-1 (2002), which was a standard method applied to determine the sound absorption coefficient of pavement. Romanova; Horoshenkov and Hurrell (2019) used an in-situ measurement with probe intensity. These results show the potential of using in-situ methods to determine the sound absorption coefficient, due to the difficulties of introducing a VGS inside a reverberant chamber or impedance tube. It proved to be a valuable tool for a realistic evaluation of VGS properties (LACASTA et al., 2016).

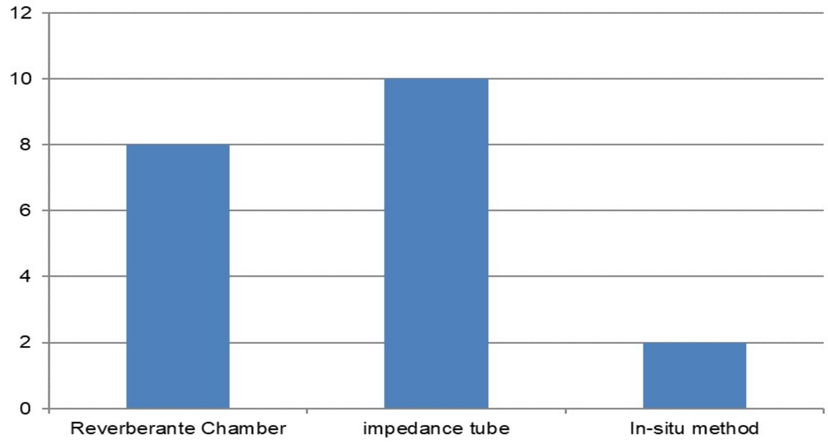

Figure 3: *Methods to determine sound absorption coefficient*

Regarding the species of plants used in VGS, the RSL listed 29 species. Figure 4 shows the main species tested in studies regarding sound absorption. The *Hedera Helix* was the most used species for tests. Species with flowers, like *Primula Vulgaris* and *Sedum Kamtschticum,* were also tested.

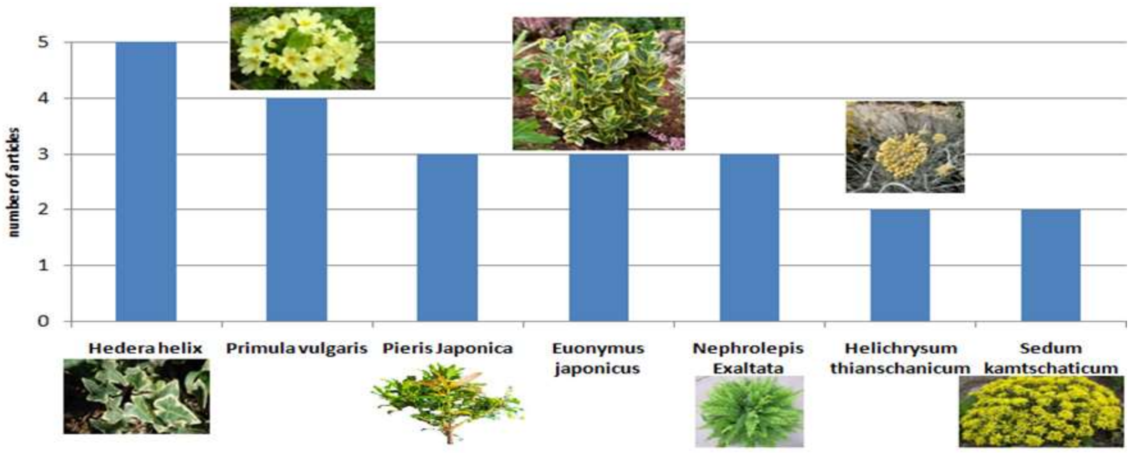

Figure 4: *Most studied species of plants, according to the RSL*

Analyzing the types of substrates used in VGS, it is possible to conclude that coconut fibers, perlite and Canevaflor were the most applied. Three studies did not specify what materials were used for the substrate. Preliminary results show influence of the substrate in sound absorption, so the omission of this information provides an incomplete analysis. *Figure 5* shows the number of studies for each substrate used in VGS.

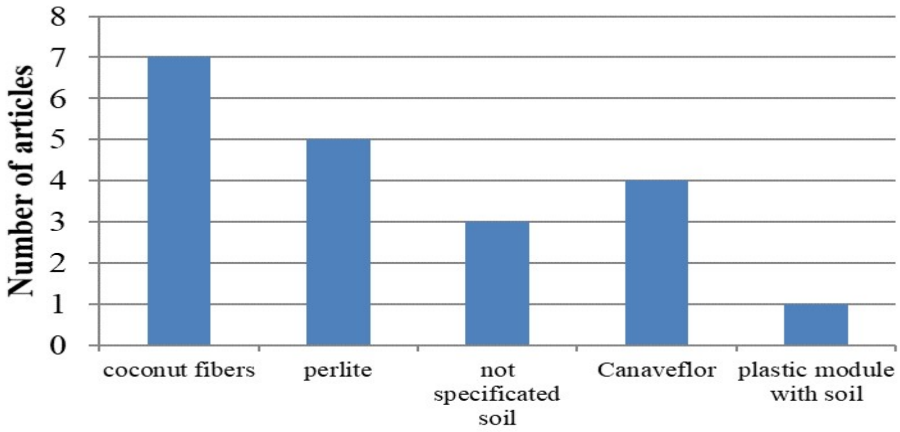

Figure 5: *Substrates used in VGS, according to the studies*

According to the analysis of the conclusions of the collected articles, some factors were important to the performance of VGS absorption. Figure 7 shows these factors. Some results and conclusions were placed together in the graphs under broader groups, that combine different results concerning a relatively similar topic, i.e. the results regarding the use of gaps of air between the vegetation and the wall, included in the broader group of "Types of VGS", that deals with the influence of the types of VGS on the sound absorption coefficient (AZKORRA et al., 2015; THOMAZELLI; CAETANO; BERTOLI, 2016).

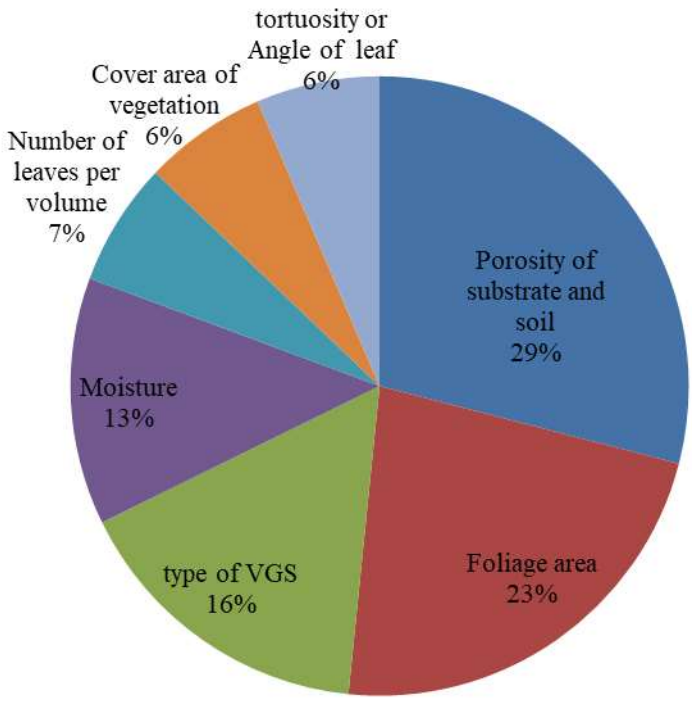

Figure 7: *Factors that promote sound absorption, according to the conclusion of the studies*

Many studies compared the measured sound absorption coefficient to the predicted sound absorption coefficient provided by a model, and the results were demonstrated to be fairly accurate. Different models - Delany-Bazley, Miki, equivalent fluid and two-layers - were used to predict the sound absorption coefficient of soils (D'ALESSANDRO; ASDRUBALI; MENCARELLI, 2015; DAVIS et al., 2017; HOROSHENKOV; KHAN; BENKREIRA, 2013b; HOROSHENKOV et al., 2011b; PRISUTOVA et al., 2014).

Some works discussed the potential of applying the VGS in an indoor environment, public spaces or urban canyons and discussed the aesthetic value of such use (AZKORRA et al., 2015; D'ALESSANDRO; ASDRUBALI; MENCARELLI, 2015; DAVIS et al., 2017; SERRA et al., 2017; THOMAZELLI; CAETANO; BERTOLI, 2016).

The results indicated that the refinement of the sound absorption models for VGS included the dispersion of the leaves. This study, in addition to promoting the acquired knowledge concerning the sound absorption coefficient of VGS, also identified other parameters for future works (i.g. porosity of substrate, moisture, foliage area, etc), aiming the improvement of the VGS sound absorption prediction models.

4. CONCLUSIONS

This Systematic Literature Review presented an overview of researches about sound absorption in vertical greenery systems. The protocol of the review was developed to promote more systematic reviews about this subject. The results showed what information is needed and how it could affect future researches. The SLR shows other potential horizons to explore, like in-situ measurements, scattering influence and simulations.

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