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Numerical study of the impact of vegetation coverings on sound levels and time decays in a canyon street model

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HIGHLIGHTS

- An experimental method for characterizing green coverings is applied.
- Simulations in a canyon street with various vegetalization scenarios are presented.
- This numerical study involves time-domain simulations until 1kHz third octave bands.

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ABSTRACT

Given a constantly increasing urban population, the mitigation of environmental impacts caused by urbanization has become a critical concern. Sprawling cities accelerate the phenomenon of soil sealing, whose impacts relative to climatology, water cycle and ecology are substantial. The "VegDUD" project, which provides the framework for the present paper, lays out a possible alternative for limiting these deleterious effects through focusing on the role of vegetation in promoting sustainable urban development. The study presented herein addresses the beneficial effect of greening building facades and rooftops in terms of both acoustic level and sound-decay time indicators at low frequency third-octave bands. This is carried out through numerical simulations in the time-domain of sound propagation in a canyon street of infinite length for various scenarios of surface vegetalization. Numerical predictions show a more significant effect in the upper part and outside the street, depending on the location of the vegetalized surfaces, frequency bands and number of reflections on the treated materials.

1. Introduction

Urban sprawl is a direct consequence of the economic and social attractiveness of cities, which coupled with more expensive real estate, has provided a great incentive for suburbanization. This phenomenon has led to major environmental nuisances, as reflected by an increase in the use of individual modes of transport and, as a result, rising energy consumption (Newman and Kenworthy, 1989). Compounding these mobility-related problems faced by city dwellers are more direct effects such as the expansion of built land area, another steady contributor to soil sealing. These consequences, qualified as disastrous from an ecological perspective (e.g. runoff of contaminant-laden sediments towards watercourses, fragmentation of natural habitats, ecosystems and landscapes), are no less so relative to meteorology (urban heat islands, global warming), hydrology and the natural environment. An ever-increasing urban population has now made it imperative to establish definitive future development guidelines that comply with urban sustainability criteria.

In this context, the introduction of vegetation into urban settings offers a tangible path to explore since such initiatives demonstrate the capacity to address relevant societal issues (Bianchini and Hewage, 2012) as well as environmental issues (Alexandri and Jones, 2008; Susca et al., 2011; Castleton et al., 2010; Jaffal et al., 2012). The VegDUD project (2010–2014), sponsored by France's ANR National Research Agency and managed by the Institute for Research on Urban Sciences and Techniques (IRSTV), is specifically devoted to evaluating the role of vegetation in promoting urban sustainable development. This multidisciplinary project combines the efforts of a wide array of partners

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across various scientific fields (climatology, hydrology, environmental acoustics, heat sciences, …), with the aim of studying feasible solutions to the cities' current sustainable development challenges.

The effect of vegetation on acoustic propagation has already been the topic of several numerical studies (Renterghem and Botteldooren, 2008; Renterghem and Botteldooren, 2009; Renterghem et al., 2012; Renterghem et al., 2013; Ding et al., 2013; European project HOSANNA, 2009–2012) and experimental investigations (Ding et al., 2013; European project HOSANNA, 2009–2012; Wong et al., 2010; Renterghem and Botteldooren, 2011; Renterghem et al., 2014). The present study focuses on the impact of vegetalized surfaces and by singling out vegetation effects in terms of absorption at the street scale. The effects induced by the presence of vegetation on acoustic propagation when subjected to wind and temperature field modifications have thus been neglected. The originality of this approach stems not only from the selected numerical propagation model, but also from the project's emphasis on qualifying and quantifying the effects of various urban greening scenarios by cross-correlation with key issues relative to climate, the water cycle, thermal considerations, the economy and society. This article is laid out in three parts. Section 2 presents the numerical acoustic propagation model along with preliminary measurements of the acoustic properties of building facades and rooftops that have been greened as part of the current project. The actual study of the effect of vegetation on sound propagation is then described in Section 3 and the various simulated scenarios are given. The final section provides and analyzes results in terms of both acoustic level and sound-decay time indicators.

2. Numerical modeling of acoustic propagation

2.1. The numerical model

The acoustic propagation model chosen to carry out this parametric study is based on the Transmission Line Matrix (TLM) method. This time-domain approach has been derived from the diffusion of sound pulses in a transmission line network, which entails a spatial and temporal discretization over the calculation domain as well as sound wave propagation. The effects of atmospheric absorption and micro-meteorological conditions have been ignored in this study due to the relatively short propagation distances and the lack of accurate temperature and wind field profiles. Nonetheless, the TLM method can potentially take into account such physical phenomena (Hofmann and Heutschi, 2007; Tsuchiya, 2006; Guillaume et al., 2014). The boundaries of the relevant calculation domain may be characterized by either a pressure reflection coefficient (Kagawa et al., 1998) or impedance condition (Guillaume et al., 2011). Virtual boundary conditions of absorbing layer type might also be introduced prior to reaching the calculation domain boundary when studying unbounded propagation media (Guillaume and Picaut, 2013).

From a strictly numerical point of view, the TLM method, like most time-domain numerical approaches, necessitates considerable computing resources. The reliance on graphics processor (GPU) computing power could help reduce computation time. This type of processor displays a highly parallel structure, offering an advantage by its capacity to significantly outperform conventional central processing units (CPUs), when the purpose is to process large blocks of data in parallel. In the area of environmental acoustics, the propagation medium typically features large dimensions, and the required memory space can disqualify models like the TLM method. The calculation domain has thus been fractioned into a series of sub-domains in order to enable performing calculations in parallel at the various cells composing a given sub-domain by means of a GPU, in addition to potentially distributing the sub-domain calculations on several graphics processors (Guillaume and Fortin, 2014; Guillaume and Picaut, 2012).

2.2. Acoustic properties of green wall coverings

As a prerequisite to this numerical study, *insitu* acoustic impedance measurements of both a widespread rooftop covering (Fig. 1) and green building wall (Fig. 2) were carried out using the method developed in Bérengier and Garai (2001) in order to estimate the specific air flow resistivity σ of this category of green surface. The facade is made up of varied species of plants (*Bergenias*, *Campanulas*, hardy *Geraniums*, *Erigerons*, coronarias, *Lamiums*, sedges, coral bells, …) arranged in patchwork. Sedums cover the vegetalized rooftop. This measurement campaign was conducted by means of a two-microphone technique: The first, R1, was placed on the surface and recorded the direct field (i.e. free-field propagation), while the other, R2, was located at a distance of 0.60 m from the material and could thereby collect both the direct field and the field reflected by the material. The source emitted a white noise 4 m from the microphones. Measurement post-processing consisted of correlating the attenuation spectrum relative to free field (i.e. the energy ratio of pressure fields measured at the two microphones R2 and R1) determined from experimental microphone signals, with the theoretical solution (Ingard–Rudnick's propagation model (Ingard, 1951) combined with Miki's model (Miki, 1990)) for this particular geometry, thus making it possible to estimate the value of the specific air flow resistivity on the investigated green surface.

For each surface element, a series of measurements was recorded by moving the measurement system between each acquisition. The average spatial values of specific air flow resistivities obtained were: $\sigma_F = 60\ \text{kN. s. m}^{-4}$ for the facade and $\sigma_R = 400\ \text{kN. s. m}^{-4}$ for the rooftop. These values must be read relative to trends, especially in the case of green facades, which have yielded a rather high standard deviation in results, due in large part to uncertainties in the experimental set-up (e.g. wave diffusion by the leaves). Along the same lines, the water content in such porous materials might also exert a pronounced impact on their acoustic properties (Cramond and Don, 1987; Horoshenkov and Mohamed, 2006). Otherwise, the measurement protocol was applied on concrete surfaces and led to typical values of the specific air flow resistivity on the order of $200000\ \text{kN. s. m}^{-4}$, what complies with a perfectly reflecting surface.

3. Presentation of the study

The study proposed herein is intended to assess the impact of greening the surface of building facades and rooftops on acoustic level and sound-decay time indicators. Consequently, the scope of this study must entail an existing site with the potential to accommodate such building renovation projects. Similarly, noise sources must reproduce those present on the target site, i.e. in this case road traffic characteristics (i.e. equivalent source heights, lanes number, …). This study only aims at estimating the differences between several scenarios of vegetation coverings and is thus independent from the emission sound spectra.

3.1. Scope of the study

The numerical study site, as illustrated in Fig. 3, is a canyon street of infinite length and sandwiched between two 4-storey buildings. Thus, the horizontal diffraction on the vertical edges which enables sound to propagate around the buildings in the horizontal plane is not taken into account. Each storey height is 3 m, except for the 5-m high ground floor. Two traffic lanes run along the street, with on-street parking and a sidewalk separating road traffic from the buildings. Windows (covering a surface area of 1.50 m × 1.50 m and offset 0.2 m relative to the facade plane) are also spaced every 1.50 m on the facade at a height of 0.65 m above the floor level of each storey. Road traffic noise is modeled by means of two line sources, with each one being discretized into 11 omnidirectional point sources spaced every 5 m in the middle of the traffic lanes at a height of 0.5 m. These sources asynchronously emit a