EFFECTS OF DIFFUSE REFLECTION BY BUILDING FAÇADES ON THE SOUND PROPAGATION AND SOUNDSCAPES IN URBAN AREAS

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ABSTRACT

Architectural morphology is an important factor for the prediction of soundscapes and noise propagation in urban areas. As in room acoustics, the sound field in a street is characterized by the building façades irregularities, in such a way that two similar streets (in size) can produce two different sound fields for two different building façades. However, most of the existing softwares and models take only the specular reflection into account implying a significant uncertainty in the sound prediction.

The main purpose of this paper is, first, to investigate how the sound field and urban soundscape perception are influenced by building façades, and secondly, to characterize several urban façade by typical reflection laws. Then, a coupling morphological and acoustical database will be built up and introduced in an urban acoustics simulation software, in order to be used by town planners and architects in urban projects.

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1 INTRODUCTION

Sound field modelling in urban acoustics has attracted considerable attention in the last decades. Thus, many mathematical and numerical models have been derived to predict the sound field in streets. However, many differences were observed between models and measurements in streets, suggesting that the part of multiple reflections, diffraction and diffusion of sound by building façades, could be more significant than expected and could account for these discrepancies. Moreover, as in room acoustics, one can also suppose that diffuse reflection effects can occur on urban soundscape perception.

In order to evaluate these effects, a research project within the "Bruit et Nuisances Sonores" Research Proposal Challenge, initiated by the French Ecology & Sustainable Development Ministry, was proposed. The first part of this project was to evaluate the influence of these façade effects on the sound propagation in a street and on the urban soundscape perception. Then, the main objective of the second part was to evaluate the reflection laws of real building façades, in order to include them in acoustic prediction software, thus to enhance acoustic predictions in urban areas.

2 DIFFUSE REFLECTION EFFECTS IN URBAN AREAS

2.1 Effects on sound propagation in a street

In order to evaluate the diffuse reflection effects on the sound propagation in urban areas, numerical simulations have been performed in a rectangular street used two different acoustic prediction methods. The first method was based on a sound particles tracing model in order to model diffuse reflections by arbitrary reflection laws, using a Monte-Carlo technique. Results, already published in Ref. [1], have shown important effects on the sound attenuation and the reverberation along the street. In some cases, these differences may reach 5 dB on the sound pressure level and 1 s on the reverberation time. These results were confirmed by numerical simulations using the MICADO boundary element method code [2], showing different sound pressure distributions in a street, for different building façade morphologies. As suggested in the paper introduction, these numerical results show that it is necessary to take the real reflection laws into account in acoustic prediction software, for accurate prediction in streets.

2.2 Effects on urban soundscape perception

A second part of this research project was to evaluate the influence of the urban façades morphology on the sound sources perception. Additionally, if this influence remains obvious, the experiment following will allow to define the exact nature of this effect. Therefore, we developed two evaluation procedures through spatial restitution of urban sonic objects, such as the tramway bells signals of Bordeaux. This will define the physical characterisation of the propagation space, with identifying the façade morphology as the varying parameter. Both recorded through a binaural technique and convoluted by a 4-channel B-Format impulse response, those bell signals are then auralised through a restitution system that preserves their spatial components. Those auralisation conditions depend on the recording techniques: headphone listening for the bells binaural recording, and immersive conditions in B-format acquisition. This experiment was proceeded within a canyon street in Bordeaux, Vital Carles street, in which six façades were selected for placement of both recording systems on the corresponding 6 points distributed into the length of the street.

The first recording system is a binaural system (SEB), consisting into a stereophonic microphone based on the artificial head principle, but using the sound recordist's ears so that they act as acoustic reflectors. This principle allows to register a stereophonic space very similar to the human hearing one. The SEB was located over the same surface as the natural source and in front of the concerned façade. The second system is based on a B-format recording technique providing a tridimensional impulse response of the street at each recording point. Impulse responses are then convolved to the reference anechoic urban signal, which makes it possible to recreate the complete three-dimensional information of the street with the tramway bell for auralization. In order to enable the identification of relevant factors used for urban ambience subjective evaluation, immersion conditions for ambience restitution proceeded with a rigorous protocol, through exploiting a multi-channel Ambisonic®6.2 sound reproduction system (6 channels and 2 subbass), lying under precise listener placement and controlled acoustic restitution [3].

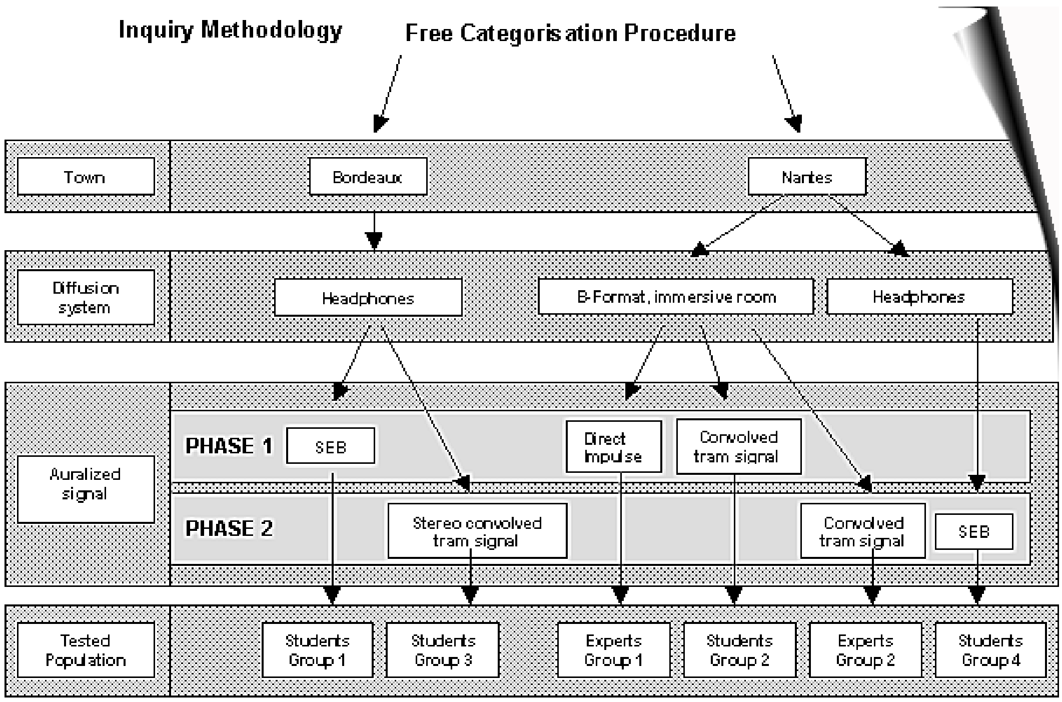

Fig. 1: Hearing tests experimental protocol.

Listening tests (Fig. 1) were organized through an 8-sound sequence corpus, made from 6 selected points from the street, plus 2 "artificial pairs", strictly identical, in order to control the discrimination process. Listening tests were made within two towns: Bordeaux exploited both binaural and stereophonic convolved signals through a headphone diffusion for its student population. Listening tests from Nantes involved four types of signal: pure Impulse Responses and B-Format convolved signals on one hand for its expert population, and B-Format convolved and binaural signals on the other hand for its student population. A unique inquiry methodology –free categorisation procedure– was applied for all experimental configurations in Nantes and Bordeaux. The free categorisation procedure consists into a classification of the sonic corpus elements, without taking into account the number of categories nor the number of elements included in each category. A second task consists into a categorical construction through a free argumentation, leading to a class qualification. This method allow the analyse of the so-created categories, including the cluster criteria of the sonic elements.

Phase 1 first results concerning the expert group n°1 investigation lead us to conclude on a quite good sample discrimination, through two emergent categorisation criteria: reverberation and sound level. SEB listening by group 1 students leads to quasi-exclusive background noise discrimination, using the following criteria: background noise source identification and description, temporal and energetic aspects of the background noise signal. As a first consequence, phase 2 results allow statements upon: (1) influence of the recording and diffusion method on the signal perception modalities, (2) influence of the sonic source recognition on the perceived signal evaluation.

Further results interpretations will help us to confirm and to define the diffuse reflection effect on urban sound sources perception.

3 CALCULATION OF REFLECTION LAWS

3.1 Method

Based on the room acoustic methods of diffuser characterisation, numerical simulation were performed to calculate the reflection laws of building façades in far field conditions [4]. This calculation treats the façade independently of the street in which it is located or any other environmental object so that a half-circle of receivers and a quarter-circle of sources can be placed around it in far field conditions. As a first approximation, the receivers and sources respectively are all at the same distance from the façade as show in Fig.2.

The 2D calculations have been performed with the MICADO code [2], that is currently the only approach that is able to give exact calculation results for such an acoustic problem, and that can be used as a reference. The reflection laws have been calculated in terms of the Excess Attenuation of the reflected field relative to the free field, and corrected by the respective 2D geometrical divergence (cylindrical sources). For each source and each receiver this Excess Attenuation EA_{refl} is given in dB by:

$$EA_{refl} = 20 * \log_{10}\left\{\frac{(p_{tot} - p_{lib}) * \sqrt{d(SR_{refl})}}{p_{lib} * \sqrt{d(SR)}}\right\}, \quad (1)$$

where p_{tot} is the total field sound pressure, p_{lib} is the free field sound pressure, $d(SR_{refl})$ is the distance from source to receiver trough the path reflected by the façade (see Fig.2) and where $d(SR)$ is the direct distance between the source and receiver position. This method has been used to calculate the reflection laws for a real façade from Vital Carles street in Bordeaux (Fig. 2). To simplify the comparison, the calculations have also been carried out for a finite plane façade.

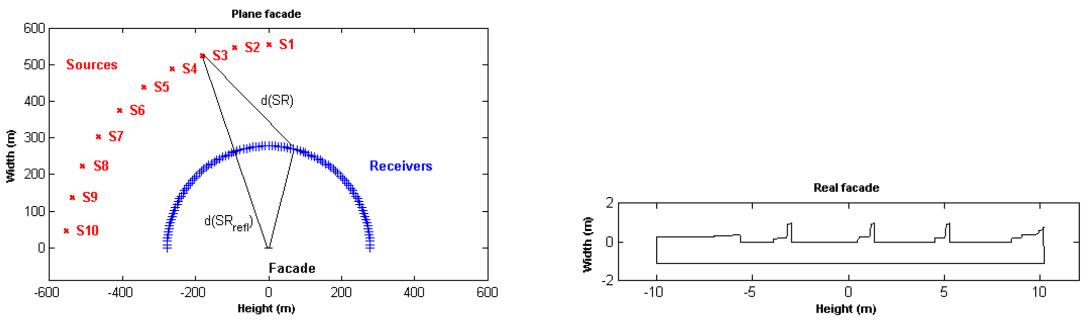

Fig. 2: Calculation set-up. Sources and receivers in far field conditions for a plane façade (left) and above a real building façade in Bordeaux (right).

3.2 Results

Fig. 3 shows the results of the reflection laws of the real façade (in blue) and the plane façade (dotted red line) for source S5 (45°) at several frequencies from 31.5 to 1000 Hz. At very low frequencies no influence can be observed. The height of the façade is too small compared to the wavelength of the incident sound field. It is the lower limit of the calculations where the reflection law is valid. At low frequencies, the façade roughness has no influence on the reflection law. The façade acts as a plane façade. Only some negligible back-scattering on the plane façade edges can be observed. At medium frequencies, the reflection law of a real façade has its own shape noticeable different to that of a plane façade. At higher frequencies the reflection law is very different to that of a plane façade where specular reflection occurs. The reflection law of the real façade can be approximated by a uniform law for frequencies higher than the Rayleigh criterion, which is in the presented case around 200 Hz.

3.3 Introduction into an acoustic prediction software

The last step of the second part of this project is to show that such real reflection laws can be introduced in acoustic prediction software. In this study, the choice was done to use the ICARE code, based on a beam tracing method [5]. Instead of using the real geometry of the façade, a plane façade is used with the reflection law of the real façade. Because of the result of the weighted sum of reflection laws, is the reflection law itself, it can be applied at each point on the building façade. In this step, which is currently in progress, 3D reflection laws will be used. Since the calculations have been performed in 2D, an interpolation between the reflection laws of a horizontal and a vertical cross-section will be done. Contrary to classical prediction software which includes diffuse reflections, it is not necessary to separate the specular and the diffuse fields, since the reflection law already includes the specular part.

4 CONCLUSIONS

The main result of this work is that diffuse reflection must be included in acoustic prediction software, in order to give accurate predictions in urban areas. On the other hand, our results show that diffuse reflection effects is difficult to correlate with urban soundscape perception. The last part of this project is to validate these results by simulating a real street with real reflection laws, then by comparing the numerical results with experimental data.

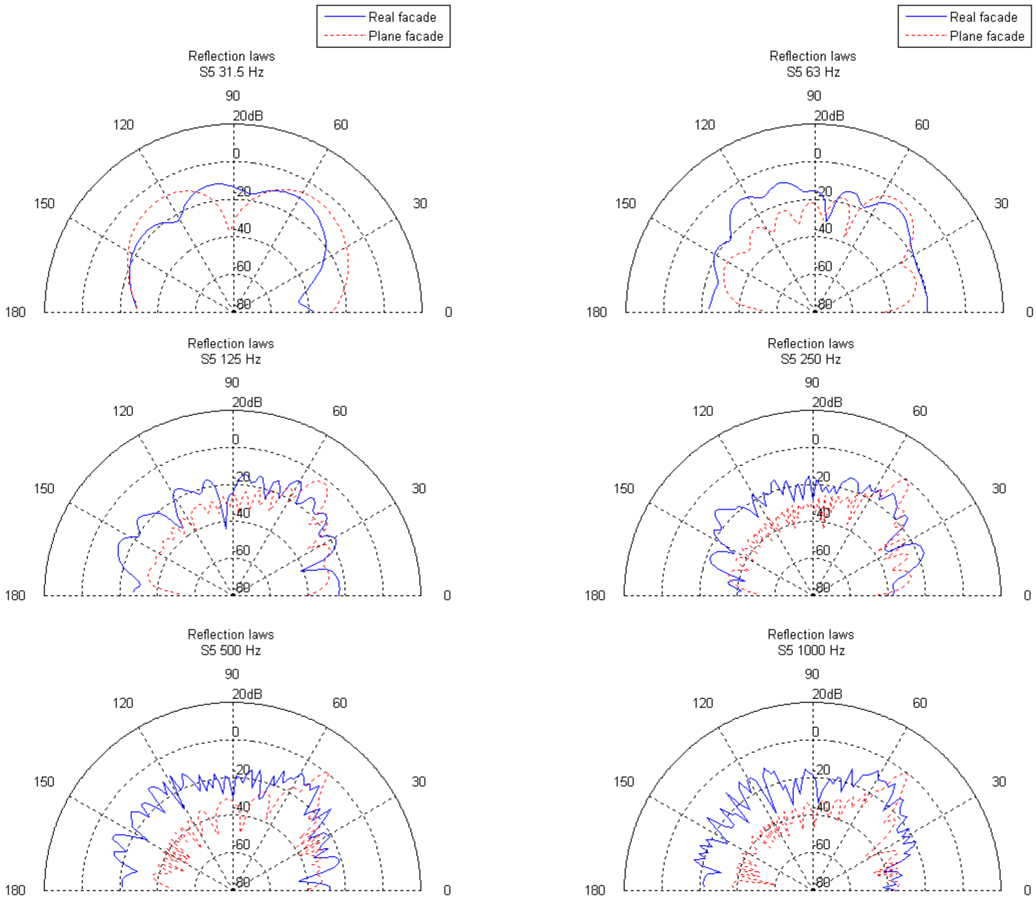

Fig. 3: Reflection laws in terms of EA_{refl} *for the real and the plane façades at 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz and 1000 Hz, for the source S5.*

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