Perceptive Evaluation Procedures for Diffuse Reflexion Listening

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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 frontages. The main purpose of this paper is to investigate how the soundfield and urban soundscapes perception are influenced by building façades. This paper is a part of the national land transport research and innovation program (PREDIT) and is supported by the French ministry for ecology and sustainable development.

Keywords: Diffuse reflection effect, Perception criteria, Free categorisation procedure, Acoustic immersion

Introduction

Soundfield modelling in urban acoustics has attracted considerable attention in the last decades. Thus, many mathematical and numerical models have been derived to predict the soundfield 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 soundscapes (Kuttruff, 1982).
As the physical approach of the influence of the facade morphology on the acoustical diffusion in an urban street is an extensive subject for acoustics papers those last ten years, one can note that the perceptual aspect of this interaction has quasi-never been developed. This is why both CERMA and GRECAU-Bx laboratories intend to proceed into this research topic within the "Bruit et Nuisances Sonores" Research Proposal Challenge, initiated by the Ecology & Sustainable Development Ministry, in collaboration with CSTB and LCPC

laboratories (Woloszyn, Barlet, Chartier, 2006). One aim of this project was to evaluate the influence of these façade effects on the urban soundscapes in a street. The present paper is referring to this research program.

Evaluation procedure

This research aims to evaluate the influence of the urban facades morphology on a sound source perception (Coll. d'auteurs, 2006). Additionally, if this influence remains obvious, the experiment following will allow to define the exact nature of this effect. Therefore, we developed an evaluation procedure 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 facade morphology as the varying parameter. Both recorded through a binaural technique and convoluted by a 4-channel B-Format Impulse Response (I.R.), those bell signals are then auralized through a restitution system that preserves their spatial components. Those auralization conditions depend on the recording techniques: headphone listening for the bells binaural recording, and immersive conditions in B-format acquisition (Gerzon, 1985).

This experiment was proceeded within a canyon street in Bordeaux, Vital Carles street, in which six facades were selected for placement of the two following recording systems on the corresponding 6 points distributed into the length of the street:

- The *binaural system* used by the GRECAU-Bx consists into a stereophonic microphone based on the artificial head principle. Two electrets capsules are placed next to 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. A digital audio tape (DAT) recorder connected to the system allows a 2 channel (stereo) recording under the PCM standard. While performing the sound recordings in Bordeaux, the binaural recording system was located over the same surface as the natural source and in front of the concerned façade.

- The *B-format recording technique* used by the CERMA provides a tridimensional Impulse Response (I.R.) of the street. This measurement technique for auralization of our urban sources has been applied at each recording point, the 4 information channels, called B-format signal, consists into acquiring the omnidirectional sound pressure signal (W), plus three first-order pressure gradient components, along the three Cartesian axes (X,Y,Z). The Soundfield 4-channel microphone used at this aim records the impulse responses with a sine sweep signal at every point of the street to be characterized. These B-format 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 sonic objects 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 (Woloszyn, 2003).

Inquiry procedure involved *listening tests*, which were organized through an 8-sound sequences corpus, made from 6 selected points from the street, plus 2 "artificial pairs", strictly identical, in order to control the discrimination process. The two other pairs to discriminate are called "natural pairs", and correspond to the grouping of two recordings made in front of similar-styled facades (i.e. two windowed or two stone worked facades).

Counting about a hundred participants, two populations were concerned with the inquiry procedures: the experts group, composed with acousticians, musicians or soundscape research workers, and the students group, within the schools of architecture from Bordeaux and Nantes, including ECN students.

The presented recording techniques has produced 4 types of signals used for the pairs discrimination :

- Bell binaural signal (stereo),
- 3D convolved bell signal (B-Format),
- Stereophonic convolved bell signal,
- Pure Impulse Response (B-Format).

The three first signal types are based upon a common urban source from the city of Bordeaux, the tramway bell, permitting an easy association between signal and source, in order to facilitate the discrimination task itself. In the contrary, the last signal type does not reefer to a known urban source, as it is targeted to the experts group listening. Each of the 8-sound sequence corpus has been realised through emission of the 4 types of signals.

Listening tests were made within two towns: Bordeaux exploited both binaural and stereophonic convolved signals through a headphone diffusion for its students groups. 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 students groups. A unique inquiry methodology – free categorisation procedure- was applied for all experimental configurations in Nantes and Bordeaux.

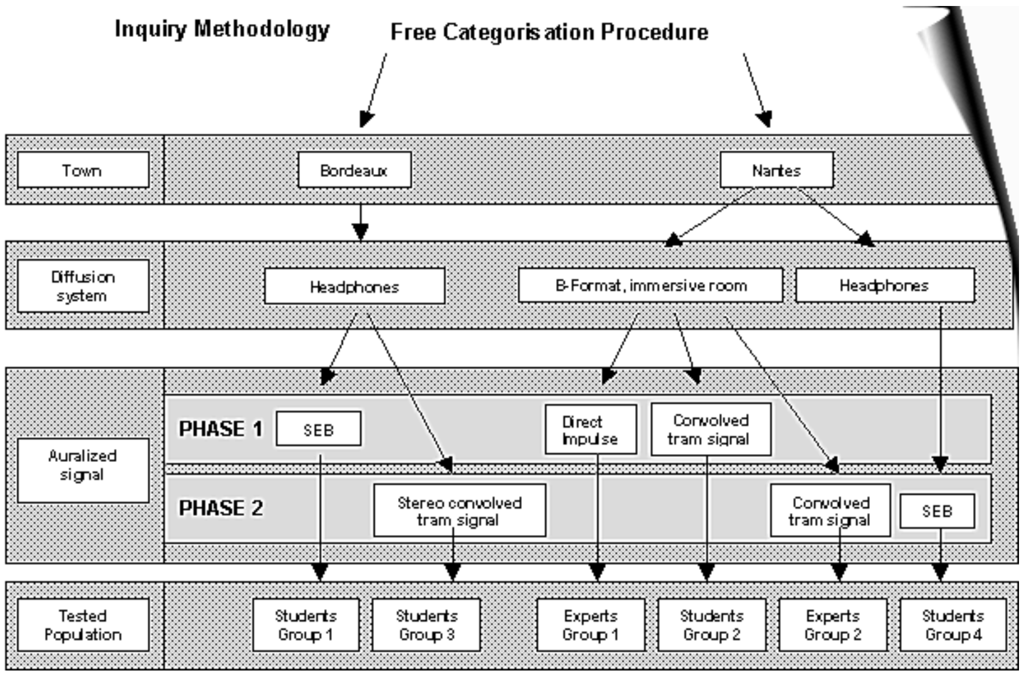

Figure 1. Hearing tests experimental protocol

Free categorisation task involved two phases: first, subjects were asked to classify the sonic corpus elements into categories, without taking into account the number of categories nor the number of elements included in each category. A second task consists into a categorial 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.

First phase: Categories creation

Phase 1 first results shows 497 categories created that way by the 100 subjects. Independently from the subject status (expert or student) and the experimental conditions (towns, diffusion systems, auralized signal types), an average of five categories were created by every subject, with an individual variation from 2 to 11 created categories.
Analysis of the inquiry results leads us to distinguish about three types of created categories including at least one pair, plus one category containing none:

- “exclusive” categories, composed uniquely from one of the proposed pairs, natural or artificial (22,13%),
- “non exclusive” categories, composed from one of the proposed pairs and from other sequences (58,15%),
- “double exclusive” categories, composed from the two proposed pairs, natural or artificial (2,01%),
- “other” categories, composed uniquely from isolated sequences (no pairs) (38,23%).

The high percentile of the “non exclusive” categories can be explained by the multiple counting due to cumulative pair and isolated sequences, leading to a >100% percentile.

This categories typology corresponds to a discrimination score of the sequences sound characterization: in the “other” categories case, nobody reconstitutes a pair, so that there is absolutely no discrimination. In contrary, when subjects isolate a pair in an “exclusive” category, discrimination is considered as “sharp”. “Non exclusive” and “double exclusive” categories describe a more “relative” discrimination performance.

Global categorisation results referring to the whole population reveals a low “sharp” recognition level, for both natural and artificial pairs. In that way, “relative” discrimination performance and “no discrimination” are more important. Moreover, discrimination capacity depends on subjects groups, signal types, restitution modes and towns.

Both bell binaural (stereo) and Pure Impulse Response (B-Format) signals allow a better “sharp” identification of the natural and artificial pairs, for specific reasons. Indeed, as Pure Impulse Response (B-Format) has only been diffused to the expert group n°1, this last accuses a “sharp” discrimination performance of more than 22%, or till 72,9% with including “relative” discrimination performance (so including non- and double exclusive pairs). Bell binaural (stereo) signal is allowing a high “sharp” discrimination performance too, as the percentile of “exclusive” categories is the highest for the two groups who listened those signals (36,90% for students group n°1 - 33% for students group n°4).

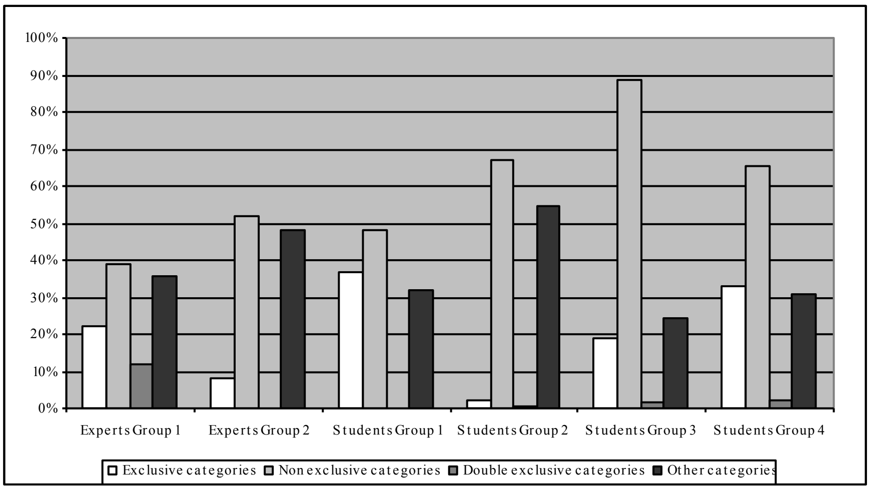

Figure 2. Categories typology vs subjects groups

Nevertheless, we have to keep in mind that, regarding to its acquisition process, binaural signal associates the tramway bell signal to its instantaneous urban background noise. Next part of the present work will tell us more about the background noise contribution in the recognition process.

Source knowledge appears to be a less significant variable for the recognition task, as the inquiry does not reveal a significant difference towards Bordeaux and Nantes sites (student group1 versus student group 4), the first of them necessary being familiar with the tramway bell. Influence of source recognition will being revealed through the qualification process, readable in the next part of the work.

Nevertheless, the two students groups 2 and 3 listening to the same signal with different *restitution conditions*, B-format signal (immersion room) for group 2, and binaural for group 3 (headphones), showed very different recognition levels concerning "sharp" (2.27% for group 2 and 18.87% for group 3) and "relative" (67% for group 2 and 88.68% for group 3) discrimination. This better performance of the group 3 confirms the advantage of the headphones restitution mode for discrimination process.

Those results lead us to the conclusion that restitution mode condition is clearly superior to source knowledge or recognition influence for pair identification task when using free categorisation method.

Second phase: Class qualification

Second phase of free categorisation task consists into description and argumentation of the created classification. This consists into identifying criterion relative to signal description, upon which were deduced categorisation criteria.

Whatever the discrimination level, "sharp", "relative", or "null", a 15 criterion items listing has been defined through the inquiry process, 8 items referring to the signal itself:

A. "Source identification": the signal itself is identified and named as a source,
B. "Reverberation": the presence or the absence of the reverberation effect is identified,
C. "Temporality": describes the temporal evolution of the signal,
D. "Description": qualities of the signal,
E. "Spatialisation": perception effect of the signal in a particular space,
F. "Sound level": sound volume perception,

G. “Signal frequency”: signal frequency perception,
H. “Evaluation”: positive or negative evaluation of the signal,

1 to the site evocation:

I. “Site evocation”, associating the heard sounds to a particular site,

6 to the background noise:

J. “Background source identification”: background sources are identified and named,
K. “Background noise description”: qualities of the background noise,
L. “Background noise level”: sound volume perception,
M. “Temporality”: describes the temporal evolution of the background noise,
N. “Background noise evaluation”: positive or negative evaluation of the background noise,
O. “Background noise frequency”: background noise frequency perception.

Those 15 criteria listing is representative of the whole categorisation process, independently from the categories themselves.

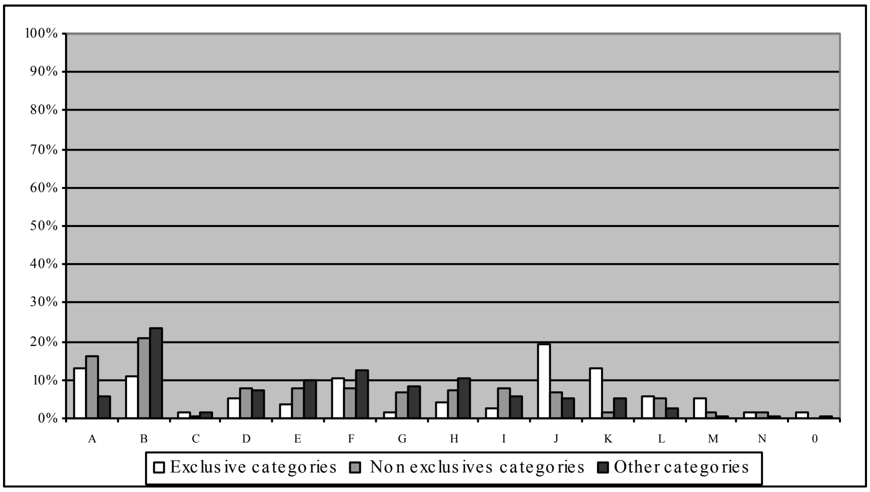

Figure 3. Criteria used by the six groups

Influence of variables on the discrimination capacity is mainly the same as for the first phase (categories creation), that means depending on subjects groups, signal types, restitution modes and towns.

Influence of the *signal type* on its description is clearly established through the two criteria groups, referring to the signal itself or to the background noise: indeed, binaural signals were recorded and diffused with their corresponding background noise, leading to a “Source identification” (A) for signal and background noise, contrary to the convolved tram signal, which corresponding criteria are “Description” (D) and “Sound level” (F), and the pure impulse response, which is described through “Reverberation” (B) and “Sound level” (F) .

Influence of the *recording / diffusion method* on the signal perception modalities cannot be established yet, as the group student 2 provided a low recognition performance at 2.27%: this percentile does not allow sufficient statistical representation of the corresponding descriptors.

Influence of the sonic *source knowledge* on the signal evaluation appears clearly on the descriptors, which reefers to the background noise in Bordeaux, and to the signal itself in Nantes. We can note that those different descriptions does not interfere with the categorisation process (first phase), that provides the same recognition levels for Bordeaux and Nantes.

Conclusion

The three variables used in this research work -signal types, restitution modes and towns- have a joint influence on sonic elements discrimination performance, and on perceived characteristics argumentation.
The experimental condition that allows the most performing "sharp" discrimination corresponds to students group 1, which is composed with subjects familiarized with the diffused source (the tramway bell from Bordeaux), under headphones listening conditions (binaural signal). Nevertheless, the categorisation criteria used by this group are referring to background noise, without any relationship with the original signal characteristics. However, it is precisely the signal itself that carries the facades diffuse reflection effects.
On the contrary, the experimental immersive conditions diffusing Impulse Response signal to experts subjects implies a less performant sharp discrimination, but on the other hand, more referenced to the signal itself. In this framework, sole the expert group 1 who listened to pure Impulse Responses obtains a significant exclusive categories rate.

Final conclusion leads us to deduce that façade morphologies impacting on sound diffusion is only perceived in specific experimental conditions. So a particular trained listening like expert one (musicians, acousticians, sound engineers,…) and background noise absence constitute the minimal conditions for a performing discrimination of façade morphologies impact in soundscapes.

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