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Research paper

Using Virtual Reality for assessing the role of noise in the audio-visual design of an urban public space

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ABSTRACT

Sound planning is not often included in the urban design process despite the well-known audio-visual interactions of human perception. A methodology to compare the overall appreciation of future renovation alternatives of urban public spaces using Virtual Reality Technology is proposed. This method is applied to assess the role of noise in the overall appreciation of a walk on a bridge crossing a highway. The auralization is a dynamic 3D surround based on B-format recordings (ambisonics), filtered by means of full-wave numerical calculations obtaining the sound field behind noise barriers along the bridge's edge. Four different styles of visual street design including different noise barrier heights in combination with the 4 corresponding predicted sound fields were evaluated for their pleasantness by 71 normal-hearing participants on 4 separate days. Each day participants experienced all the visual environments with only one soundscape (to elude direct sound comparison) and anything related to sound was not mentioned in the first part of the experiment. Even in this non-focussed context, a statistically significant effect of the sound environment on the overall appreciation was found. In general, the pleasantness increases with traffic noise level reduction, but the visual design has a stronger impact. By mentioning the soundscape while introducing the evaluation, slightly lower (but statistically significantly different) pleasantness ratings were obtained. Instead of increasing noise barrier height, improving the visual design of a lower barrier seems more effective to increase pleasantness. Visual designs including vegetation strongly outperform others. The virtual experience was rated as immersive and realistic.

1. Introduction

The fact that soundscape is not commonly taken into account in urbanism might contribute to the ubiquitous noise problem in our cities nowadays (Bild et al., 2016Bild, Coler, Pfeffer, & Bertolini, 2016). Similarly, when visual quality is not given sufficient attention in acoustic interventions, the result might even be a worsening of the general environmental quality of the urban space. The lack of simultaneous consideration of both visual and sound may give rise to inefficient interventions in urban areas, often resulting in disuse of public spaces by pedestrians. Any urban renovation should be at the disposal of pedestrians from a holistic point of view, taking into account all the elements affecting activity in the urban context.

The combined audio-visual influence on human environment perception is known since long. The study of Southworth (Southworth, 1969) showed for the first time how sounds influence perception of the visible city, concluding that sound has the function of enriching the environment. Recent studies further showed how sound and visual interaction affect perception. Auditory perception improves when accompanied by visuals cues, and similarly, sounds can direct attention to related visual elements (Broadbent, 1958; Carles, Barrio, & De Lucio, 1999; Hong & Jeon, 2014; Joynt & Kang, 2010). The effects of non-auditory factors on soundscape perception has been investigated concluding that urban soundscape is dominated by acoustic comfort, visual images and day lighting (Jeon, Lee, Hong, & Cabrera, 2011). Natural green to improve noise perception takes a special place in this context. Natural features are indicators of tranquillity (Pheasant, Horoshenkov, Watts, & Barrett, 2008). The view on vegetation as seen from a living room's window facing a city ring road was shown to strongly reduce the self-reported noise annoyance (Van Renterghem & Botteldooren, 2016). Aylor found that there was a 7 dB difference in the perception of loudness between hemlock trees and a minimal fence obscuring an acoustic source (Aylor, 1977). Also traffic noise can influence the perceived visual impact of motorway traffic, especially in a natural

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landscape (Jiang & Kang, 2016). The visual perception of traffic was shown to have a significant influence on perceived noise, increasing the average ratings of noisiness where the degree of visual screening was higher (Watts, Chinn, & Godfrey, 1999). Perceived loudness and noise annoyance was found to be lower for transparent noise barriers than for opaque barriers (Joynt & Kang, 2010; Maffei, Masullo, Aletta, & Di Gabriele, 2013). Certain sounds like traffic noise and especially bird song are rated more negatively the more urban the visual setting is (Viollon, Lavandier, & Drake, 2002). The effects of visual characteristics in landscapes on soundscape perception in city parks was studied, concluding that the percentage of buildings, vegetation and sky in panoramic views were landscape elements effectively influencing soundscape perception (Liu, Kang, Behm, & Luo, 2014).

These findings are guiding towards an assessment method for design and renovation of urban public spaces that fully accounts for coupled audio-visual perception. State-of-the-art Virtual Reality technology is facilitating this objective, simulating the useŕs physical presence in a virtual replication of a real environment, and allowing the interaction with the urban space. Some recent studies have already used VR to simultaneously assess sound and visuals in the perceived urban environment (Aletta, Masullo, Maffei, & Kang, 2016; Maffei, Iachini et al., 2013; Maffei, Masullo et al., 2013; Ruotolo et al., 2013).

However, to fully unleash the possibilities opened by modern VR, a few factors in the audio-visual experience need to be considered carefully. Firstly, a realistic audio-visual interaction needs to include movement as we do in real life (Nordahl, 2006), where people walk and move the head around willingly to explore the environment. Previous research has concerned acoustically static environments based on binaural recordings from a fixed head position (Maffei, Iachini et al., 2013; Ruotolo et al., 2013). Achieving a virtual dynamic acoustic ambiance is especially difficult for non-existent soundscapes that need to be auralized and reproduced in a 3D soundscape. Secondly, the daily use of the public urban space usually does not involve active listening (Lindborg, 2015). Hence it could be expected that assessment of urban designs may be affected by focussing attention of the participants on the sound environment. It was also observed that landscape preference varies when being informed about the context (Van der Wal et al., 2014). This would imply that a very careful experimental design is needed to guarantee ecological validity of this assessment.

In this paper, a method for 3-dimensional auralization of future sound interventions is proposed, allowing simultaneous interaction with the useŕs head movement. Furthermore, physical movement within the virtual environment is possible, allowing the user to walk, perceiving the changing visuals and changing soundscape along the journey and having the possibility to look around freely and localizing in space the different sound sources. The design of the future soundscapes in an urban renovation can include noise abatement measures. The proposed method modifies the existent urban sound recorded in B-format (ambisonics) according to an accurate calculation of the correspondent frequency-dependent insertion loss by means of a full-wave technique: the Finite Different Time Domain (FDTD) method is used here. An existent bridge over a highway is considered as a case study where this method is put into practice. This methodology is fully explained in Section 1.

In this paper, the above methodology is applied to investigate the influence of highway traffic noise on the overall pleasantness of experience of walking towards a park, in particular when the users of the space are not made aware of the presence of this sound. As subliminal sound was shown to influence perception (Kang & Schulte-Fortkamp, 2016), some effect is expected. An experiment was conducted with 75 participants (that had no prior knowledge of the place) to compare the quality of different urban renovation proposals. The experiment was carefully designed to achieve ecological validity needed to assess the different renovations in the same urban scenario, recreating a realistic experience in a lively surrounding of a city created with elements in motion (cars moving, trams passing by and people walking). In a first phase, the same sound environment was present during the presentation of all designs but the same evaluation was repeated during different days with a different sound environment. This experimental design strongly reduced the awareness of the differences in the sound environment.

In a second part of the experiment participants were asked to specifically pay attention to the different visuals and sounds (informed). Section 2 discusses the results of this experiment.

2. Methodology

2.1. General methodology

A new methodology is proposed to compare the quality of future urban renovation alternatives for an urban street area by means of Virtual Reality, including the sound planning strategy. VR artificially replicates an environment allowing user interaction in 360°. The immersion is experienced through different sensory modalities providing the perception of being physically present. This method uses the full-sphere surround sound of the existent soundscape of a current noisy area, and auralizes future urban renovations. VR allows to walk immersed through an urban environment with the freedom to look around as we do in normal life, ensuring sufficient ecological validity. This presentation of the sound environment goes far beyond the more common binaural presentation that limits the movement of head. The freedom of the user to move the head while walking in a virtual scene forces to build a dynamic 3D sound environment (ambisonics). The headphone playback requires instant head tracing and accounting for average Head Related Transfer Function HRTF.

The visualization of the urban area can be built in any 3D software or Game Engine and reproduced with any head-mounted device to provide the virtual visual experience. The necessity to reproduce a realistic feeling in the users requires a detailed and accurate visual and audio model as similar as possible to the real urban area.

The auralization process of the renovation starts from a 4 channel B-Format recording of the existing sound environment, which allows to include auditory spatialisation partially due to the limited directivity of the first order channels of ambisonics. It is however enough to provide a feeling of sound immersion while keeping the mobile sound recording relatively straight forward. The urban intervention might include noise abatement measures whose corresponding noise reduction needs to be calculated in detail, resulting in a frequency-dependent insertion loss used for filtering the aforementioned B-Format recordings. In this work, the detailed finite difference time domain (FDTD) method was used to numerically predict the effect of different noise barriers (Ding, Van Renterghem, & Botteldooren, 2011). This accurate method is capable of computing all physical phenomena involved like multiple diffractions and scattering. This technique has been successfully validated over a wide range of acoustical applications, including sound level predictions in urban streets (Echevarria Sanchez, Van Renterghem, & Botteldooren, 2015). The B-format is decoded in a 3 dimensional reproduction audio system and applied the insertion loss previously calculated. Thereafter, it is implemented within the Virtual Reality model as an equidistant surround sound source system around the character controller associated to the position and movement of the person experiencing the VR. To allow for a dynamic assessment of the environment (users are moving in the urban environment), the virtual sources for B-Format reproduction move in parallel and simultaneously to the character controller and are synchronized in time and space with the original recording.

In a final step, test persons are asked to make virtual walks through the urban environments to assess their experiences in detail. In the following section this general methodology is applied to a case study.