The relative importance of visual and sound design in the rehabilitation of a bridge connecting a highly populated area and a park.

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ABSTRACT

Audio-visual interactions can have an important effect on people's perception of the urban environment. The aim of this study is to research to what extent such measures can help in improving citizens' noise perception, and in extension, in increasing the general quality of the urban environment. Different renovation designs in a degraded area were put to the test by means of a virtual reality experiment. The test is performed with 100 normal hearing participants experiencing a walk over a visually and acoustically degraded bridge that connects a highly populated area to a park over a highway. Interventions to improve that state were both visualized and auralized. The Virtual Reality Environment is experienced by the participants with Oculus 3D glasses and headphones. The auralization includes noise abatement measures such as the addition of (low-height) noise barriers. The corresponding noise reduction was calculated in detail with the FDTD method, resulting in frequency-dependent insertion losses filtering the B-field (ambisonics) recordings made along the bridge. The participants are invited on several days, and exposed to the same audio-samples but with different visuals each time. Detailed questionnaires will help unraveling the importance of the auditive and visual stimuli when assessing the environmental quality. In the current paper, the setup of the experiment is discussed.

Keywords: Road traffic noise, Noise control, Audio-visual interactions, Urban geometry, Architecture, Urban planning.

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1. INTRODUCTION

Urban circumvallation highways are needed to guarantee accessibility when a city reaches a certain dimension. However, many studies have shown the negative impact of road traffic noise on individual's quality of life and health (1). Reducing the impact of urban traffic on livability can be achieved in many ways. One can work on the source and the propagation path, and - less explored - how the receiver perceives the sonic environment. For people living close to the main roads, indoor sound quality can be improved using façade insulation. As it was shown that noise exposure in the vicinity of the dwelling also contributes to noise annoyance and overall assessment of the livability of a neighborhood (2), improving the sound environment on walkways can be envisaged. Recently, the effect of the general shape of the buildings, street configuration and urban furniture was explored, showing some possibilities to reduce the exposure at pedestrians on walkways along a street (3).

Furthermore, most of the research related to perceived noise is centered exclusively on the sense of

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hearing. However, it has been proven that the human perception of the urban environment is multisensorial (4, 5), especially the visual sense is related to the auditory sense. There are studies indicating that visual information influences auditory judgement and vice-versa (6, 7, 8). The visual perception also gives information about the functional aspects of the urban space, influencing the perception of the urban environment (9). The effect of the inclusion of greenery and the way it affects the perception of noise has also been studied (10, 11, 12). The appearance of barriers also affect the perception of noise (4). The present research aims to expand knowledge on the audio-visual characteristic of human perception with the objective of better understanding to what extent the sonic environment influences the overall experience of walking towards a green public space close to home. Improving the quality of an urban space like the bridge under study would increase its connecting function, providing better accessibility to the park, and thus increasing people's mobility and social cohesion.

The subjective awareness of noise is a well-known fact (13) that most of the experiments related to noise annoyance with participants do not take into account. The continuous or intermittent characteristic of noise affects annoyance and the attentiveness is one of the factors. Continuous noise, e.g., might not be perceived if the participant is not attentive to the sound environment. In this research, the participants will not be directly asked about the sound environment until the last experience, increasing the ecological validity. Only in the last part of the experiment, they will be asked to pay attention to the sounds.

There are already studies that made use of virtual reality (VR) to assess noise annoyance (14, 15); nevertheless, the graphics were still far from being realistic showing a non-natural appearance. Since a few years the technology has evolved, improving the graphics and the realism of Game Engines up to the limit where a character is not distinguishable from a real human. The interface is also simplified making it accessible to non-professional game developers. In this study, the free Game Engine Unity was used to create four different virtual renovations of a degraded bridge with a high and realistic graphic detail. Furthermore, previous studies assessing noise annoyance using Virtual Reality were static experiences. In this research the virtual experience provides a dynamic experience consisting in a virtual walk along the bridge, adding as a consequence more ecological validity to the experiment.

Section 2 explains the methodology for audiovisual presentation of different urban designs to lay people, Section 3 describes the experiment that has been designed to evaluate the influence of the sound environment on the quality of experience of crossing a bridge. At the time of the writing of this proceedings paper, the experimental work was not finished. Hence, only expected results can be described in Section 4.

2. METHODOLOGY

2.1 Procedure

An experimental study allowing non-experts to evaluate different audio-visual rehabilitation designs is performed. The area under study is a strategic bridge in Antwerp crossing the highway R1. Nowadays it is a visually degraded area with high noise pollution. The visualization of the different designs together with the current case has been built in 3D with Unity Engine Game. The urban renovation includes the reorganization of different mobility modes and public areas, the use of different materials and urban furniture. The auralization contains noise abatement measures such as the addition of noise barriers on the bridge. The corresponding noise reduction of these barriers has been calculated with the Finite Different Time Domain (FDTD) technique obtaining frequency-dependent insertion losses to be applied to the B-field (ambisonics) recording on the existing bridge across the highway.

In the experiment the participants experience a walk along the bridge for each of the different designs. The overall experience of the participants while crossing the bridge is collected via a brief questionnaire that avoids participants to focus attention to sound or to visual elements.

This experiment has the final aim to assess the audio-visual perception of the urban environment, verifying to what extent the visual design influences the perception of traffic noise and quantifying how sound pressure level influences the overall perception of the urban environment. Additionally, it is aimed at detecting the elements and the perceptible features of urban landscape that help to perceive a better soundscape. Besides this, the subjective awareness of noise and how attention can influence the perception of sound and noise annoyance will be evaluated.

In this research both auditory and visual perception are assessed using the immersive Virtual Reality Technology (VR). It allows the simulation of an artificial world in a natural scale giving the observer the sense of real presence in the scenery. This mean of reproduction ensures the ecological validity compared to the traditional setups like pictures, photomontages or video projected on flat screens (16).

2.2 Rehabilitation of the urban area.

Antwerp is one of the most populated cities in Flanders (Belgium), and therefore, open green spaces are important. Rivierenhof park is one of the largest parks in the city, located in the North West.

The area used for this study is a strategic bridge (Turnhoutsebaan straat) in Antwerp crossing over the highway R1 connecting the center of the city with Rivierenhof park. The bridge is important as it connects the park which the densely populated district of Borgerhout which lacks green and open spaces. This park is the only green area that is accessible.

However, this bridge is an urban degraded area (See Figure 1), visually it is an unattractive space and acoustically, the intense traffic produces high noise pollution. The noise levels on the bridge exceed 80 dBA. Consequently, the bridge turns out to be a barrier between the two sides of the highway instead of functioning as a connector.

Figure 1 – Bridge in Turnhoutsebaan straat; Antwerp (view on the bridge and from the highway R1).

The first approach to reduce the visual degradation and the safety problems on the bridge was to reorganize the distribution of the different street uses to promote shared and safe movement routes for different modes of mobility. As it is shown in the Figure 2, the slower and faster modes of transport are separated: the pedestrian and bicycle surface is combined into a broader area, the two road lanes are reunited and moved at the other side of the tram lines that remain at their current location.

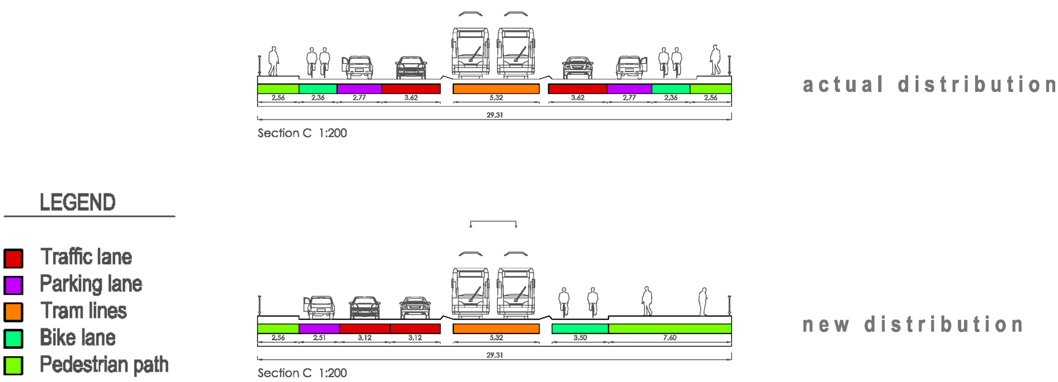

Figure 2 – Street use redistribution.

From the aesthetic point of view, four different urban renovations of the bridge are proposed (see Figure 3) allowing a better integration of the movement function, improving the pedestrian and cycling environment and providing new areas of rest, increasing the feeling of security. Different designs of noise barriers with different heights are included in the virtual environments. The correspondent noise reduction for each barrier was auralized.

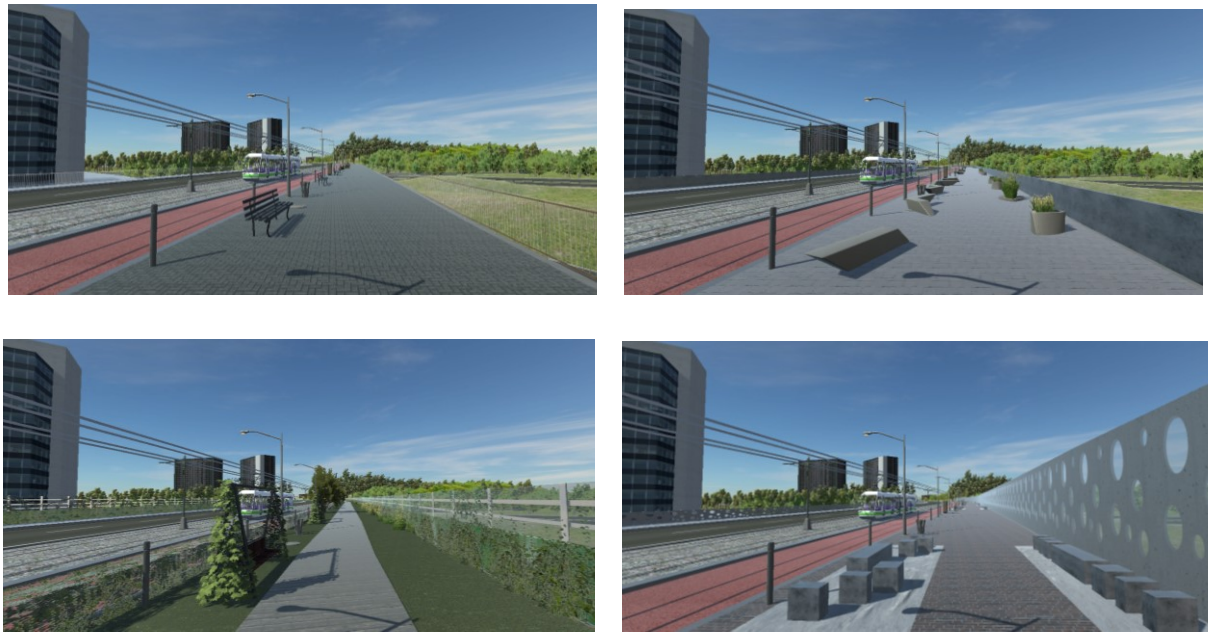

Figure 3 – Four different urban renovations of the bridge. Image from the virtual model in Unity.

2.3 Virtual Reality

The experiment is performed by means of the technology of immersive multimedia Virtual Reality (VR) which replicates an artificial environment allowing user interaction. It is experienced through sensory stimuli (in this case sights and sounds are included) giving the feeling to the user of being truly transported in the simulated environment.

2.3.1 Visualization

The virtual environment of the bridge and the area of Borgerhout were geometrically modeled in 3Dimensions with the Unity Game Engine trying to visually reproduce the real environment as accurately as possible: the Unity Terrain and the different roads and highways are manually modeled corresponding to the heights of the topographic map. The buildings are modeled individually corresponding in shape and dimensions to the existent ones. The applied textures and the sky characteristic are also carefully chosen. In order to add the characteristic life of a city, other pedestrians walking along the bridge are included in the model. Special importance is given to the highway R1which is the main source of noise on the bridge. Different cars and trucks are included in the model and assigned the physical ability to move along the highway.
The Character Controller is included in the model as the first-person player control. However, the ability to play and walk around is restricted to follow a unique path along the virtual bridge at 3m from the edge of the bridge at a constant speed of 5 km/h. This restriction guarantees the same experience for all participants. The ability to move the head around to see 360x360 degrees of the whole environment around is the only interactive freedom allowed. The head movement of participants could provide information about the degree of tranquility of a person and the region where they are looking at would give information about the elements attracting attention. Therefore, the experience of each participant will be recorded. The Oculus Rift DK2 is the head-mounted device that provides the immersive virtual reality experience.

2.3.2 Auralization

The virtual soundscape for each of the urban design is the result of the addition of two categories of sounds: invariable sounds (a) that are identical for all the virtual environments, and variable sounds (b) that vary for different designs.

a) The invariable sounds are the group of sounds that appear punctually in the virtual soundscape. They all happen over the bridge at a certain moment: the sound of a tram, different cars passing by and the sound of the character controller steps. They are static monaural recordings without modification, applied directly in the virtual model with a single source attached to the moving element. The Oculus Rift drivers provide spatialisation of these sounds. These sounds not only add to the realism of the bridge's virtual reality, they also provide an auditory frame of reference for the participants in the experiments.

b) The variable sound corresponds to the traffic coming from the highway received by the pedestrian while walking along the bridge. B-format recording of the R1 highway where done walking over a nearby pedestrian bridge. The recording is modified per frequency band depending on the height of the different noise barriers considered (absence of barrier, 1.2m, 2m, and 3m). To auralize the shielded sound of the highway, the insertion loss for each barrier was calculated in octave bands with the FDTD method (see values in Table 1). Finally, a hexagon decoder was used to produce a 3D hexagonal audio system. The reproduction in VR consists of 6 equidistant sources located around the character controller and assigned a parallel movement and speed, correspondent to the recording. No modification is added within the Game Engine software. The audio reproduction needed to be synchronized in time and space in the virtual model.

Table 1 - Insertion loss for pedestrian 3m from the edge of the bridge (dB)

Barrier height (m)	125Hz	250 Hz	500 Hz	1000 Hz
1,2	-4.5	-4.8	-6.6	-8.1
2	-5.6	-7.0	-9.5	-11.8
3	-5.3	-9.2	-11.7	-13.1

3. EXPERIMENT

The elaborated experiment with 100 test persons is still ongoing at the time of the writing of this proceedings paper. Such a number is needed given the inherent large variation between people in perceived quality assessments.

3.1 Participant selection

100 Participants between 18 and 50 years old are invited to participate in the experiment. They are required to be in good health (not pregnant, not reporting epilepsy episodes, good hearing and normal sight). It is advisable not to use glasses in the experiment.

3.2 Schedule

The experiment is divided in 4 different days. A total of 16 different environments of the bridge is assessed. 4 environments per day are evaluated in 20 minutes.

There are four different visual designs and four different soundscapes. Four visual designs combined with one single soundscape are presented each day as described in the Table 2. Only one of the visual designs is correspondent to the soundscape. Both the order of the visual designs and the order of the soundscapes on each day are randomized.

Participants are asked to experience the environment as a pedestrian, taking into account that they come from the center of the city and want to reach the park at the other side of the bridge. A couple of questions are asked regarding the pleasantness of the experience. The word "sound" or "listen" is intentionally omitted, avoiding a focused attention to the soundscape. The intention is to let them walk as a real pedestrian sensing the overall environment and being influenced by the soundscape as they would in real life. In other words, they would be focusing on the sound only when this sound draws their attention.

Table 2 - Schedule for the 16 environments

	Design 1	Design 2	Design 3	Design 4
Day 1 = Soundscape 1	1 (D1-S1)	2 (D2-S1)	3 (D3- S1)	4 (D4- S1)
Day 2 = Soundscape 2	5 (D1-S2)	6 (D2-S2)	7 (D3-S2)	8 (D4- S2)
Day 3 = Soundscape 3	9 (D1-S3)	10 (D2-S3)	11 (D3- S3)	12 (D4-S3)
Day 4a = Soundscape 4	13 (D1-S4)	14 (D2-S4)	15 (D3-S4)	16 (D4-S4)
Day 4b + sound awareness	1 (D1-S1)	6 (D2-S2)	11 (D3- S3)	16 (D4-S4)

* Environments with shading imply correspondent Soundscape and Design

Once the 16 environments are evaluated, participants are informed about the importance of noise and are asked to repeat the four experiments where sound and vision match attending to the soundscape and the details of the visual environment. A detailed questionnaire asks about the differences in noise perception to assess the influence of the attentiveness in the assessment of noise disturbance. The ability of each person to be attentive to noise might be an important influence, as well as the sensitivity and personality. For that reason, after the experiment other short tests are complimented. 1) An attention test to measure the attentive capability of each participant. 2) A personality test to understand how calm or nervous each participant was, the type environment they are used to live in and the ones they prefer. 3) A noise sensitivity test. 4) Finally a hearing test excludes participants with reduced hearing capabilities (that they did not report during recruitment).

3.3 Survey description

During the first 4 parts of the experiment, each participant is asked to fill in two questions about the experience of virtually crossing the bridge:

1. How would you rate your personal experience while passing this bridge to go from the city center to the park? Allowing the answer in an 11-point linear scale from *very unpleasant* to *very pleasant*.

2. Rate how much you would consider taking a break and sitting for a while on one of the benches on the bridge? Allowing the answer in an 11-point linear scale from *I wouldn't consider it at all* to *I would definitely consider it*.

On the last day, participants are also asked to remember the last environment experienced and to select the sounds they remember. All the sounds present are available in checkbox's together with sounds that are not audible in the sonic scene.

After repeating the four audio-visually matched environments with an analytic focus on the sound environment, participants are asked to rate their awareness to noise to evaluate how different the overall perceived environments was in both cases.

Other questions assess the personal visual preference of the environments. Participants are asked to rank the four designs in order of preference. A set of questions regarding the design of each element in the virtual scene (benches, pavement, barrier…) is also included.

4. EXPECTED RESULTS

At the time of writing this conference paper, the experiments were still ongoing so actual results cannot be provided.

This research intends to bring a better understanding of the multisensory human perception of the urban environment, specifically the audio-visual interaction, and the role that sounds and visually perceived objects play. In particular, it is expected to discover the influence of continuous traffic noise on the overall perception of the urban environment, and to show the threshold of the sound pressure level for this effect.

As the experiment is carefully designed to avoid focusing attention on sound, it is expected that it will lead to a better understanding of the role of auditory attention in the perception of environmental sound. It may also shed light on the role that subluminal sound could play in urban design. Further conclusions are expected from the results of the visual and auditory elements in the urban environment that tend to draw attention of people.

Besides that, the suitability of using a realistic model in VR technology is evaluated, not only to assess the quality of the audio-visual environment, but also as a new tool for urban planners.

Overall, the results may contribute to give urban sound the place it deserves in urban planning. Design rules are expected to be collected to mitigate perceived noise in urban interventions and to increase livability of future urban developments. Furthermore, including the quality of the soundscape as an integral part of the environment taking into account the audio-visual influence in human perception will help architects and urban planners to design higher quality urban spaces.

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REFERENCES

1. Ouis D. Annoyance from road traffic noise: a review. J Environ Psychol. 2001;21(1):101–20.
2. Botteldooren D, Dekoninck L, Gillis D. The influence of traffic noise on appreciation of the living quality of a neighborhood. Int J Environ Res Public Health. 2011;8(3):777–98.
3. Echevarria Sanchez GM, Van Renterghem T, Botteldooren D. The effect of street canyon design on traffic noise exposure along roads. Build Environ. 2015;97:96–110.
4. Hong JY, Jeon JY. The effects of audio–visual factors on perceptions of environmental noise barrier performance. Landsc Urban Plan. Elsevier B.V.; 2014;125:28–37.
5. Liu J, Kang J, Behm H, Luo T. Effects of landscape on soundscape perception: Soundwalks in city parks. Landsc Urban Plan. Elsevier B.V.; 2014;123:30–40.
6. Viollon S, Lavandier C, Drake C. Influence of visual setting on sound ratings in an urban environment. Appl Acoust. 2002;63(5):493–511.
7. Ernst MO, Bülthoff HH. Merging the senses into a robust percept. Trends Cogn Sci. 2004;8(4):162–9.
8. Hunter MD, Eickhoff SB, Pheasant RJ, Douglas MJ, Watts GR, Farrow TFD, et al. The state of tranquility: subjective perception is shaped by contextual modulation of auditory connectivity. Neuroimage. 2010;53(2):611–8.
9. Hong JY, Jeon JY. Influence of urban contexts on soundscape perceptions: A structural equation modeling approach. Landsc Urban Plan. 2015;141:78–87.
10. Aylor DE. Some Physical and Psychological Aspects of Noise Attenuation by Vegetation. Metrop Phys Environ. 1977;229–33.
11. Watts G, Chinn L, Godfrey N. The effects of vegetation on the perception of traffic noise. Appl Acoust. 1999;56:39–56.
12. Van Renterghem T, Botteldooren D. View on outdoor vegetation reduces noise annoyance for dwellers near busy roads. Landsc Urban Plan. Elsevier B.V.; 2016;148:203–15.
13. Lamy D, Mudrik L, Deouell LY. Unconscious auditory information can prime visual word processing: A process-dissociation procedure study. Conscious Cogn. 2008;17(3):688–98.
14. Ruotolo F, Maffei L, Di Gabriele M, Iachini T, Masullo M, Ruggiero G, et al. Immersive virtual reality and environmental noise assessment: An innovative audio-visual approach. Environ Impact Assess Rev. Elsevier Inc.; 2013;41:10–20.
15. Maffei L, Iachini T, Masullo M, Aletta F, Sorrentino F, Senese VP, et al. The effects of vision-related aspects on noise perception of wind turbines in quiet areas. Int J Environ Res Public Health. 2013;10(5):1681–97.
16. Bishop I, Rohrmann B. Subjective responses to simulated and real environments: a comparison. Landsc Urban Plan. 2003;65(4):261–77.