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Bridging the gap between architecture/city planning and urban noise control

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ABSTRACT

The research carried out by the ESR9 within the SONORUS project intends to improve the city sound environment at street level by bridging the gap between city planning and urban noise control. A holistic approach is applied to assess the effect of urban design on citizen's perception of road traffic noise, taking into account pedestrians and the dwellings facing the road. It was found that canyon geometry can have a strong impact on noise levels in the street. More than 60 different façade designs and street configurations have been designed and simulated using the FDTD method. The urban design at small scale also affects people's perception of the environment, subconsciously influencing their appreciation of the soundscape. Different designs of barriers are tested on a bridge crossing a highway using Virtual Reality by means of Unity software and an Oculus Rift headset. As a conclusion, architectonic guidelines are proposed to be used for architects and urban planners to reduce current citizen's noise problems and to avoid these in future developments. The participation of an "urban sound planner" is certainly needed to include sound in future urban planning as an integral part of the planning and design process.

Keywords: Street design, Noise control, urban planning.

I-INCE Classification of Subjects Number(s): 52.9, 52.3, 68.7, 63.7.

1. INTRODUCTION

Although the sonic environment forms an integral part of the experience of living in a modern densely populated city, urban planning and architectural design seldom takes this into account from the start of a project. A clear view on how a future urban neighborhood or dwelling complex should sound like (its soundscape) is often missing. Future urban sound planning should consider including sound as an integral part of the planning and design processes – which was a main goal of the EU FP7 project SONORUS.

Even in absence of a clear vision on the soundscape, there is still a benefit in considering control of the unwanted noise – often but not always related to (road) traffic – in the planning and design phase. In doing so, one should not only take into account personal dwellings, but also public space, including walking and cycling routes. It has been shown previously that architectural elements can be used to scatter (and redirect), absorb, and screen sound in built-up areas (1). Noise control in the context of soundscape design is not only about reducing levels of unwanted sound but also about improving the audiovisual perception as a whole (1).

In this contribution we explore the use of these architectural elements to improve the sound environment in the direct vicinity of main road traffic infrastructure. Not only dwellings facing the

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road are considered, but also pedestrians and cyclists making use of the same infrastructure as the motorized traffic or crossing motorized traffic infrastructure. The methodologies that are used and proposed in this work are both computationally and experimentally intensive. Such approaches may be directly applicable for large infrastructure works or redevelopment of larger parts of a city, fitting in a smart city concept that uses all available modern technology to improve the livability of cities. As less ambitious projects could probably not afford elaborate numerical modelling or large experimental campaigns, guidelines for traffic noise friendly architectural design are also derived.

2. METHODOLOGIES

2.1 Numerical simulations (FDTD)

The effect of detailed architectural design on the sound propagation in the city requires a calculation with a fine spatial resolution. Furthermore, sound diffraction on edges and scattering on different elements in the urban environment can have a strong influence on the sound field. A full wave based method is capable of taking all sound phenomena into account in addition to the reflection from surfaces. The Finite Difference Time Domain (FDTD) is a full wave numerical technique that solves the sound propagation equations directly in the time domain, which has some advantages (2, 3). To avoid excessive computational cost, calculations were run in 2D. More than 60 different geometrical designs in a typical street canyon were calculated obtaining accurate results and determined conclusions regarding the effect of each element. Further details about the calculation process, the results and conclusions can be found in (4). Although these results should not be directly extrapolated to other canyon geometries, it is possible to conclude a list of useful guidelines from the parametrical studies that could be helpful for architects and urban planners to contribute to controlling and reducing noise in the city.

2.2 Virtual reality

People walking along a street or crossing a bridge experience their environment as a whole. Therefore, studies on perceived quality of the sonic environment benefit from presenting the visual environment as accurately as possible. Today, virtual reality tools and game engines allow to create such environments quite accurately. In this work, 3D Studio Max and Unity Engine Game are used for this purpose. The 3D experience is delivered with the Oculus Rift and high quality headphones that are calibrated using a HATS. Different building materials, urban furniture as well as persons, cars and trucks, trams, green elements, etc. are available and can relatively easily be inserted in the 3D environment. These objects can be made to move in a realistic manner; this is important for the main noise sources such as cars and trucks but also for persons. Absence of other persons on a walkway would give a very desolate feeling.

Game engines and 3D virtual reality, in general, also allow attaching sound to moving objects. Although the quality of this auralization may not be very accurate, the head tracing embedded in de Oculus Rift allows to create a realistic experience. This quality is sufficient for producing sounds that are used mainly for reference in this work such as the sound of one’s own footsteps. Previous studies have indeed shown that the sound of footsteps contributes to the soundscape experience (5) (6).

However, for auralizing the noise control measures envisaged, typical 3D virtual reality engines fail. Indeed, scattering elements, noise barriers, etc. are generally not very accurately accounted for nor is the local road vehicle composition. Therefore a methodology is used that starts from multichannel recording (B-field) of a comparable real situation. This methodology has previously been validated for auralisation of the effect of a berm (7). The effect of the noise control measure can be calculated using a preferred sound propagation model. In this case, corresponding noise reduction of these barriers has been calculated in detail with the Finite Different Time Domain (FDTD) method, resulting in frequency-dependent insertion losses applied to the B-field (ambisonics) recordings.

3. EXAMPLES

3.1 Street canyon

More than 60 different canyon shapes have been calculated. The most relevant cases are shown in this paper. The configuration is always symmetric with respect to the center of the street. The different cases calculated are variations of a basic geometry consisting of a 20-m street and an 8-floor building as shown in (Figure 1).

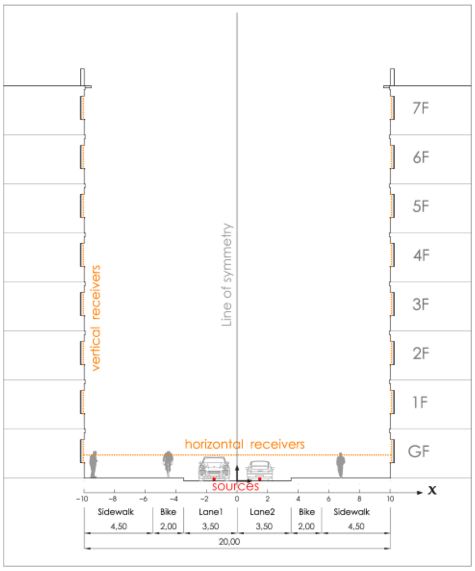

Figure 1 – Basic canyon shape reference.

A two-lanes road is included and road traffic noise power levels were calculated using the CNOSSOS equivalent source power model (8). Special care was taken to tune the impedances of the typical materials present in urban streets, like bricks, concrete and glazing, including the amount of diffuse reflection in urban streets due to recessions and protrusions of windows. A line of receivers is placed along the street width at pedestrian height and along the façade at 0.01m spacing. Thus, the full picture regarding noise exposure in urban streets is visualized. In this paper, only the results for pedestrians (4.5m next to the facades) and along the windows are presented. Further details are available in (4).

42 different cases are shown organized in street cases (S) (Figure 2) and façade cases (F) (Figure 3). The geometrical variation of one urban element is studied within a sequence. In the Street configuration sequences (S), different urban elements in the street were analyzed: various low barrier shapes and inclinations, the addition and position of green absorption on a low barrier, a depressed road with respect to the walkway level, and a two-level street where pedestrians can walk on the first-level walkway.

It is important to consider the flexibility of the function in the elements under study. Low noise barriers, e.g., could be used as longitudinal multifunctional benches.

Figure 2–Street configuration cases (S). Sequences are distributed horizontally. S1 Low barrier shape. S2 Green absorption on low barrier. S3 Depressed road. S4 Two level street.

In the Façade cases (F), the effects of different elements along the façade were calculated: general building shape, various materials, setbacks of the lower storey, balcony shape, triangular prominences and shielded inclined windows.

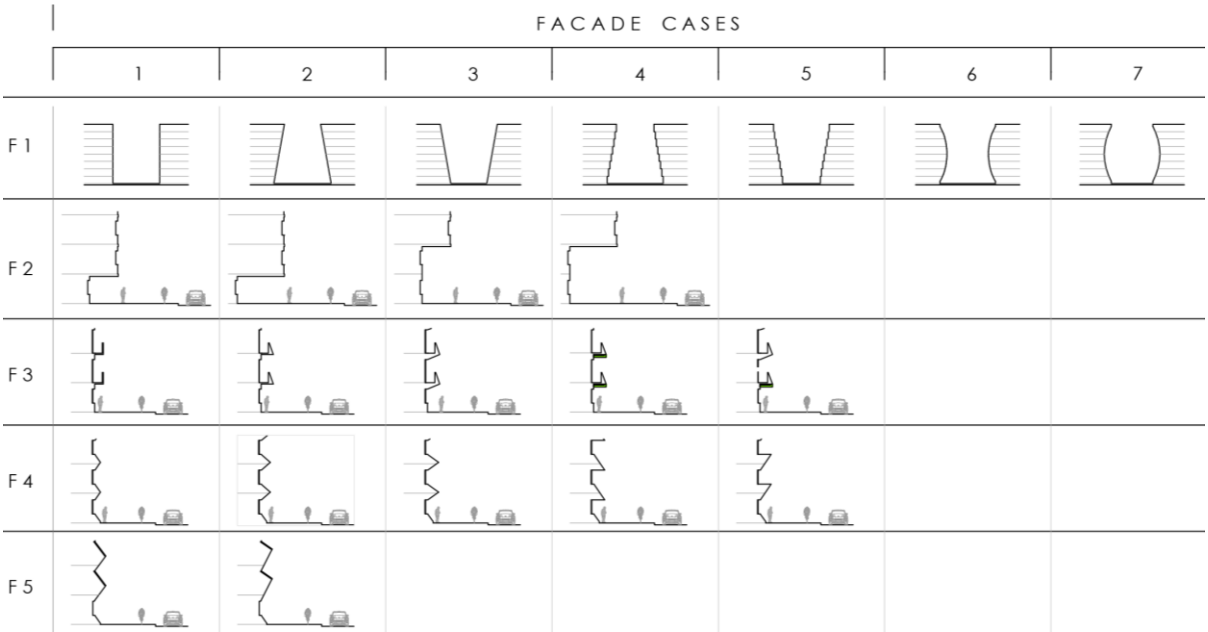

Figure 3 – General building shape and Façade cases (F). Sequences are distributed horizontally. F1 General building shape. F2 Setback of the lower storey. F3 Balcony geometry. F4 Triangular prominences on façade. F5 Shielded inclined windows.

The results of this study (4) revealed the important effect that canyon design can have on the street's sound field. The design of the façade, the street configuration and small urban furniture placed next to the road can highly reduce noise exposure for pedestrians and on the facades. This is thus an important message to be conveyed to architects and urban planners: such passive elements and changes to the street geometry could reduce noise exposure.

3.2 Bridge across a highway

A second case study concerns a bridge across an urban ring road that connects a densely populated area to an extended park. The bridge should become an attractive gateway, inviting inhabitants to enjoy this public space, be more physically active and engage socially with their peers. As it is expected that the noise from the highway will have a negative influence on the perception of crossing the bridge even though it is designed in a visually attractive way, virtual reality is used to present different experiences to potential users of the park.

In absence of a noise barrier on the bridge, sound levels recorded on-site show that the total equivalent sound level experienced while crossing the bridge is equal to 75.9 dB(A). Using a 1.2-m high noise barrier, the sound level at the ear of a pedestrian crossing the bridge can be reduced by 7.4 dB(A). This reduction achieves 10.5 dB(A) for a 2m high barrier and 17.2 dB(A) for a 3m high barrier. As the noise level from the bridge is reduced through increasing barrier height, the sound of one's own footsteps becomes more audible. This effect of unmasking was expected, yet it is generally more noticed and contributes more to the experience than initially assumed. This statement cannot be quantified exactly and more focused research in this regard may be needed.

The effect of a barrier is not only to reduce the noise level at the ear of the observer, but also to hide the sound source (partly) from sight. Both effects may influence the overall perception. However, a barrier also creates some feeling of being enclosed, in particular for the larger ones; a suitable and attractive visual design is thus needed.

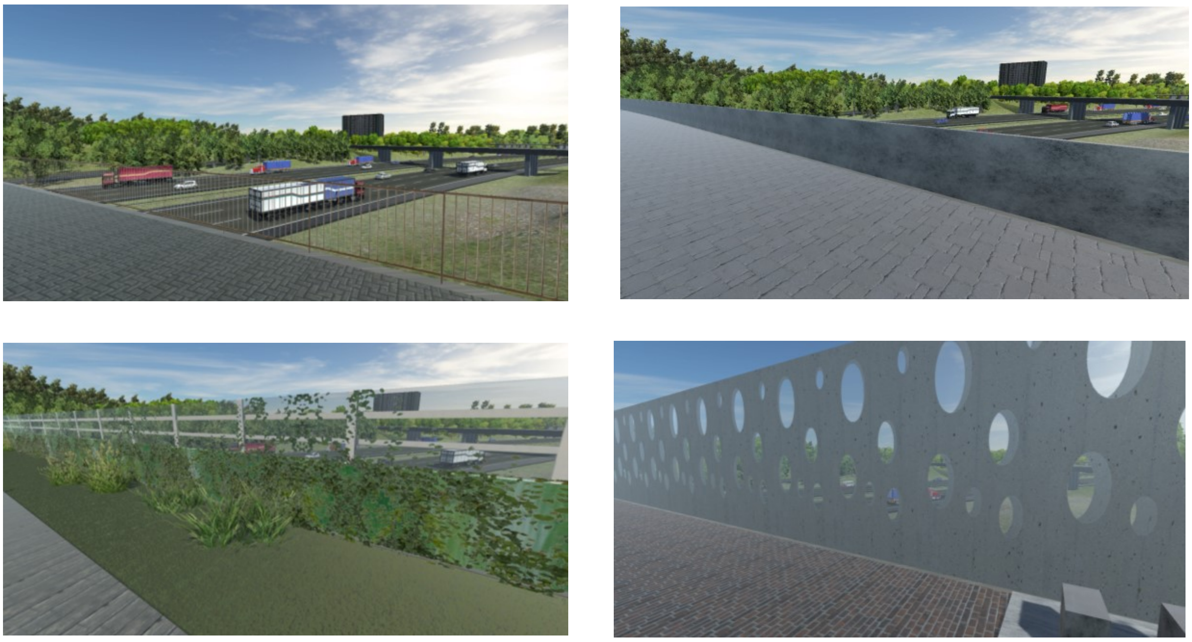

Figure 4 – Four different barriers on the virtual model of the bridge.

This virtual reality representation of the experience of accessing the park by walking across the bridge over the highway is also used in an experiment focusing on disentangling the importance of visual and acoustic elements in the perceived quality of the walking path. Results of this experiment are also presented at this conference (9).

4. TRAFFIC NOISE FRIENDLY ARCHITECTURAL DESIGN

From this research, a list of architectonical methods related to the urban geometry and the design of the urban environment at small scale are proposed as tools to reduce urban noise. Besides the applicability in restorative projects for existent noise problems, they also should be taken into account in future urban developments. This involves the capability of architects and urban planners to control noise in the streets by means of architectural design from two different perspectives: by adjusting the geometrical design of the street canyon to physically reduce noise levels and by the careful design of the urban environment to enrich the quality of the urban space influencing the subjective perception of pedestrians, and thus their perception of the soundscape. A short summary with the range of noise reduction values at pedestrians and at the facade are provided as general guidelines in Table 1. The most outstanding conclusions of the effect of different elements are also summarized.

Table 1 – Effect of diverse urban canyon shape in sound pressure level (dB(A)). A negative value means a reduction in exposure level.

case	Range at Pedestrians	Max at lower storeys	Max at upper storeys	General guidelines per sequence
S1	-4 to -9	-9	0	Inclined low barriers are better than vertical barriers.
S2	-5 to -9	-9	-2	The position of green absorption is optimal at the source side, except if the low barrier is inclined. Inclined surfaces to reflect sound towards the top of the street canyon are equivalent to the addition of absorption on vertical ones. Both effects are non-accumulative.
S3	-2 to -10	-11	0	Great efficiency when placing low barriers at the edge of the depressed road.
S4	-5 to -11	-12	-2	A two level street is the most efficient measure at pedestrians and on facades.
F1	+1 to -2	-	-	Full building facades in glass can increase exposure with 6dB(A) for pedestrians. Upwardly inclined facades are most efficient, independent of facade material.
F2	-2 to -4	-4	-1	Noise reduction is proportional to the setback dimensions. Adding absorption can increase the reduction.
F3	0 to -1	0	-13	Inclined ceilings or absorptive ceilings at balconies achieve the highest noise reduction.
F4	+2 to 0	+1	-9	Triangular prominences with up vertex are most efficient.
F5	+1 to +2	0	-8	Noise reduction in this sequence is proportional to the inclination of the window.

CONCLUSION

The research carried out by the ESR9 within the SONORUS project demonstrates the important influence that the design of our cities has on noise problems. The geometry of streets can have a strong impact on the physical noise levels to which pedestrians are exposed, and the urban design at small scale also affects the people's perception of the environment, subconsciously influencing their appreciation of the soundscape. The awareness of these effects by architects and urban planners is therefore important. Taking into account the soundscape as an integral part of the urban environment from the start of the urban project is essential to prevent noise problems in our cities. As conclusion, a list of architectonic guidelines is proposed to improve the city sound environment at street level from the perspective of the architect and the urban planner.

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