The influence of urban canyon design on noise reduction for people living next to roads

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Summary

Nowadays a big gap exists between architecture-urbanism and acoustics. Noise is one of the most important environmental problems in the cities. However, architects and urbanists take decisions on urban regulations that define the shape of streets and buildings without taking noise into account. Furthermore, there is little information about the influence of urban geometry on the distribution of sound in the streets. In this study, the effect of detailed urban canyon geometry on the distribution of sound pressure level is numerically studied at small scale with the finite-difference time-domain method. The Cnossos equivalent power spectra were used to approach road traffic noise sources along two traffic lanes. Receiver positions both along the facades and the walkways have been analysed. Results demonstrate the importance of geometry in a canyon shape. Different building shapes can lead to variations of up to 9 dBA as for road traffic sound pressure levels for pedestrians. Building-façade design can reduce the average value along a window with 8.5 dBA. Geometric configuration of the street can increase the positive effect of low barriers and reduce 11 dBA in pedestrian exposure.

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1. Introduction

Road traffic noise generated in the city has become one of the main environmental problems that significantly affect the quality of life of its citizens.

The current approach to this problem is mainly based on corrective methods applied when the problem already exists. Noise pollution in the city should preferably be dealt in advance in urban design.

Some studies approach the impact of a street canyon design on noise exposure at a non-directly exposed and thus possibly quiet façade [1] [2].

The effect of noise on the directly exposed façade has also been studied. Absorption and promoting diffusion are the main abatement principles. Examples are a scale model to study façade irregularities [3], noise abatement in urban areas [4], streets [5] or facades [6], the use of barriers [7], the effect of recesses in a building façade [8] or the influence of balcony shape in facades [9] [10] [11] [12].

In this study, different canyon shapes were numerically studied. The influence of detailed geometries in sound pressure levels for pedestrians at directly exposed facades was analysed.

The main objective is compiling architectural guidance to reduce the overall noise levels for pedestrians and along façades in a realistic road traffic noise case.

2. Numerical approaches

The influence of urban canyon design is assessed by means of a detailed full-wave numerical simulation technique through namely the finite-difference time-domain (FDTD) method. A grid cell of 2 cm was used, allowing frequency accuracy up to the 1-kHz octave band.

A perfectly reflective material was assigned to the street surface; bricks along facades are modelled by a frequency-independent impedance of 4080 kg.s.m^{-2} following ISO 9613-2, and glazings with 31416 kg.s.m^{-2}.

At the location of the traffic lanes, an acoustic pulse is emitted and its propagation is simulated during 30 000 time steps, i.e. 0.6 s of propagation time (using a temporal discretisation step of 20 us). In this time interval, sound reflects about 20 times at the facades.

Immission levels (Lp) are calculated in octave bands using the Cnossos Equivalent source model (Lw) as indicated in (1), where rel SPL is the Sound Pressure Level in the street canyon relative to free field sound propagation, and Aff is the Attenuation as would be observed in Free Field.

$$Lp = Lw + rel\,SPL - Aff \qquad (1)$$

Horizontal line of receivers separated each 6cm are positioned along the street width at pedestrian ear height (1.5m). Vertical lines of receivers are distributed along the façade, at 1cm distance.

An average value is specified for each window whereas the median value within 4.5m length next to both facades is calculated to assess the impact on pedestrians.

3. Reference geometry

Different designs were considered, departing from a basic canyon section of 20 m wide and 26 m high (corresponding to an 8 floor building, GF + 7 floors).

Two incoherent line sources are symmetrically placed at 1.5 m from the canyon center, modelling a 7 m wide road located 20 cm below walkways. The street use distribution is shown in Figure 1. The car's bodywork is not modelled and other sources are not considered.

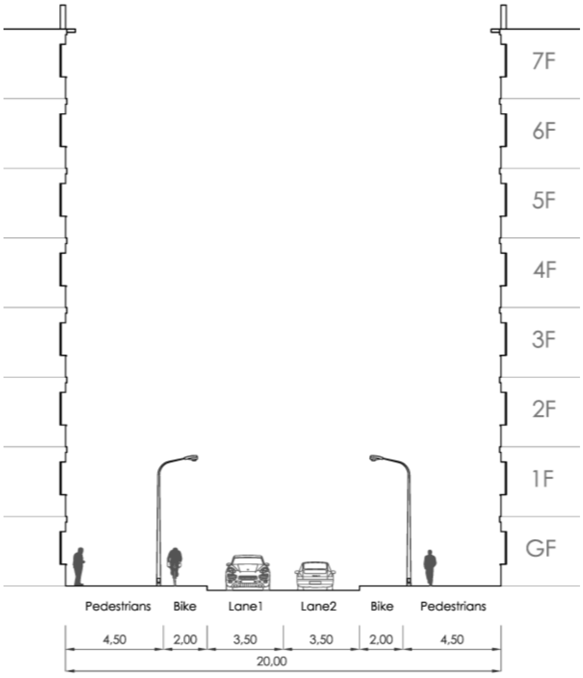

Figure 1: Street canyon setup in the numerical study.

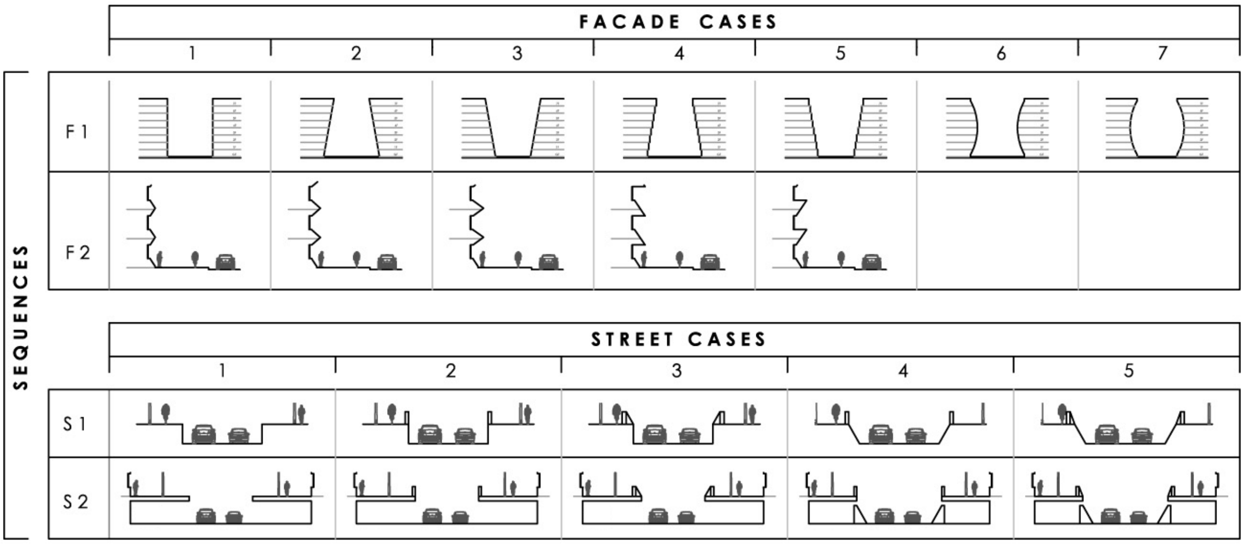

Figure 2: Facade sequences: F1_General shape of buildings. F2_Triangular shapes in facades.
Street sequences: S1_Depressed roads at -1.7m level. S2_Second level road + parking spaces.

4. Cases

Two sequences with different façade geometries and two with different street configurations are shown in Figure 2.

4.1 Sequence F1: General Shape of building

Five cases are analysed:

- F1.1_ Flat vertical
- F1.2_ Flat inclined downwardly
- F1.3_ Flat inclined upwardly
- F1.4_ Stepped downwardly
- F1.5_ Stepped upwardly
- F1.6_ Convex
- F1.7_ Concave

All these cases maintain the same amount of space between buildings, to equal the building area and street volume.

Median values in pedestrians are calculated within a zone of 4.5m next to each facade; therefore pedestrian position varies in this sequence according to the street geometry.

Results show up to 9 dBA difference in the three first cases (flat façade) on the same position (Figure 3).

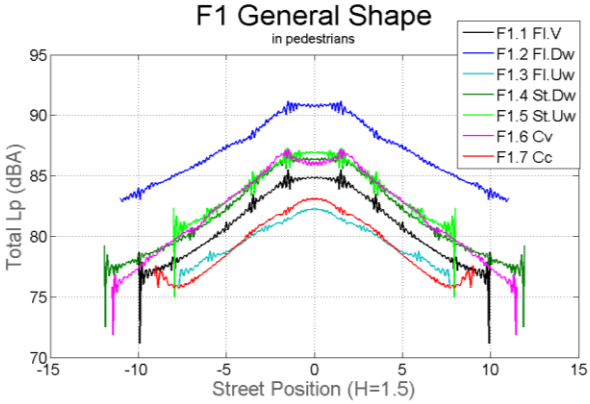

Figure 3: Total Lp along street width. Seq F1.

The flat vertical case (F1.1) is considered a reference, as it is the most common canyon shape.

The flat inclined downward case (F1.2) highly increases pedestrian exposure with 6.2 dBA. The flat inclined upward case (F1.3) reduces only the median value with 0.3 dBA. Nevertheless for the same positions in the street a reduction of around 2 dBA is achieved (Figure 3).

The different inclination of the facades causes a change in direction of the early noise reflections; downward inclination causes a larger amount of sound energy reflected towards the pedestrians, while an upward inclination beneficially reflects sound towards the canyon opening.

The stepped downward case (F1.4) increases the median value with 0.3 dBA for pedestrians while the stepped upward case (F1.5) increases 4.1 dBA, though it is one of the cases that takes least time to dissipate noise. Pedestrian area is also closed to the road.

The convex façade case (F1.6) increases pedestrian exposure with 0.1 dBA while the concave façade case (F1.7) reduces the median value with 1.5 dBA. Nevertheless reduction up to 2.5 dBA can be found in this case for the same position in the street compared to the reference case (F1.1).

4.2 Sequence F2: Triangular shapes in facades

Five cases are studied and compared to the reference case F1.1:

- F2.1_ Middle vertex at 0,6m
- F2.2_ Middle vertex at 0,9m
- F2.3_ Middle vertex at 1,2m
- F2.4_ Down vertex at 1,2m
- F2.5_ Up vertex at 1,2m

The addition of a triangular shape on facades slightly affects noise levels for pedestrians; nevertheless it has an important influence on the façade, especially in the last floors where an average reduction of 8.5 dBA can be found compared to the reference case F1.1 as shown in Figure 4.

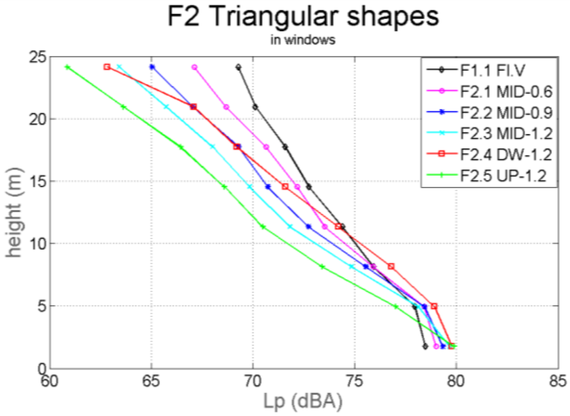

Figure 4: Total Lp average for each window. Seq F2

The size of the protruding elements is important: the larger, the better (cases F2.1, F2.2, F2.3). Only for the ground floor window a slight increase in noise level is observed relative to the reference case i.e. a flat vertical façade (F1.1).

Down vertex case (F2.4) is the most disadvantageous for the window exposure, as this geometry promotes a higher percentage of reflections towards the windows.

Up vertex (F2.5) is the most advantageous case for facade receivers, as it partially shields the windows.

4.3 Sequence S1: Depressed roads at -1.7m level

Five cases are shown and compared to the reference case F1.1:

- S1.1_Depressed Road with no barrier
- S1.2_Depressed Road with low vertical Barrier on the sidewalk edge
- S1.3_Depressed Road with low inclined Barrier on the sidewalk edge
- S1.4_Depressed Road with inclined walls and low vertical Barrier on the sidewalk edge
- S1.5_Depressed Road with inclined walls and low inclined Barrier on the sidewalk edge

This sequence shows a big influence in the pedestrian area as shown in Figure 5.

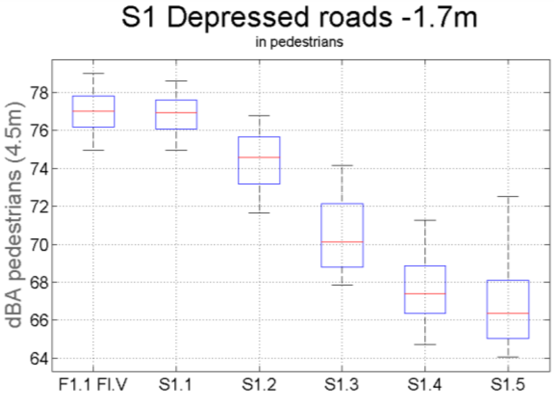

Figure 5: Total Lp values for pedestrians. Seq S1

Important noise reductions can be achieved at the first floors. However the effect becomes smaller with height.

The important influence of the inclination of a low barrier on the sidewalk edge is demonstrated (S1.3); reducing additionally 4.4 dBA for pedestrians.

Depressed roads (S1.1) have practically no effect for pedestrians compared to non-depressed roads (F1.1). However, when depressed road walls are inclined (S1.4, S1.5) there is a significant reduction in pedestrian exposure. A low vertical barrier on the sidewalk edge (S1.4) additionally reduces 2.8 dBA, achieving a total reduction of 9.6 dBA. In case this barrier is 20 degrees inclined (S1.5) the reduction is 3.8 dBA, reaching a total reduction of 10.7 dBA relative to reference case (F1.1). However, road inclined walls have the disadvantage of reducing the useful surface area of the street.

A parallel sequence was calculated with a -3m depressed road. The three first cases with vertical walls (S1.1, S1.2 and S1.3) show similar results for pedestrians and along the façade, whereas the two cases with inclined walls (S1.4 and S1.5) show an additional noise reduction for pedestrians when lowering the road up to -3m.

4.4 Sequence S2: 2nd level road at -3m + parking spaces

This sequence analyses different cases of a two level street where the road is placed in an underground level at -3.0m below surface. There are parking spaces at both sides of the road.

Five cases are shown and compared to the reference case F1.1:

- S2.1_Second level street with no Barrier
- S2.2_Second level street with low vertical Barrier on the sidewalk edge
- S2.3_Second level street with low inclined Barrier on the sidewalk edge
- S2.4_Second level street with inclined Walls and low vertical Barrier on the sidewalk edge
- S2.5_Second level street with inclined Walls and low 20˚ inclined barrier on the sidewalk edge

Results in pedestrians are shown in Figure 6.

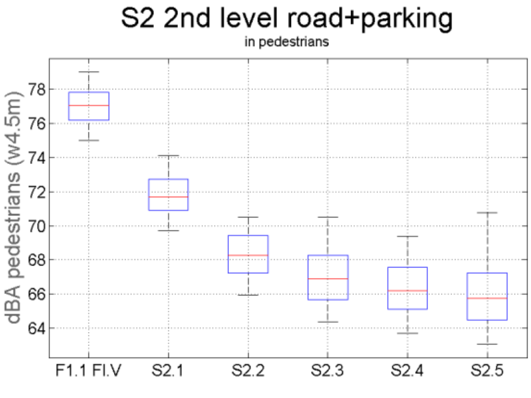

Figure 6: Total Lp values for pedestrians. Seq S2.

This sequence has high positive effect for pedestrians and on façade in all cases.

The road positioned in an underground level with parking places at both sides of the road (S2.1) reduces the median value with 5.3 dBA for pedestrians and on façade from 5.3 dBA in GF to 1.6 dBA in last floor.

The placement of a low vertical barrier on the sidewalk edge (S2.2) reduces additionally 3.4 dBA for pedestrians, and 4.9 dBA when the barrier is inclined (S2.3) reaching a total reduction of 10.1 dBA compared to the reference case (F1.1).

The inclination of the two walls next to the road (S2.4 and S2.5) reduce additionally 1.1 dBA, reaching an outstanding total reduction of 11.3 dBA relative to reference case (F1.1).

In this sequence reductions of 6.2 dBA can be found on façade, however the effect becomes smaller with height as shown in Figure 7.

There is a significant noise reduction on façade compared to the reference case (F1.1); from 2 dBA reduction in last floors to 11.5 dBA on the first floors.

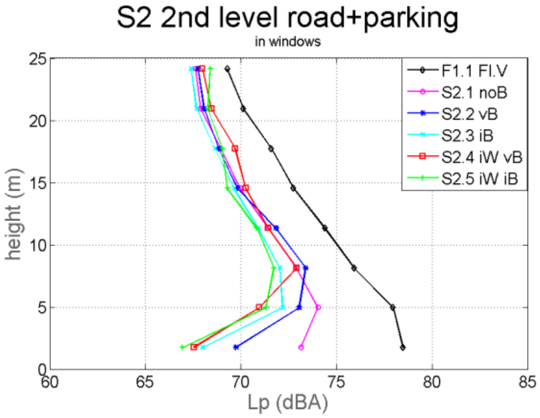

Figure 7: Total Lp average values for each window. Seq S2 .

5. Conclusions

Results show that different configurations of buildings and streets can lead to highly different noise levels for pedestrians and near the windows along the façades.

Building geometry mainly influences noise levels along the facades whereas objects next to the source have higher relevance for pedestrians but could also achieve reductions on the lower floors.

The general shape of buildings can be important for pedestrians. Flat façades inclined upwardly are most efficient; flat vertical façade and concave shape are also beneficial.

Triangular shapes added to facades are of special interest on higher floors. However, they slightly increase noise levels for pedestrians. Small changes in the triangular geometry cause notable variations, where the “up vertex case” seems most efficient.

Inclined low barriers are preferred over vertical low barriers as they reduce additionally up to 4.4 dBA for pedestrians. Low barriers might be useful as street furniture like long benches or planters.

Depressed roads are efficient for pedestrians when low barriers are placed near the sidewalk edges. In addition, a major reduction is predicted when walls next to the road are inclined. A Depression of 3m is more efficient than one of 1.7m.

Constructing a second level road is highly efficient for both pedestrians and along façades. Maximum reduction is found when inclining the walls next to roads.

The numerical predictions presented in this paper show that geometrical changes at street level and along facades can be an architectonic means to reduce noise exposure. They can also be considered in urban design to prevent noise problems in future developments. A promising bridge between urban environmental acoustics and architecture-urbanism is therefore opened.

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