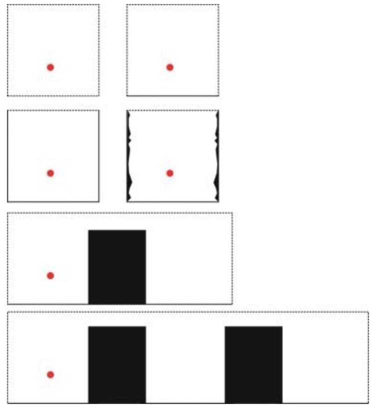
Acoustic street design

Timothy Van Renterghem

Introduction



Free field sound propagation

Ground reflection

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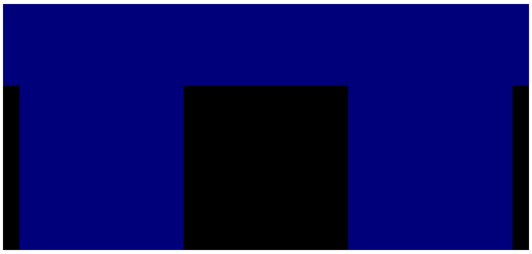
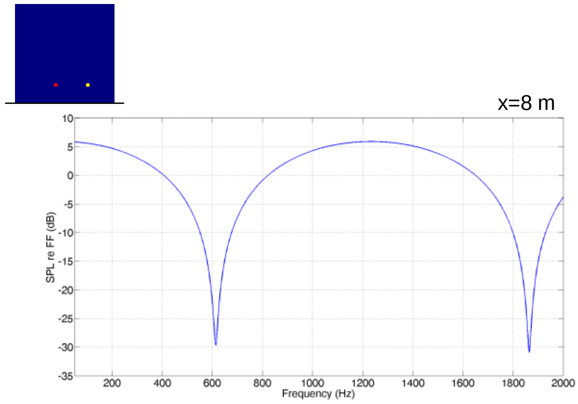
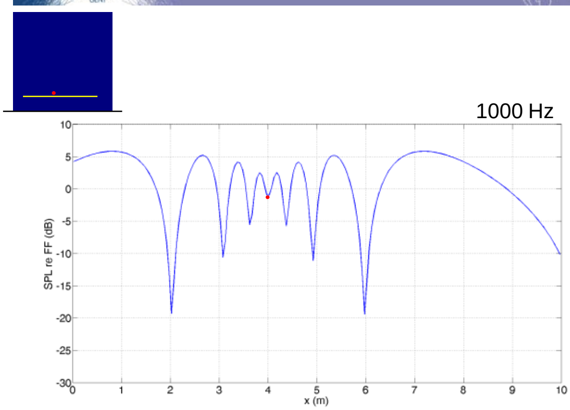
Specular reflecting facades



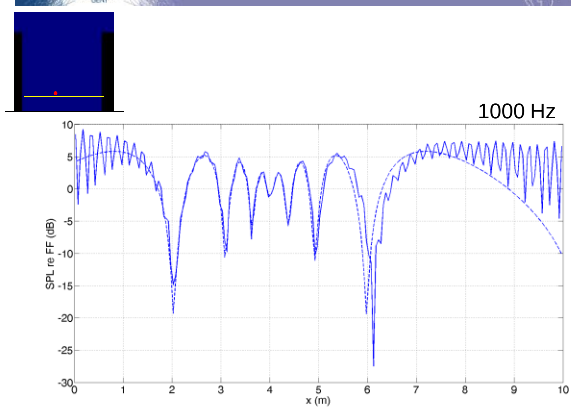
Ground reflection



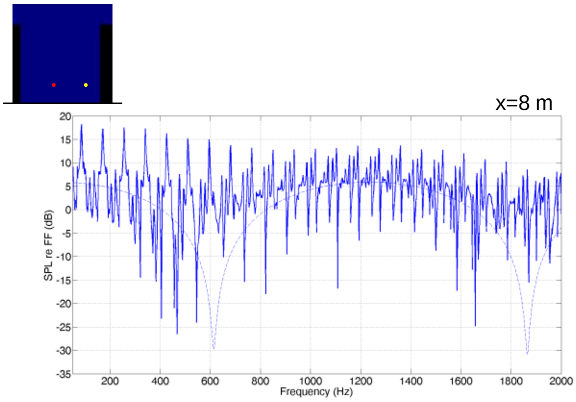
Ground reflection



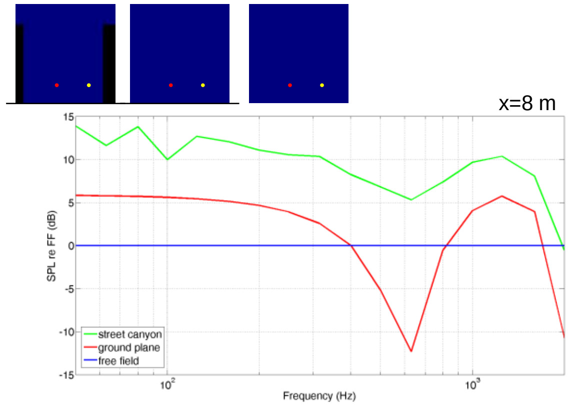
Ground+facade reflection



Ground+facade reflection



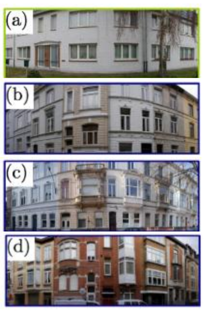
Ground+facade reflection



Diffuse reflection

Fig. 1. Examples of urban façades.

Ismael et al., Applied Acoustics, 2005.



Thomas et al., Journal of the Acoustical Society of America, 2013.

Diffuse reflection

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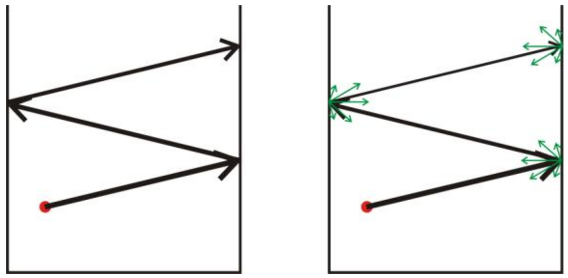
Diffuse reflection



Diffuse reflection

Picaut et al., Acta Acustica united with Acustica, 2009

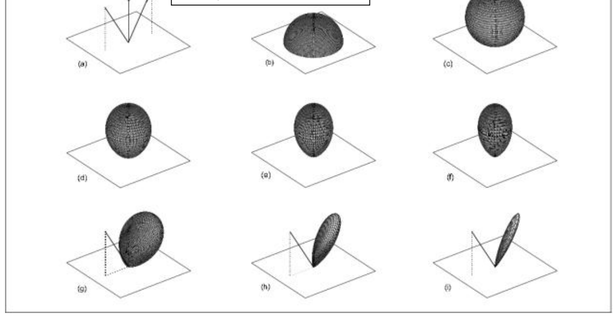


Figure 1. Building façades and diffusors reflection laws. Reference configuration: (a) specular (SP). Normal laws w^n: (b) Uniform (UN, $n = 0$), (c) Lambert (LA, $n = 1$), (d) w^2 (W2), (e) w^3 (W3), (f) w^4 (W4), (g) Semi-diffuse reflection laws with $T/\sigma = 5$ (SD5), (h) $T/\sigma = 10$ (SD10), (i) with $T/\sigma = 20$ (SD20).

Diffuse reflection

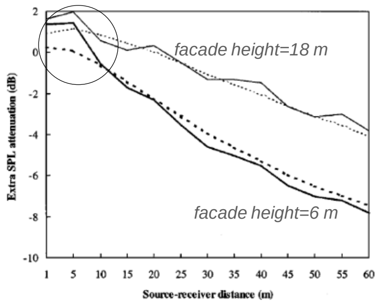
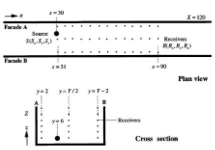


FIG. 6. Extra SPL attenuation along the length caused by replacing geometrically reflecting boundaries with diffusely reflecting boundaries. $Z = 6$ m: ———, receivers along $y = 2$ m and $z = 1$ m: - - -, receivers along $y = 18$ m and $z = 6$ m. $Z = 18$ m: ———, receivers along $y = 2$ m and $z = 1$ m; ···, receivers along $y = 18$ m and $z = 18$ m.

Kang, Journal of the Acoustical Society of America, 2000.



Diffuse reflection

Picaut et al., Acta Acustica united with Acustica, 2009

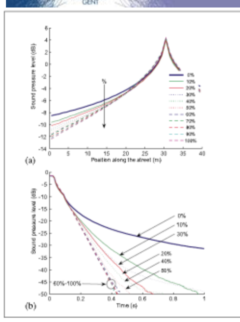


Figure 6. Effect of the relative surface p (in %) of acoustic diffusors, on the sound propagation along the street: (a) sound attenuation and (b) sound decay in the street. Percentile are relative to the surface of the building façade covered by diffusors (see Figure 5). Configurations RE00 (0%) and RE100 (100%) correspond to a street with specularly (SP) and diffusely (UN) reflecting façades, respectively.

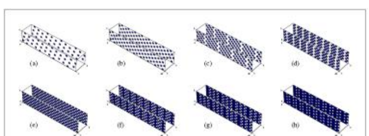
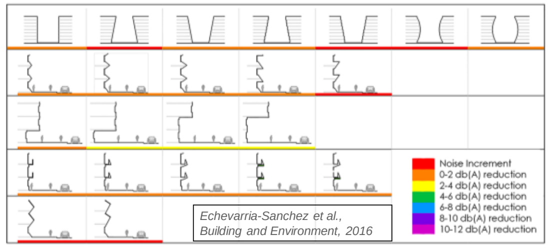


Figure 5. Regular arrangement (RE) of acoustic diffusors on the buildings façade. Each configuration is defined by the percentile p of the building façade (white background) that is covered by diffusors (in blue), as well as by the corresponding number of diffusors: (a) RE10 (10%, 64), (b) RE20 (20%, 128), (c) RE30 (30%, 192), (d) RE40 (40%, 256), (e) RE50 (50%, 320), (f) RE60 (60%, 384), (g) RE 70 (70%, 448), (h) RE80 (80%, 512), (i) RE90 (90%, 576). Configurations RE00 (reference) and RE100 are not presented, but correspond to a street with specularly (SP) and diffusely (UN) reflecting façades, respectively.

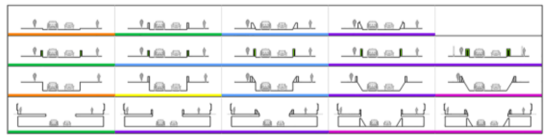
Diffuse reflection

- **Balconies**
  - Lowering facade exposure
    - **Direct shielding**
    - **Balcony details are important**
    - **Higher storeys better protected**
  - Building up a low-frequency diffuse sound field
  - Changing the street's directivity pattern

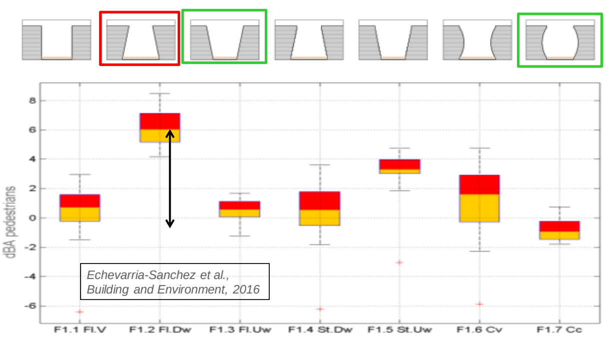
Urban street design



Echevarria-Sanchez et al., Building and Environment, 2016



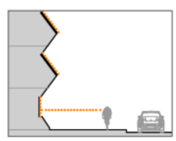
Urban street design

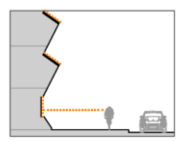


Echevarria-Sanchez et al., Building and Environment, 2016

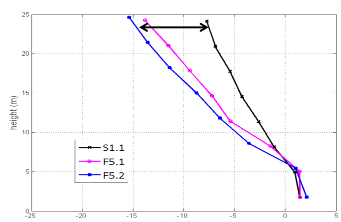
Urban street design

Echevarria-Sanchez et al., Building and Environment, 2016





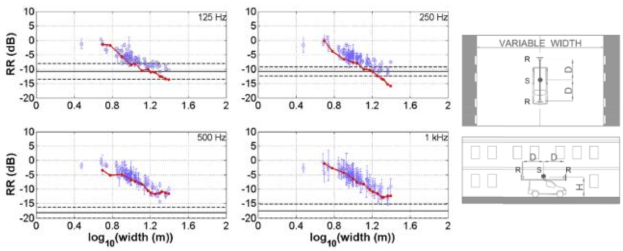
self-shielding windows



Urban street design

Echevarria-Sanchez et al., Building and Environment, 2016

model validation



Street amplification

- **Quantification**

Heutschi, Applied Acoustics, 1995.

simulations

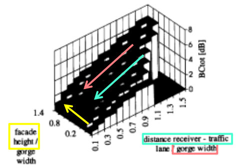
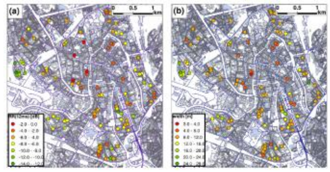


Fig. 8. Building correction BC_{tot} in dB for a completely built-up street gorge.

$$BC_{tot} = 10\ \log\left(\frac{\text{energy}_{\text{direct+reflections}}}{\text{energy}_{\text{direct}}}\right)$$

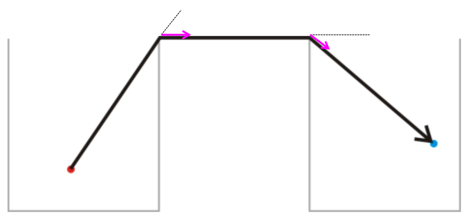
Thomas et al., Journal of the Acoustical Society of America, 2013.

experiments



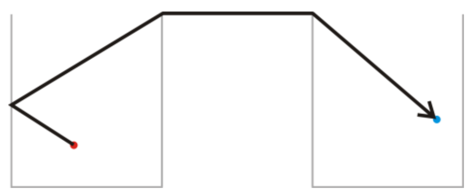
$$RR(t_0) = 10\log_{10}\left(\frac{\int_{t_0}^{\infty} h^2(\tau)\,d\tau}{\int_{0}^{t_0} h^2(\tau)\,d\tau}\right)$$

Diffraction to adjacent canyon

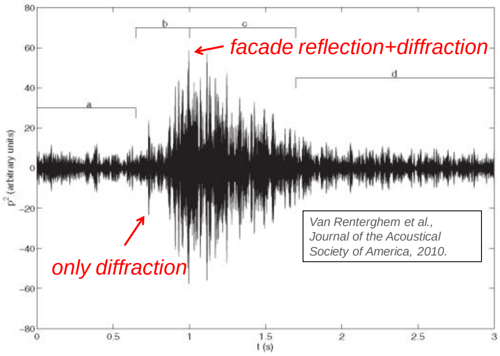


low-frequencies are favoured

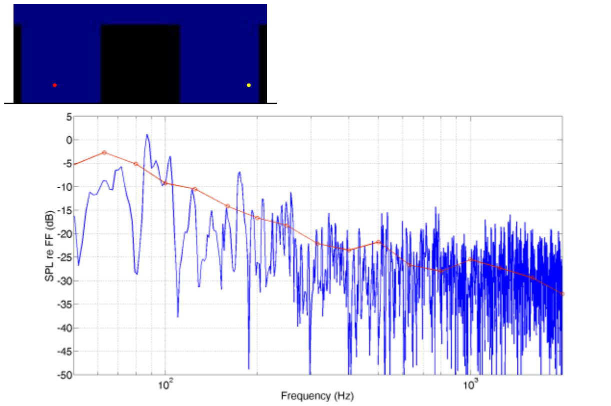
Diffraction to adjacent canyon



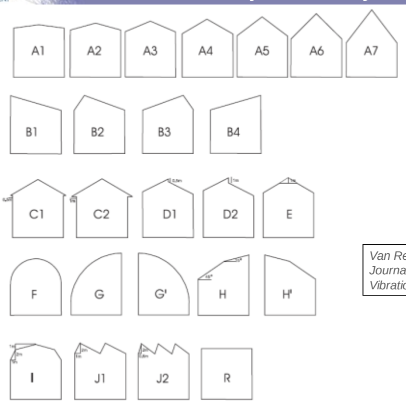
Diffraction to adjacent canyon



Diffraction to adjacent canyon

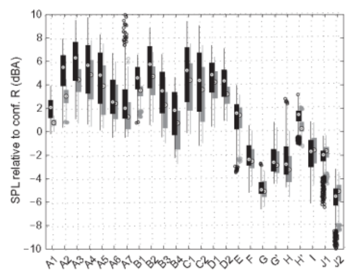


Diffraction to adjacent canyon



Van Renterghem et al., Journal of Sound and Vibration, 2010.

Diffraction to adjacent canyon

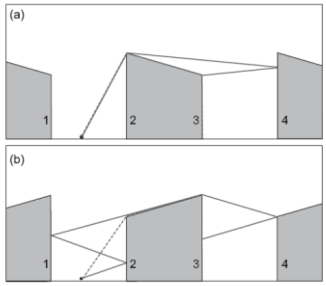


Van Renterghem et al., Journal of Sound and Vibration, 2010.

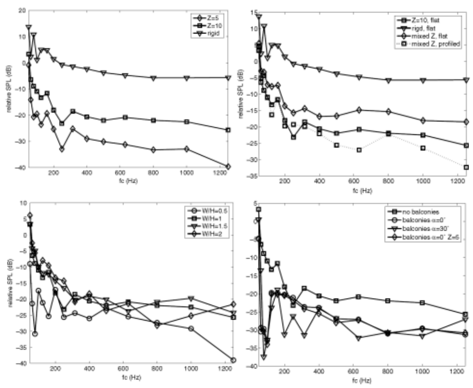
Fig. 5. Boxplots showing the sound pressure level, relative to configuration R, for total A-weighted traffic noise, along the shielded façade (from ground level up to 7.5 m). Vehicle speeds ranging from 30 to 70 km/h are considered. The boxplots for light vehicles are shown in black, for heavy vehicles in gray.

Diffraction to adjacent canyon

Diffraction to adjacent canyon



Diffraction to adjacent canyon



Van Renterghem et al., Applied Acoustics, 2006.

Multiple canyon propagation

- **Intermediate canyons**
  - 1-4 dB excess attenuation/canyon
    - **Rather frequency independent**
    - **Canyon depth of limited importance**
    - **Canyon width important**
  - Additive effect
  - QSide engineering model : 1dB/100 m propagation over roofs in dense urban setting
  - No absorption, no meteo-effects, no variation in building height

Schiff et al., Applied Acoustics, 2010.

Wei et al., Acta Acustica united with Acustica, 2014.

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Conclusions

- **Street design reduces sound pressure levels**
  - Promote diffuse reflections
  - Silent zones (pedestrians, facade)
  - Small architectural details can have a strong effect
  - Street amplification mainly governed by street width
- **Reductions in streets will help at the non-directly exposed side (stronger!)**
- **Complex interactions between multiple reflections and diffraction patterns**