# Environmental Noise: the Influence of the Relationship between the Height and Width of Urban Canyons

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## Abstract

This paper aimed to demonstrate the influence of urban geometry on the noise level on urban streets, considering the relationship between the height and width of urban canyons (H/W factor) as a representative unit for this type of analysis. To achieve this, urban profiles with distinct characteristics were selected for field observations and measurements. These included five urban reference points that differed with respect to the height of the buildings and the distances between the façades located on opposite sides of the street. The field study was carried out during peak vehicular hours and on weekdays. In addition, sound mapping was performed by application of a computational model in which the variation of the receivers' heights was used to evaluate the sound pressure level at 1.5, 10, 20 and 30 meters above the ground level. The general results showed that the highest values of the H/W factor were associated with the greatest noise levels in urban canyons.

## 1. Introduction

Sound pollution differs from other types of pollution due to its diverse effects on human health and quality of life (Doygun and Gurun, 2008).
Pollution is one of the residual consequences of social and economic development, and it is one of the most frequent environmental problems in large- and medium-sized cities (Giunta et al., 2012). This issue is even more problematic in urban agglomerations, where multiple sound sources are mainly associated with vehicular flow (Zannin et al., 2002; Alves Filho et al., 2004; Giunta et al., 2012) and are increased due to the activities of industries and commerce and the presence of buildings. As a consequence, and contrary to human requirements, cities suffer from deterioration of the quality of sound.
Many aspects of environmental noise in cities have been discussed in the literature, including the sources of sound and the exposition of noise levels (Zannin et al., 2002; Souza and Giunta, 2011), the interactions between the sources of noise, contamination levels and urban geometry (Niemeyer, 1998; Guedes et al., 2011) and the psychological effects of noise (Ouis, 2001; Fyhri and Aasvang, 2010).
In this context, urban canyons configured along streets (Arnfield and Grimmiond, 1998), together with vehicular flow, have a significant influence on environmental noise. Urban canyons are usually related to densely built-up areas, with tall buildings aligned on both sides of the street (Huang et al., 2009), therefore, allowing the establishment of a relationship between the buildings' heights and the street width (Panão, 2009) - the H/W factor. The volumes and heights of the buildings, distances and façades, in addition to the urban profile and the street networks, directly influence the sound propagation (Guedes and Bertolli, 2005). Picaut et al. (2005) and Richoux et al. (2010) observed that buildings' façades act as barriers, mainly reflecting high frequencies, thus enhancing noise levels inside the urban canyons.
Hence, according to Niemeyer et al. (2005), concerns about noise must extend beyond the physical limits of the buildings' interior environment and reach into the outdoor spaces, public or private, because the indoor environment is conditioned by the acoustical characteristics of the nearby surroundings.
Brazilian cities, large- and medium-sized, are also usually surrounded by sound pollution, as demonstrated by the work of Costa and Lourenço (2010) in Sorocaba, Brito and Sinder (2009) in Taubaté and Souza and Giunta (2011) in Bauru. All these cities are situated in the state of São Paulo, which belongs to the most developed region of the country. Despite al-

ready presenting noise problems, medium- and small-sized Brazilian cities still present a strong potential for preventive noise treatment or control, and their monitoring and environmental analysis are therefore important.
Currently, sound mapping is one of the tools used to characterise the noise and implement noise control in cities and to evaluate the noise levels and spatial configuration. This approach has the advantage of allowing visual access to the acoustical environment of a geographical area at a specific time or over a period of time. Furthermore, noise data that are either measured on site or predicted may be utilised in this type of technique (Guedes and Bertoli, 2005).
There are some examples of the application of this technique in Brazil, as presented in the studies of Moraes et al. (2003), Pinto and Mardones (2009), Costa and Lourenço (2010) and Cantieri et al. (2010). Most of the available examples are restricted to academic and scientific purposes. In contrast to European Community countries, where in accordance to Directive 2002/49/EC, all urban areas with more than 250,000 inhabitants must present a sound mapping for noise control, there is no effective control of sound pollution in Brazilian cities.
Considering the facts mentioned above, studies that integrate noise mapping and urban geometry should be taken into account to facilitate the urban planning process and to address human comfort requests. In this research, the influence of urban geometry on noise levels was verified by applying a simulation model. The noise data were collected on an important urban street in a medium-sized city, for which the H/W factor was determined at reference points representing urban canyons.

## 2. Methodology

Considering a real situation for field observations, the study included data collection, considerations for validation of the model, simulation for noise mapping and analysis of the results.
The selected area for sampling was the city of São Carlos. In the centre of the State of São Paulo, Brazil, the city of São Carlos (Figure 1) presents a population of 221,950 inhabitants (IBGE, 2010).

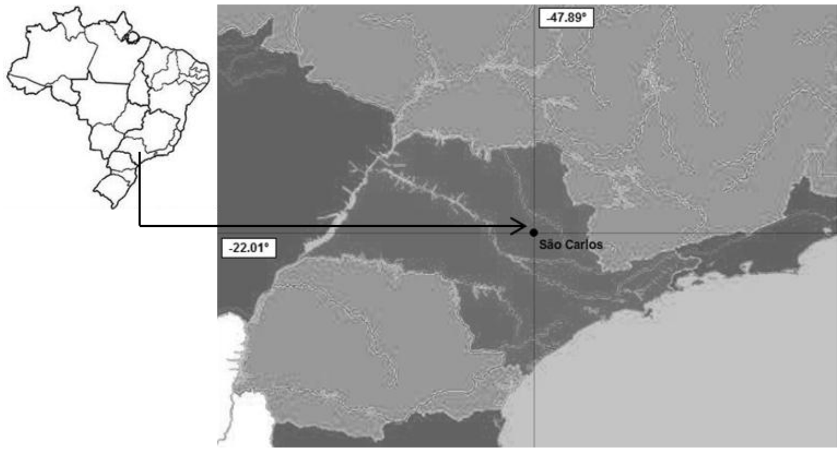


**Fig. 1.** Location of the City of São Carlos, São Paulo, Brazil

Noise mapping was developed using a computational simulation, allowing for verification of the influence of urban geometry on environmental noise. For this purpose, the concept of the H/W factor was applied at five observation points. These points were located on a street named XV de Novembro, which has significant vehicular flow. This street can be accessed from the east side and the west side of the city.

For the calculation of the H/W factor, the estimation considered the mean height of the buildings on both sides of the street canyon, and the width was calculated as the distance between the building façades along the street at the specific points.

In the simulation process for noise mapping, the software CADNA-A was used. CADNA-A® (Computer Aided Design Noise Abatement) is a computational model for the calculation, prediction and evaluation of environmental noise (Datakustik GMBH. 2005). This program also considers directives, standards and regulations as parameters of environmental noise. This allowed for the modelling of sound propagation and a graphical output representing the distribution of the sound pressure levels on the canyons.

The calculations were performed by the application of the French method NMPB-2008, which is recommended by the European Directive on Environmental Noise 2002/49/CE in cases when European countries have not developed its own method.

## 2.1. Data collection

Data on the traffic flow were collected for 5 minutes at the peak hours from 7 a.m. to 8 a.m., 12 a.m. to 1 p.m. and 5:30 p.m. to 6:30 p.m. on typical week days (Tuesday, Wednesday and Thursday), avoiding the atypical dynamics of Fridays, Mondays and weekends.
At the same peak hours, the data for the sound pressure level were collected at the five observation points. The sound descriptor applied was the A-weighted and wind-protected Leq (equivalent sound level), registered by a sound pressure meter from Brüel & Kjaer.
The street geometry was reproduced from field observations, measurements, images obtained from Google Earth® and cadastral documents made available by the Municipal Administration of São Carlos. The geometrical representation of the points was plotted in a computer-aided system, which facilitated the determination of the H/W factor (H being the average height of the buildings and W being the distance between the façades).

## 2.2. About the model validation

For noise mapping, the noise sources could be represented by roads, railways, industries and punctual or linear sources. However, the Brazilian legislation does not have any specific regulation for propagation, reflection, diffraction or other effects that are considered for noise mapping. Therefore, this research applied the French method for predicting road traffic noise (NMPB-Routes-2008), which is one of the modules available in the software CADNA-A.

Before applying CADNA-A, a model validation was processed by our research group in another study carried out by Giunta (2013). The referred validation process of Giunta (2013) compared real and simulated data at a height of 1.50 meters at 48 observation points in a broader part of the same city, including the XV de Novembro street. According to the Portuguese Environmental Agency, the range of differences between simulated and collected data should be approximately ±2 dB (A). For Silva (2010), this limit may be extended to ± 3 dB (A), and in urban areas, may be up to ± 4 dB.
The results of Giunta (2013) showed that for the same urban area, if the map is generated by inputting the measured Leq(A) values, the model tends to underestimate the noise at a magnitude of 2 dB (A). This underestimation may be up to ± 4 dB (A) if the input considers the vehicular flow

values instead of Leq (A) values. Therefore, CADNA-A was considered to be valid for application in this area, according to the criteria described above.

## 2.3. Sound mapping, inputs and data analysis

The urban scene was incorporated into CADNA-A. Along the street XV de Novembro, maps of the noise levels were developed for the five reference points. Receptors for simulated data extraction were placed in the middle of the canyon at 1.5, 10, 20 and 30 meters above ground level. Values of the simulated noise level for these receivers were related to their respective H/W factors, allowing for the analysis of the geometrical influence on urban sound levels.

Moreover, other variables, such as reflection loss or reflected rays, were assumed to be equal to two. While the value of the reflection loss is a default of the program and also implies an alpha coefficient of 0.37 (meaning non-absorbent materials on façades), the variable of reflected rays refers to the contribution of the façades to reflecting sound.

Finally, for mapping, the following parameters were applied: receiver spacing of 2.00 x 2.00, initial receiver height of 1.5 m (this varied for the other height analyses) with isophonic lines ever 5 dB(A). The output values in CADNA-A are based on the $L_{den}$ (in dB) calculation, which is a parameter for the equivalent day and night noise, assuming continuous noise during each of the periods.

# 3. Results

Figure 2 exemplifies the horizontal map of the street range studied, showing the tendencies of the sound pressure level in the urban canyons. Figure 3 shows a tri-dimensional image of the same area, representing the buildings' locations, their respective volumes, the position of the receivers and the vertical noise maps for each of the five reference points.

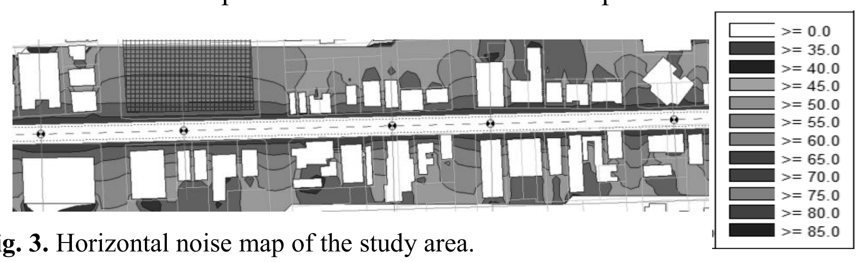


**Fig. 3.** Horizontal noise map of the study area.

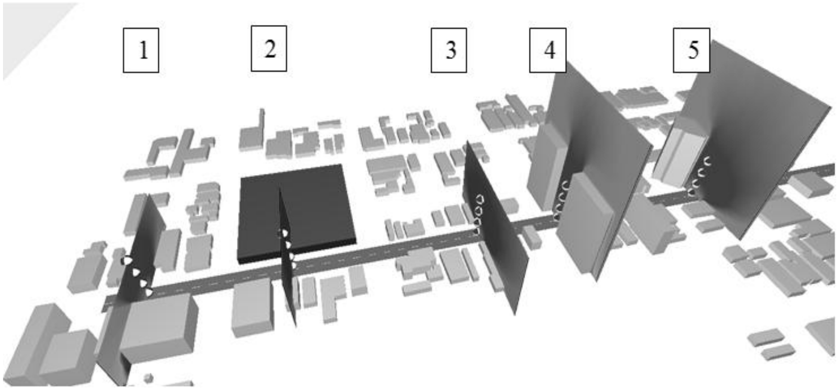


**Fig. 32.** Tri-dimensional image of the street XV de Novembro, São Carlos, SP, Brazil: buildings, volumes and vertical noise maps at the five reference points (1, 2, 3, 4 and 5).

In relation to the height of the buildings, profiles 1, 2 and 3 shown in Figure 3 present similar characteristics, with low-height buildings, compared to the profiles of points 4 and 5. Consequently, profiles 1, 2 and 3 correspond to similar values of H/W (Table I). However, a singular feature is remarkable in profile 2, where a green area exists. In this case, the heights of the trees were also considered for the H/W calculation**.**
This is the same green grid that is shown in Figure 2. The horizontal noise map of that image reveals that noise is maintained at higher levels inside the canyons than on the backside of the buildings. As the green area was not able to act as a barrier, sound was propagated through the square environment.

**Table 1.** H/W factor for the reference points on the street XV de Novembro, São Carlos, SP, Brazil.

| Profile | Average Height of Buildings or Trees (m) | Distance between opposite façades(m) | H/W factor |
|---|---|---|---|
| 1 | 9.,50 | 27.52 | 0.35 |
| 2 | 3.5 | 16.05 | 0.22 |
| 3 | 4 | 15.76 | 0.25 |
| 4 | 52.5 | 18.10 | 2.90 |
| 5 | 24.5 | 17.71 | 1.38 |

The results shown in Figure 4 complement the data presented in Figure 2 and Table 1, showing the isolines of the profiles 1, 2 and 3 and their similarities regarding the behaviour of the sound propagation.

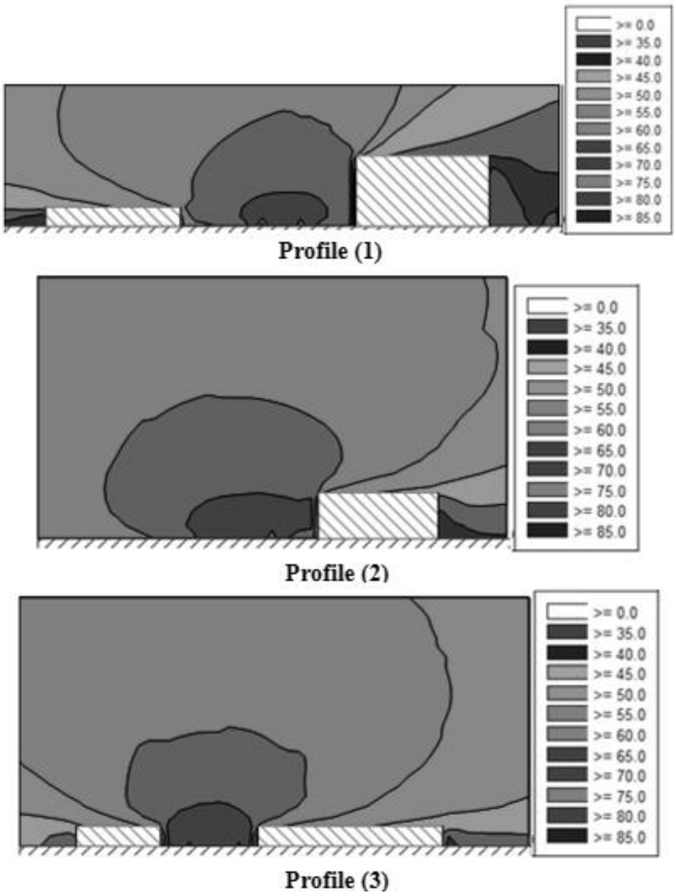


**Fig. 4** Vertical noise maps at points 1, 2 and 3 on the street XV de Novembro, São Carlos, SP, Brazil.

The influence of urban geometry on noise propagation is mainly observed in the profiles 4 and 5, and it is visually displayed in Figures 5 and 6.

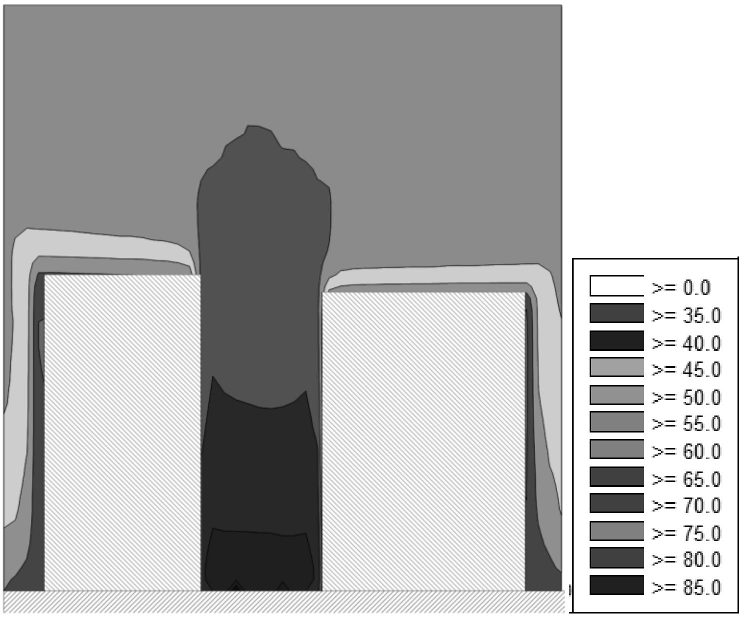


**Fig. 5.** Vertical noise map at point 4 on the street XV de Novembro, São Carlos, SP, Brazil.

Point 4 presented the highest value of H/W (2.90). At these points it is possible to verify the role that is played by buildings. On one hand, the buildings serve as sound barriers for the areas surrounding the façades on the back side; on the other hand, as they serve as multiple reflection elements for the inner side of the urban canyon. In contrast to this enclosed propagation, profile 5 in figure 6 shows another situation, in this case with an asymmetric configuration. This profile corresponds to an H/W value of 1.38. While the configuration of the buildings' height causes a barrier for the back side of the tallest building, on the other side, above the smallest one, the open space creates a favourable condition for sound propagation in a spreading pattern.

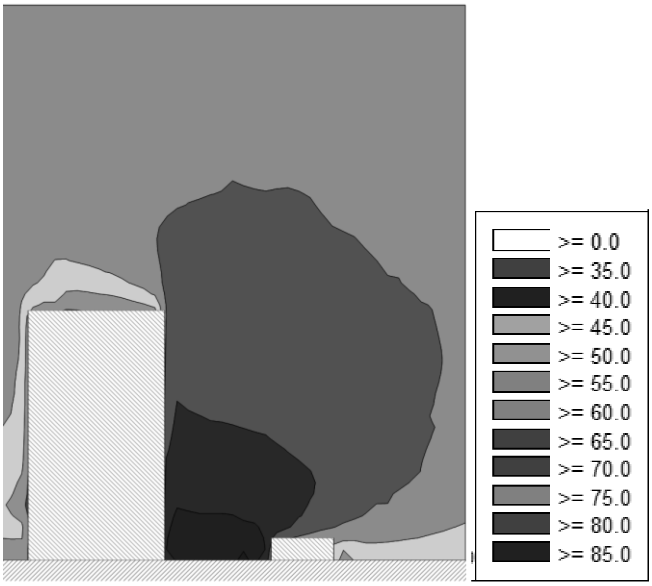


**Fig. 6.** Vertical noise map at point 5 on the street XV de Novembro, São Carlos, SP, Brazil.

Figure 7 presents the $L_{den}$ values simulated for the receivers at a specific height above the ground level. As expected, the sound intensity decreased with the increasing distance between the vehicular source and the receiver.

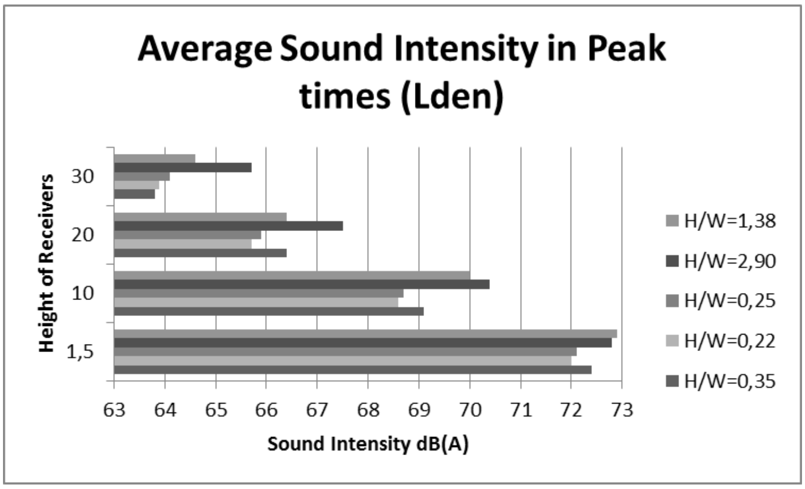


**Fig. 7.** Average sound levels at peak hours for street XV de Novembro, São Carlos, SP, Brazil.

Nonetheless, the influence of the H/W factor on sound decay can also be observed. For the receivers located at the profile with a value of 2.90 (the highest one), we observed the largest values for the noise levels due to the reflection promoted by the façades, consequently implying an increase of the reverberation time inside this canyon.

In Figure 8, where the sound levels for the receivers at 1.5 m are plotted, it is observed that within the range of H/W from 0.22 to 1.38, for all periods, the sound levels tended to increase with increasing values of H/W. A difference of 0.8 dB is found between the lowest and the highest value of this H/W range. However, above 1.38, at this receiver's height, it was verified that there was no significant influence of H/W.

The same type of analysis for the receiver at 10 m above ground level, shown in Figure 9, revealed an increase of 1.8 dB between the lowest (H/W of 0.22) and the highest points (H/W of 2.90). The increasing tendency at 10 m was much more significant than at 1.5 m.

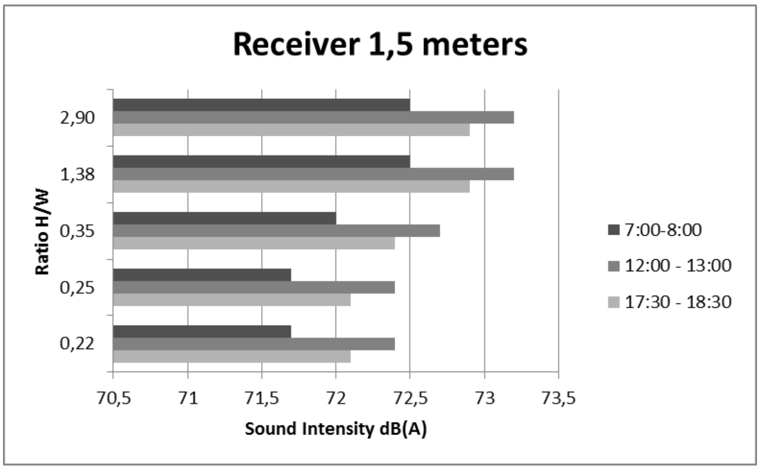


**Fig. 8.** Noise levels in relation to the H/W factor for receivers located at 1.5 meters above the vehicular source on the street XV de Novembro, São Carlos, SP, Brazil.

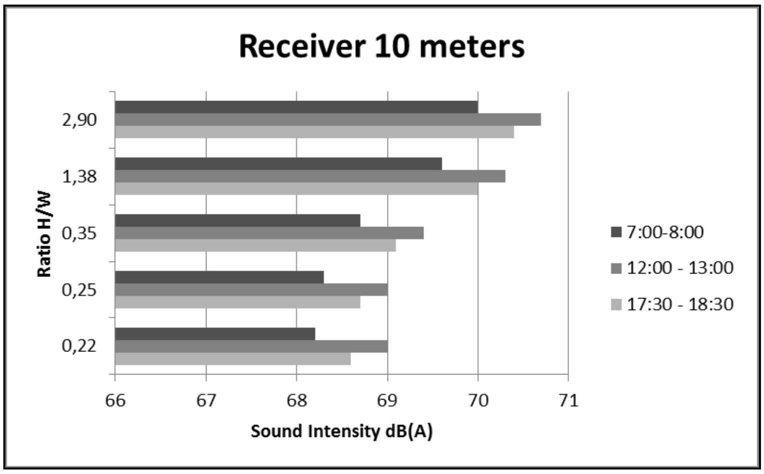


**Fig. 9.** Noise levels in relation to the H/W ratio for receivers located at 10 meters above the vehicular source on the street XV de Novembro, São Carlos, SP, Brazil.

In addition, the receivers at 20 m height (Figure 10) also followed this tendency. Though point 4 did not maintain the same proportionality for the noise increase, the difference between the sound level simulated for an H/W value of 0.22 and a value of 2.90 was approximately 1.8 dB.

Considering that the decibel scale is logarithmic, an increment of 1.8 dB (A) indicates a large increase in energy and the presence of an enclosure between façades. This amount of energy is almost equivalent to the amount of energy associated with the noise reduction observed when the speed of the vehicles in a road decreased by 10 km/h under the conditions measured by Bendtsen et al. (2005).

Taking into account that the increase of 1.8 dB was caused by the vertical surfaces of the façades and not by the noise source itself, buildings have a large influence on the urban sound environment.

In addition, Figure 11 shows the results for the receivers at 30 meters. In this case, for the lowest values of H/W (0.22, 0.25 and 0.35) there was no significant difference in the noise levels. Yet, a tendency of increasing noise levels from the lowest to the largest ranges of H/W was observed.

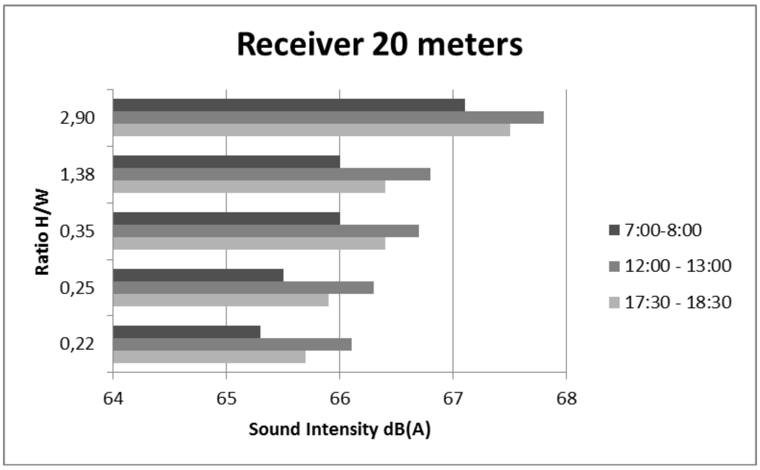


**Fig. 10.** Noise levels in relation to the H/W ratio for receivers located at 20 meters above the vehicular source on the street XV de Novembro, São Carlos, SP, Brazil.

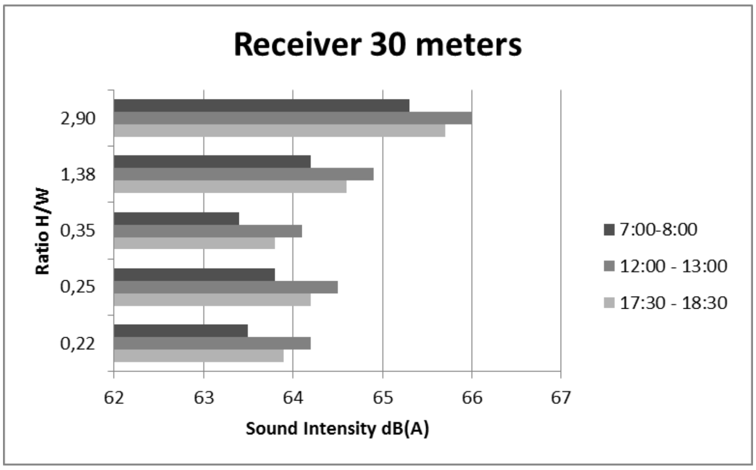


**Fig. 11.** Noise levels in relation to the H/W ratio for receivers located at 30 meters above the vehicular source on the street XV de Novembro, São Carlos, SP, Brazil.

## 4. Conclusions and recommendation

Based on the actual conditions of buildings' volumes and vehicular flows at peak hours, the results of this research indicated that urban geometry plays an important role in acoustical propagation in urban canyons.

Simulations performed by applying the French method incorporated in a computational model demonstrated that variations in the H/W factor may account for variations of 1.8 dB in noise levels for the street studied. In general, the higher the H/W factor, the greater the noise levels inside the urban canyons.

On the other hand, buildings can also act as noise barriers for the façades on the back side. However, this influence must be carefully analysed, avoiding the overestimation of this effect. As the simulation does not consider the openings of the building façades, this simplification causes an enhancement of the barrier effect. In a real scenario, there are windows on the façades, which are weak acoustic elements if not properly treated. Any open window or gaps in the façades will allow the propagation of outdoor sound to the indoor environment.

Hence, the urban acoustical environment must be considered not only based on the inner side of urban canyons but also with regard to the whole surroundings.

Finally, the results highlight the importance of integrating simulations and urban geometry tools for the noise prediction of future scenarios. This could help with regard to planning and decision making, to reduce the acoustical impact of the increasing vehicular flow in cities and to minimise the human discomfort caused by noise in urban areas.

Although a wide application of noise maps for the whole street network is desirable, this is still a difficult task that requires a huge amount of input data, either related to Leq (A) or to the vehicular flow of each street.

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