The role of traffic flow and the Floor Space Index (FSI) in predicting environmental noise

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Abstract

Traffic flow and building parameters are analysed jointly to identify urban noise tendencies. For this purpose, the building parameter applied is the Floor Space Index (FSI). Acoustical and traffic flow data were collected and incorporated into a Geographical Information System (GIS). The future scenarios for this zone were created. For the FSI parameter, it was verified that the higher the value of the average FSI, the higher the noise levels registered in urban canyons.

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1 Introduction

The last century presented an increase in urban sprawl as well as an increase in urban activity. In a general context, urban development was accompanied by an increase in the number of cars in cities, which caused high levels of noise and placed air pollution as one of the largest problems in cities today. Buildings' façades and urban geometry can intensify the noisy environment of cities and act as sound reflectors, which may even lead to reverberation in urban canyons, as once confirmed by Picaut et al. (2005).

Sound ambience is conditioned by the intervention of the architectural aspects, urban features and elements of the surroundings. Hence, urban geometry has an influence on sound propagation in terms of the building volumes, heights, and distances between buildings. According to Guedes et al. (2011), the construction density, the open spaces, and the shape and physical position of buildings impact on the environmental noise. So, the variables of urban design affect the quality of urban life, revealing the importance of a commitment to design with regard to sound propagation. This is another reason why design decisions are important in achieving a healthy urban environment.

Wang and Kang (2011) showed that the differences in urban morphology cause differences on the traffic noise distribution and that there are correlations between noise indices and a number of morphological indices. This influence was also emphasised by Souza and Giunta(2011), who showed that the levels of noise on the street might be related to the average floor space index (FSI) such that the higher this ratio, the louder the level of noise reaching pedestrians in urban canyons. FSI is a ratio between the total area of the constructed area of building (including all pavements) and the plot area.

In this context, the use of computational programs for acoustical simulation of the urban environment is a very handy tool. However, there are limitations to their application in a municipal scale, mainly if we consider the costs for the acquisition of commercial programs and for the human training on the tool, besides the difficulty in accessing the required input data.

Thus, this paper presents an alternative of predicting urban noise by identifying useful data that could help planners establish relationships among their decisions and the features of the noisy environment of cities. For this purpose, computational acoustical simulations are performed and some information extracted from these simulations. Hence, this paper investigates the noise caused by urban traffic flow with sound reflections incremented by buildings, while applying the concept of the average FSI as the parameter under analysis.

1.2 Contextualization

Estimated by the Directive 2002/49/EC (European Union, 2002), noise control and mapping are already important issues under consideration by the European community. Conversely, there are still many urban areas in the world in which urban planning neglects the acoustical environment and there are no effective noise control programs.

In the case of Brazil, despite the importance of the issue, there is no effective action for the evaluation, diagnosis or mitigation of the acoustical environment in the future scenarios of impacted Brazilian urban areas. Noise is not yet recognized as a main environmental problem (Pinto and Mardones, 2009). The consideration of acoustics and atmospheric issues is basically concentrated within pollutant industries.

Brazilian municipalities are responsible for the implementation, supervision and regulation of sound pollution. Moreover, municipalities are able to apply technical standards or create municipal regulations that are even more restrictive based on local characteristics. However, this procedure is rarely adopted.

Noise issues are present not only in large cities but also in medium cities, where acoustics problems already exist. Medium and small cities, however, have greater potentiality of preventive treatment and noise control than large cities, which emphasises the importance of monitoring and analysing the acoustical environments of these classes of cities.

One way of doing this is by mapping noise on street canyons, aiming at the evaluation of sound levels and the spatial distribution. However, sound maps are not yet extensively used throughout Brazil and are more frequently applied to academic matters (Pinto and Mardones, 2009 and Costa and Lourenço, 2010). Noise mapping enables the quantification of noise, the evaluation of population exposure, the development of futures scenarios, the identification of conflict areas and the testing of solutions. It also helps in controlling the evolution of noise issues with time and in the verification of effective actions. The spatial distribution of information on a noise map may help in the identification of conflict areas, even if a very simplified procedure is undertaken for its development.

2 Material and Methods

The methodology of this research uses the concept of an average floor space index for an entire urban block, as once considered by Souza andGiunta (2011) and defined in Eq. 2.1:

$$FSI = (NblockaverageX\ Aconstructed)/Atotalblock \quad (2.1)$$

where:

FSI is the Average Floor Space Index for the whole block, Nblockaverage is the average number of stocks of the block, Aconstructed is the constructed area of the block in square-meters and Atotalblock is the total area of the block in square-meters.

Additionally, a medium-sized city was taken as a reference for measurements and a ground truth for simulations and as a basis for the development of future scenarios. Therefore, the main steps of this research consisted of selection of a reference area, noise measurements, urban noise mapping in GIS, urban noise prediction by application of a French method and analysis.

2.1 Selecting an study area for ground truth reference

Considering the potentiality of preventive treatments presented by medium and small cities, a Brazilian urban area was selected to be a source of ground truth and extraction of the relationships between noise, traffic and buildings. This area is the medium-sized Brazilian city of São Carlos, which is situated in the geographical centre of the state of São Paulo (SP), Brazil. The city has a population of 219,865 inhabitants and a municipality area of 1,137.303 km² (IBGE, 2010). The São Carlos urban area corresponds to 6% of the total area, or 33 km2. The city, which has a total of 128.705 vehicles (IBGE, 2010), has a linear centre configured with an avenue and parallels streets with mixed land uses (residential buildings, schools, churches, hospitals, commercial buildings and services and many activities). This centre is the main source of the traffic demand of the urban area, which has led to many conflict points for pedestrians. Additionally, in the city centre, the street network is developed on a slight-hilly topography, delimited by two valleys.

Based on the Master Plan of the city from 2005 the urban core of São Carlos is expected to have an induced occupation of residential use applying an incentive-based concept for the transfer of development rights. In addition, there is an intention to maintain the variety of uses in this zone. Therefore, the floor space index may be increased to conciliate coexisting uses. According to the Master Plan, the maximum FSI value in this zone is 3.5 and the maximum building area/lot area ratio is 70%.

In the city core, forty-eight points were taken as references for the registration of acoustical and traffic flow data. These points were positioned on sidewalks at the middle point of blocks avoiding corners and covered approximately 30% of the existing blocks in the area. First, these reference points enabled the visualization of noise tendencies values for the whole core area. Subsequently, after identifying a conflict zone, eleven points from this cluster were selected to more closely study the relationship between noise levels and the Floor Space Index.

By physical recognition in site, the characteristics of the area were collected to identify street and sidewalk widths, pavement types, the heights of buildings, uses and occupation patterns, vegetation and topography (altitudes, longitudes and latitudes). These field campaigns were complemented by Google Earth's online images and overlain cadastral and topographical plans made available by the City Hall and by the Master Plan of the Municipality. To estimate building heights, we assumed an average height of 4 meters for one-story buildings and 3 meters for each story above the ground level.

2.2 Collection of noise data

At all the points, the sound pressure levels and vehicular flows were registered. The measurements took place at the peak hours of vehicular flows (7 a.m. to 8 a.m., 12 a.m. to 1 p.m. and 6 p.m. to 7 p.m.) on weekdays (except Mondays, Fridays and Holidays, due to the differences on city dynamics usually present in these days).

In addition, a Brüel&Kjær Hand-Held Analyser 2250-L, type 1, with a wind protector was applied for noise registration. The equipment was adjusted for external noise measurements, A-weighted with a slow response for a period of 5 minutes. The sound pressure meter was kept away from reflexive surfaces (a minimum of 2 meters from walls) and 1,20 meters from the ground, as determined by the Brazilian standard technical regulations.

At each collecting point, the levels of Leq (equivalent noise levels in dBA) and statistical parameters of L10 (intrusive noise), L50 and L90 (environmental noise) were registered. Simultaneously, the vehicular flow was counted considering the number of vehicles/minute.

2.3 Geoprocessing

The physical characterisation of the surroundings, together with the cartographical basis made available by the city Municipality, allowed us to develop maps, which included data on the land use, occupation and building heights.

All the information was incorporated into a GIS (Geographic Information System) using ArcGIS version 10 – ESRI. This platform was also used to compose a map for visualise the isolines of noise occurrence in the area. This map was developed in a very simplified way, with the unique intention of identifying the concentration of conflict areas. Therefore, it did not consider the noise propagation interactions among urban surfaces and was constructed by a method of interpolation (Spline) available in the GIS tools. The interpolation of noise levels collected in the area allowed the determination of the isolines. The vehicular traffic was also plotted in the maps with overlaying lines, which were weighted with the flow values. In the same GIS, histograms were created to verify noise occurrences and the predominance of levels registered.

This process provided the very first step in understanding the noise environment of the area and helped in the cross-examination of data. Furthermore, the analysis considered the topography of the area for the identification of the acoustical environment.

2.4 Noise simulation and Index

Simulations were performed by application of the French method NMPB-2008, the mathematical representation of which corresponds to Eq.2.4 2. The method includes an algorithm that calculates the long-term equivalent noise level (LLT), taking into account the meteorological conditions of the study area.

$$LLT= 10\log [p.10LF/10 + (1- p). 10LH/10] \qquad (2.4.2)$$

where:

LLH is the noise level for homogeneous meteorological conditions in decibels, as described by Eq. 2.4.3, whereas LLF is the noise level for favourable meteorological conditions, as described by Eq. 2.4.4, in decibels. The term p assumes values from 0 to 1 depending on the occurrence of favourable conditions.

$$LLH= LW – Adiv- Aatm- Asolo,H- Adif,H- Aref \qquad (2.4.3)$$

$$LLF= LW – Adiv- Aatm- Asolo,F- Adif,F- Aref \qquad (2.4.4)$$

where:
LW represents the acoustic power associated with the traffic flow.
Adiv is the attenuation due to geometric divergence;
Aatm is the attenuation due to atmospheric absorption;

Adif is the attenuation due to diffraction;
Asoil is the attenuation due to soil effects;
Aref is the attenuation due to the absorption of vertical surfaces

Next, the algorithm of the method was run using the software CADNA-A (from Datakustik). The accuracy of this simulation was verified by comparing the simulated values to real ones. In this step of the methodology, the area of simulation was restricted to the cluster of eleven points of reference as aforementioned. As a result, the restriction to a small area of the simulation guaranteed similarities in the general ambience, traffic flows and topography.

Afterwards, acoustic maps for the actual situation and for a future scenario of this small portion of the area were developed. This process of mapping allowed the identification of simulated noise valuesin other new points than only those eleven reference points of the data collection in the restricted area. Then, this step helped on the extraction of some relationships between the noise value and the FSI values.

The future scenario considered a maximum FSI of 3.5 previewed by the Master Plan of the city of São Carlos together with an increase in vehicular flows. The estimation of the latter was based on an increment of 50% in relation to the actual flow, foreseeing a 10-year projection based on the increase in cars over the last 5 years.

3 Results and Analysis

Table 3.1describes the average data of Leq, L10, L50 and L90 and the corresponding vehicular flows for the peak hours of the day according to the values measured at the forty-eight reference points.

Ta**ble 3.1**Average values of measurements.

Parameters	Morning	Afternoon	Evening
Leq (dB A)	68.7	68.2	68.4
L_{10} (dB A)	71.7	71.1	71.2
L_{50} (dB A)	63.5	62.8	63.4
L_{90} (dB A)	56.4	55.4	56.9
Vehicular flow (vehicles/minute)	40.9	54.9	56.3

An analysis of Table 3.1shows that the values of Leq were very similar for the three periods of measurement. They reached 68 dB (A) in average, exceeding the recommended 50 dB (A) established on NBR 10.151:2000, thus indicating that pedestrians are subjected to excessive levels of noise.

Likewise, a similarity among the periods was registered for the statistical parameter L10, which was rounded to an average value of 71 dB (A) for all the peak hours of measurement. Therefore, the intrusive noise is very similar among the peak hours. During measurement, it was also noticed that these intrusive noises were usually created by motorcycles and buses.

The values among the peak hours were very similar. In all of them, the average was above 50 dB (A), demonstrating once more the issues with pedestrians' health.

The histogram of the morning peak hours (Figure 3.1) shows that all the points were above the recommended maximum value of 55 dB for human comfort in areas of mixed uses. More than 80% of the points of measurement presented values above 65 dB (A). The range of 65 to 70 dB (A) was the most frequent and corresponded to more than 40% of the points. In the period of the morning peak hours, 3% of the points reached the range of 80 to 85 dB (A). Thus, this period was responsible for the largest value of all the periods.

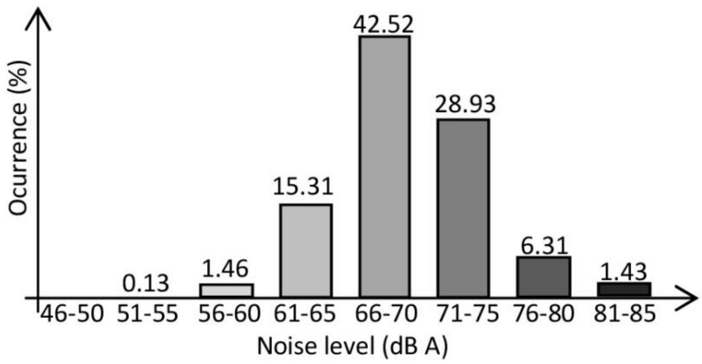

Fig.3.1. Histogram for the morning peak flow of vehicles.

Analysing the histogram of the afternoon in Figure 3.2, there are some points within the limits. However, the range of 65 to 75 dB (A) was still predominant and corresponded to 50% of the points, which means that there were more points in this range in the afternoon than in the morning peak hours.

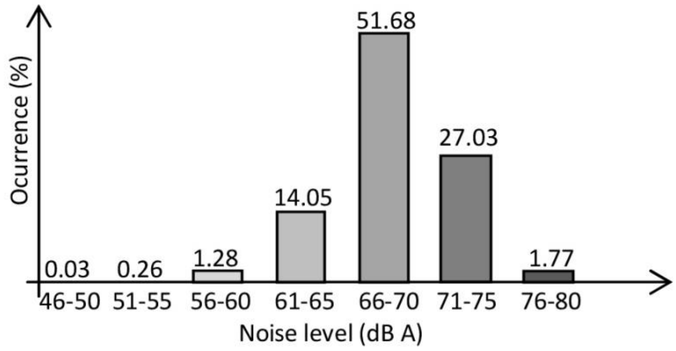

Fig.3.2. Histogram for the afternoon peak flow of vehicles.

During the evening (Figure 3.3), more than 80% of the points were above 60 dB (A). Moreover, the range of 70 to 75 dB (A) was higher than in the other periods, almost achieving an occurrence of 35%.

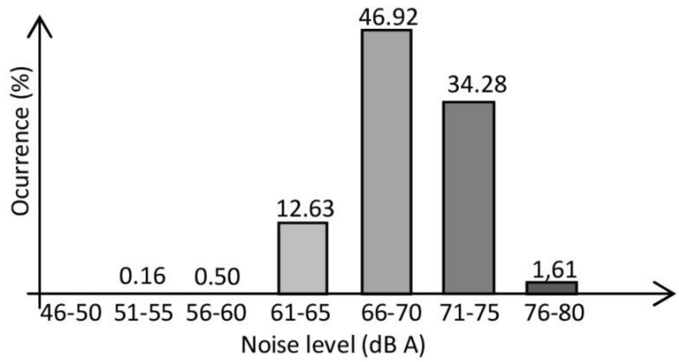

Fig.3.3. Histogram for the evening peak flow of vehicles.

In Figures 3.4 the configuration of the noise isolines for the morning peak hours complement this analysis in a way that allows visual observation of the noise distribution and cross-examination with the vehicular flow. The circles on these figures detach the noisiest urban fraction in this area. Figure 3.4 shows that the avenue with the highest vehicular flow of the area corresponded to the point with the highest noise level. This main avenue crosses the entire study area. At the exact point where the levels were between 80 to 85 dB (A), the topography was hilly and vehicles flowed in an ascendant movement. On this same avenue, where a street crossing resulted in the lowest vehicular flow, the lowest noise level was registered.

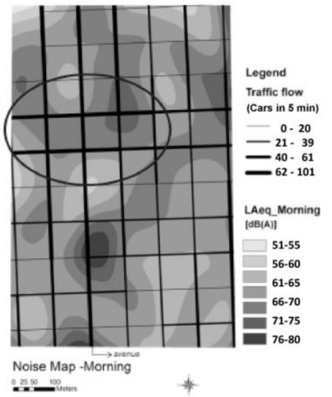

Fig.3.4. Noise isolines during the morning peak hours.

The same kind of map for the afternoon peak hours (Figure 3.5) revealed a more homogeneous acoustical environment than in the morning. There is a spatial expansion of the ranges from 71 to 75 dB (A). This map was especially helpful to support the analysis of the histograms. In the histogram, the quantification could not express the spatial tendencies that the map does. However, in a very simple and visual way, the histogram shows that the avenue is an important nucleus that determines the acoustical conditions of its surroundings.

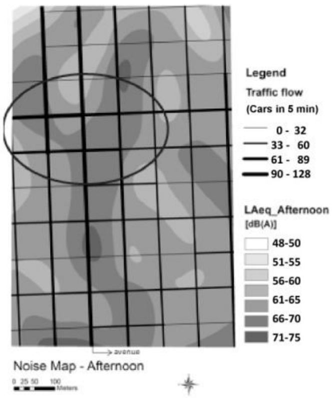

Fig.3.5. Noise isolines during afternoon peak hours.

During the evening peak hours (Figure 3.6), the entire area exhibited excessive noise conditions. The isolines indicate that the environments were similar in the evening and in the afternoon with respect not only to the noise levels but also to the vehicular flow.

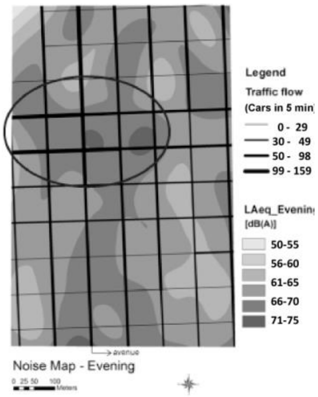

Fig.3.6. Noise isolines during evening peak hours.

Figure 3.7 presents the details of the hilly profile of the main avenue, which exhibited the most unfavourable environment for pedestrians.

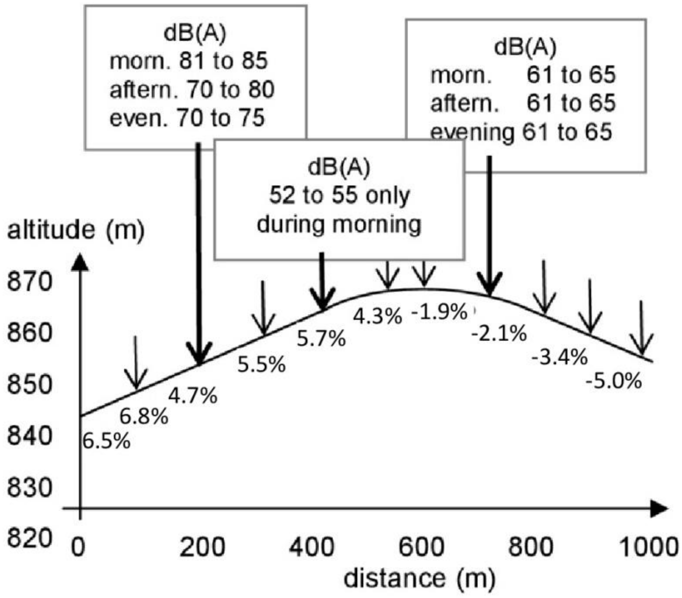

Fig.3.7. Terrain profile of the main avenue.

It is thus possible to observe that the highest levels of all the periods were related to the middle point of a hill with a slope of 4.7%, a condition possibly related to the change of gears of cars due to their position on the ascendant slope. Compared to the conditions on a descendent slope, noise levels were consistently more than 10 dB (A) higher on the ascendant slope.

Taking into account all the noise data and the study area configuration afore discussed, it is then possible to realise the acoustical fragility of this area. There are not only conflicts for pedestrians, but also an incompatibility with the proposals of the master plan, which stipulates an intensification of residential uses in this area.

Limiting the analysis to a small portion where the largest conflicts were found (that fraction marked with circles in Figures 3.4, 3.5 and 3.6), simulations applying the French model were performed. Figure 3.8 shows the result of such a simulation, comparing noise levels at 1.20 m and 4 m above the street level. This comparison shows that the ground surfaces acted on the propagation of noise, inducing resulting vectors to the highest superior layers. At 1.20 meters for all the periods (Figures 3.8a, 3.8c and 3.8e), walls and buildings acted as acoustical barriers, which together with the distance between source and receptors in the centre of the blocks, created lower noise levels. Whereas at the centre of the blocks, levels lower than 40 dB (A) were observed, at the street level, values above 75 dB (A) were found, which is an important aspect to take into account when analysing noise ambience because the pedestrian point of view is different from users inside the blocks. Pedestrians are more frequently exposed to higher levels than users positioned in the centre of the blocks.

For the 4-meter height maps (Figures 3.8b, 3.8d and 3.8f), these differences were less perceptible. The buildings acted as barriers but not as significantly as in the first-mentioned situation.

Concerning this subject, Picaut et al. (2005) showed that the reverberation time in urban areas increases with the distance between source and receptor, verifying that sound attenuation is less for low frequencies because the building façades are favourable to the reflections of high frequencies and low frequencies are canalised to the inner parts of blocks. Thus, frequencies in the centre of blocks are related to low frequencies, whereas pedestrians are subjected to the reflections of the façades and high frequencies. Therefore, pedestrians are even more exposed to the discomfort of high frequencies than the users on the ground levels of buildings. The same authors stated that the attenuation of noise at the street level seems to depend on the width and height of the street canyon. In this case, urban geometry is once more a key in indicating acoustical conditions in urban areas.

Considering the FSIaverage as an urban geometry parameter, an average value of 0.22 was found in this area, varying from 0.11 to 0.35. These values were cross-examined with the simulated noise levels in the small fraction that was analysed. In this analysis, the points of the border area were avoided to eliminate the influence of simplifications and limitations on the simulation process. The average values were considered as the mean values of the FSI in the blocks that surrounded the point under consideration.

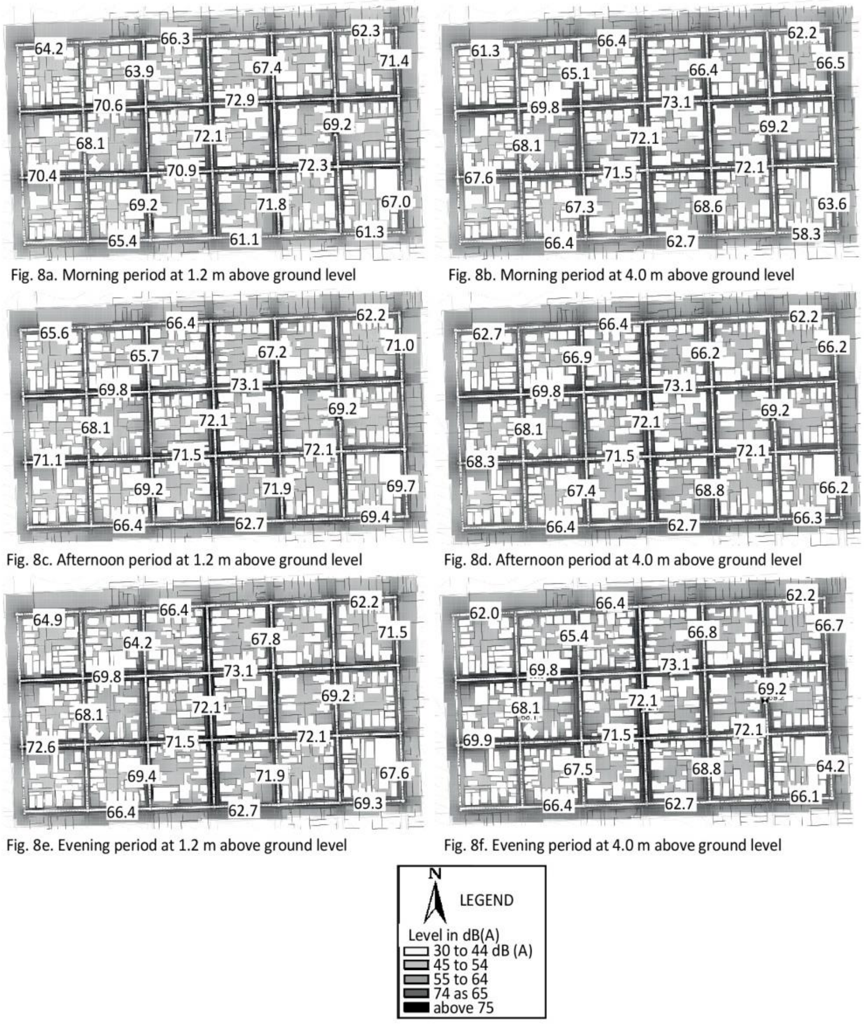

Fig.3.8. Noise maps for the actual situations for an urban fraction in the mornings, afternoons and evenings, at 1.2 meters and 4 meters above ground level.

Figures3.9 and 3.10 show this relationship, takinginto account two ranges of FSIaverage: one above average and the other below average.

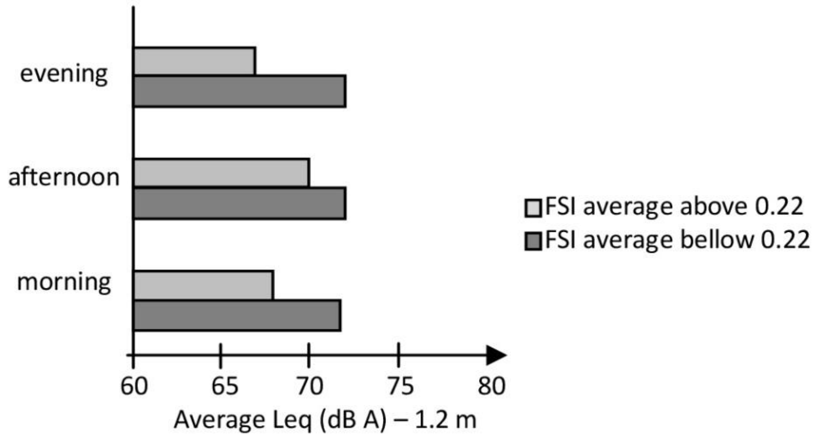

Fig.3.9. Noise levels at 1.20 meters above the ground for the FSIaverage ranges at peak hours.

Fig. 3.10 Noise levels at 4 meters above the ground for the FSIaverage ranges at peak hours.

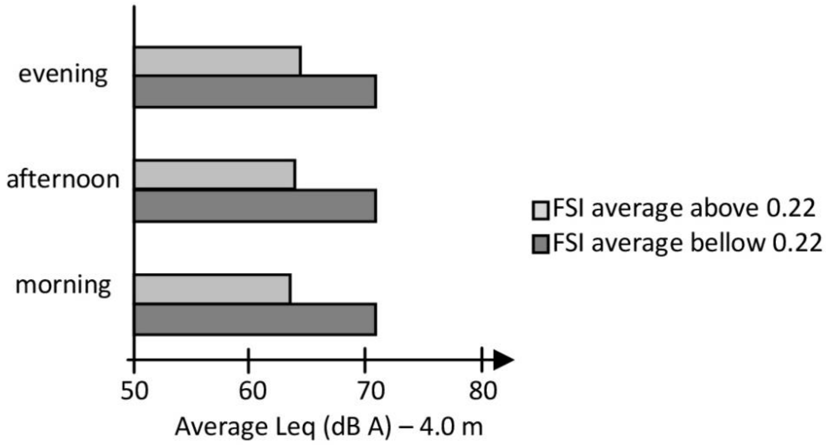

Fig.3.10. Noise levels at 4 meters above the ground for the $FSI_{average}$ ranges at peak hours.

Hence, it is possible to observe that for the 1.2 and 4 meters above ground level, the highest values of FSIaverage are related to the highest noise levels. This result is one of the most important achievements of this research because it allows the establishment of the predictive potential of FSI as a parameter and presents a practical application for building regulations and urban planning.

According to the period of analysis, not only for the pedestrian level (1.20m) but also for the top-of-building level (4 m), differences up to 6 dB may be found among values of FSIaverage higher than 0.22 and below 0.22, which suggests that when predicting future scenarios, FSI values can be associated with vehicular flows for the verification of the urban acoustical environment.

Therefore, a scenario based on the maximum FSI allowed for the area, together with an increment of 50% in the vehicular flow was simulated for 1.20 and 4 meters above ground level. The relationship of FSI and respective noise levels for this is shown in Figures 3.11 and 3.12, and maps are presented in Figure 3.13. The latter is for a FSI incremented to 0.43.

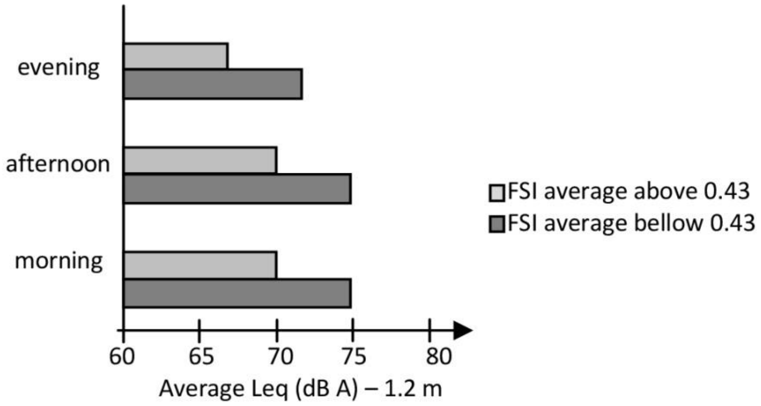

Fig.3.11. Noise level at 1.20 meters for the future scenario of FSI equal to 0.43.

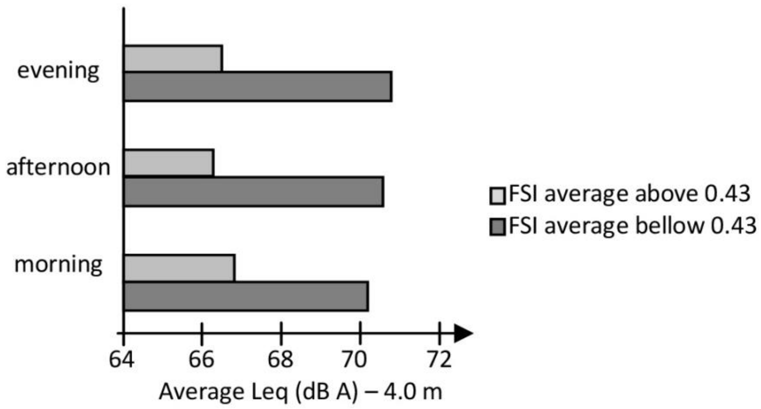

Fig.3.12. Noise level at 4 meters for the future scenario of FSI equal to 0.43.

The analysis of Figure 3.11, 3.12 and 3.13 allows the prediction of a significant increase in the noise levels for a future scenario. Namely, at a height of 1.20 m, or the pedestrian level, it is possible to observe values of 75 dB(A) for places with an FSI above 0.43.

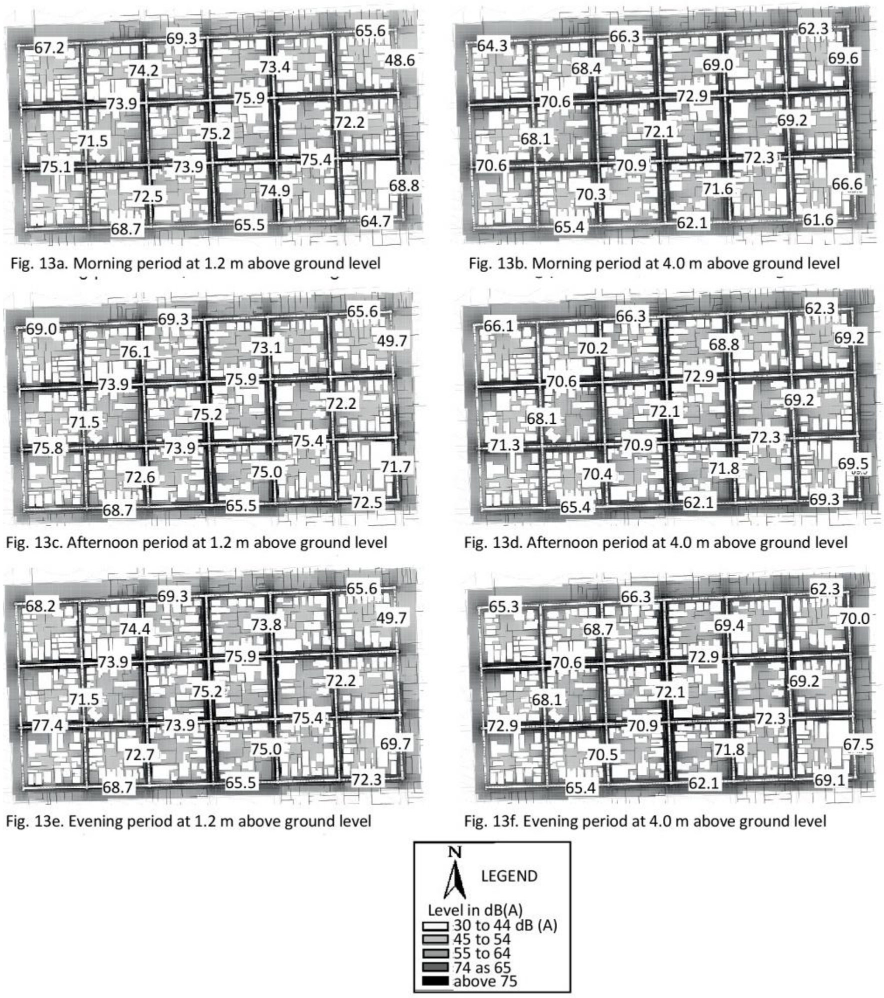

Fig.3.13. Noise maps for the future scenario in mornings, afternoons and evenings at 1.2 and 4 meters above ground level.

4 Discussions and Conclusions

In general, the noise levels reached higher measured values in the canyons than those recommended by technical standards; hence, the results show that pedestrians are subjected to excessive noise levels in the study area. In addition, the topography of the study area exhibited a significant influence on the noise generated by vehicles, revealing that the direction of vehicular flows uphill may cause levels 10 dB (A) greater compared to downhill conditions. Nevertheless, because the study area was only a small part of the city, it is important that a more extended approach is followed in future research to guarantee a more comprehensive study.

There are many aspects inherent to urban noises that are related to the building surroundings that must be identified for an accurate analysis of the urban environment.

With regard to this matter, as proved by the results of our research, noise maps may be a valuable tool. The simulations with CADNA-A applying the French NMPB-Routes 98 method demonstrate significant adequacy for this kind of research, enabling the development of acoustical maps and serving as an effective tool for urban planning. The map representation of the noise environment helped in the identification of critical noisy areas and preserved ones. This result corroborates the works of Pinto and Mardones (2009), Arana et al. (2010) and Foraster et al. (2011), who also showed that computational models are helpful in the creation of acoustical maps for planning purposes.

Moreover, the most important finding of our research supported by the acoustical maps is the potential relationship among urban geometry and noise levels. We did not aimed at a statistical analysis, instead, we focused in an exploratory research. Nevertheless, the average FSIhas proved to be a relevant aspect for noise prediction. This index wasan urban geometric factor already studied by Souza and Giunta(2011), and our results corroborate those authors and emphasize that this feature of the urban tissue should not be neglected.

If urban growth is accompanied with the increment of building heights and, consequently, by FSI enlargement, the noise environment is also being modified. This potential is even clearer when simulating the scenarios 1.2 and 4 meters above ground level because the highest average noise levels were related to the highest FSI values.

Taking into account its practical nature, we believe that this parameter could be a reference for the acoustical guides of buildings and urban planning. Thus, because FSI is a typical factor and easily applied by municipalities, planners should be aware of its value as an acoustical environment parameter, assisting in the creation of future scenarios and urban planning decisions. In this way, legal regulations together with urban guidelines should guarantee a healthy sound environment for cities.

These results lead us to believe that the Master Plans should incorporate specific acoustical studies because there are areas in the case study for which higher FSI levels were simulated, although the actual present noise levels and future predicted values may deteriorate the acoustical quality of the urban environment.

Acknowledgments

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References

Arana M, San Martin R, San Martin ML, Aramendía E (2010) Strategic noise map of a major road carried out with two environmental prediction software packages. Environ Monit Assess 163:503–513

Costa SB, Lourenço RW (2010) Geoprocessing applied to the assessment of environmental noise: a case study in the city of Sorocaba, São Paulo, Brazil. Environ Monit Assess 172(1-4):329-37.

Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002, relating to the assessment and management of environmental noise.Official Journal of the European Communities, L189, 0012–0026

Foraster M, Deltell A, Basagaña X, Medina-Ramón M, Aguilera I, Bouso L, Grau M, Phuleria HC, Rivera M, Slama R, Sunyer J, Targa J, Künzli N (2011) Local determinants of road traffic noise levels versus determinants of air pollution levels in a Mediterranean city.Environ Res 111:177-183

Guedes ICM, Bertoli SB, Zannin PHT (2011) Influence of urban shapes on environmental noise: a case study in Aracaju-Brazil. Sci Total Environ 15(411-413): 66-76

IBGE, Instituto Brasileiro de Geografia e Estatística (2010) Indicadores sociais municipais: uma análise dos resultados do universo do Censo Demográfico (IBGE,Brasil)

Picaut J, Polle`s TLE, Lõhermite P, Gary V (2005) Experimental study of sound propagation in a street. ApplAcoust 66:149-173

Pinto FANC, Mardones MDM (2009) Noise mapping of densely populated neighborhoods – example of Copacabana, Rio de Janeiro – Brazil. Environ Monit Assess155:309-318

Souza LCL, Giunta MB (2011) Urban indices as environmental noise indicators. Comp Environ Urban Syst 35(5):421-430

Wang B, Kang J (2011) Effects of urban morphology on the traffic noise distribution through noise mapping: A comparative study between UK and China. ApplAcoust 72 (8):556–568