IMPACT OF TRAFFIC-RELATED ENVIRONMENTAL NOISE ON SCHOOL CHILDREN AND TEACHERS IN A NORTHEAST BRAZILIAN CAPITAL

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Abstract

Environmental noise in urban areas is known to cause functional abnormalities reflected in human health and behavior. In developing countries such as Brazil, public schools are exposed to high levels of noise due in part to poor infrastructure, especially with regard to noise protection. In schools exposed to noise levels above the limits specified by regulations and international guidelines, students and teachers are at greater risk of health problems, and performance may be compromised. In this study we evaluated the impact of environmental noise on children and teachers at three public schools (a kindergarten, an elementary school and a high school) in a Northeast Brazilian metropolis, with emphasis on noise generated by street, metro and air traffic. Environmental noise maps were generated with software and teachers were administered questionnaires focusing on the impact of noise pollution on health and performance. The study was intended to subsidize efforts at urban planning and public policy making by measuring actual noise levels and probing their possible effects. As shown by our results, public schools are in urgent need of noise protection measures, and enforcement of noise emission regulations for public transportation needs to be more emphatic.

Key words: Noise pollution. Noise mapping. Noise assessment. Noise limits. Noise in schools.

Résumé

Les bruits environnementaux dans les zones urbaines sont connus pour provoquer des anomalies fonctionnelles, reflétées dans le comportement et la santé humaine. Dans les pays en développement tels que le Brésil, les écoles publiques sont exposées à des niveaux de bruit élevés à cause des mauvaises infrastructures, en particulier dans le domaine de la protection contre le bruit. Dans les écoles, exposées à des niveaux de bruit au-dessus des limites fixées par les normes et directives internationales, les étudiants et les enseignants sont à risque plus élevé de problèmes de santé et leur performance peut être compromise. Dans la présente recherche, nous avons évalué l'impact du bruit environnemental sur les enfants et les enseignants dans trois écoles publiques (une école maternelle, une école primaire et une école secondaire) dans une métropole brésilienne dans le Nord-Est, à savoir : Fortaleza, en mettant focus sur le bruit généré par le transport routier, le métro et le transport aérien, qui sont importants générateurs des bruits dans les centres urbains. Les cartes de bruit environnemental ont été générées avec le logiciel et pour les enseignants qui ont répondu des questionnaires visant l'impact de la pollution sonore sur la santé et sur les résultats des élèves. Cette recherche visait à soutenir les efforts de la planification urbaine et de politiques publiques, à travers d'une mesure réel des niveaux de bruit et leurs effets possibles de sondage. Les résultats démontrent la nécessité d'adopter des mesures de traitement acoustique des milieux scolaires ainsi que celles de la réglementation et de la supervision du fonctionnement des véhicules de différents modes des transports.

Mots clés: pollution sonore, cartographie acoustique, évaluation du bruit, les limites de bruit, bruit dans les écoles.

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1 Introduction

Public schools in developing countries such as Brazil are often strongly impacted by environmental noise associated with heavy traffic and the absence of proper noise protection due to insufficient investments in infrastructure. In this study we looked at the impact of environmental noise on school children and teachers in Fortaleza, a state capital in Northeastern Brazil. To do so, we assessed the acoustic characteristics of three public schools exposed to environmental noise generated primarily by street, metro and air traffic.

According to WHO guidelines (Berglund et al., 1999) [1], noise is the second-most important source of pollution worldwide, and noise levels over 70 dB† can cause illness. While noise is generally defined as an undesirable sound, perception varies from one individual to another, depending on interest: a sound perceived as attractive by one individual may be intolerable to others [2]. Environmental noise is known to cause functional abnormalities reflected in physical and behavioral health. Powaska et al. [3] have shown that high noise levels cause the organism to release adrenaline into the blood stream, associated with changes in heart rate and blood pressure. According to Berardi and Ramakrishnan [4] "Sound represents one of the most valid and often underestimated ways to experience a space. The acoustics of heritage buildings is often crucial".

The WHO [1] has concluded that noise pollution can affect the health and academic performance of children and adolescents. In fact, school children constitute a particularly vulnerable group. Noise levels over 80 dB are believed to increase aggressiveness and withdrawal in children. According to the same report, exposure to undesired sounds increase listening and reading difficulties, attentional dispersion and irritability among students, compromising communication. Average noise levels in classrooms should not exceed 35-40 dB. Levels between 50 and 65 dB, though acceptable, can induce mild stress which may develop into loudness discomfort, hypervigilance and anxiety over time [4]. Asuquo et al. [5] alerts for noise-induced hearing loss due to exposure to loud noise. They state also that "Noise is a disturbance to the human environment that is escalating at such a high rate that it will become a major threat to the quality of human lives if nothing is done to reduce it".

High noise levels can also lead to the development of occupational voice disorders and is one of the main causes work-related diseases [6]. As shown by Oliveira [7], noise in the work environment is an important source of health problems among school teachers. The negative effects of noise pollution include cognitive fatigue, memory loss, loss of ability to perform complex tasks, irritation, tension, headache and occupational dissatisfaction. Fiorini and Matos [8] compared health complaints and discomfort reported by teachers from two public schools, one located in a relatively quiet neighborhood where noise was mostly produced by the students, and one located downtown where noise was primarily external to the school. The teachers of both schools reported working in a noisy environment, but voice disorders were less frequent in the first school (44.4%) than in the second (50%).

To reduce the negative effects of noise pollution on the well-being of the population and on public spending, the problem must be clearly defined based on information collected in real-life scenarios. The purpose of the present study was to evaluate the impact of primarily traffic-related environmental noise on school children at different ages. It is hoped our findings will serve as subsidy for urban planners, encourage greater allocation of public funds to noise protection measures (especially in schools) and highlight the need for controlling noise emissions by vehicles and monitoring health deficits associated with noise pollution.

2 Noise from urban traffic

Calixto [9], Gilbert [10], Griffiths [11] and Langdon [12], among many others, have identified traffic as the main source of noise pollution in the urban setting. The pollution results from a blend of multiple sounds generated by cars, trucks, motorcycles, buses, trains and airplanes at different speeds and rates of acceleration. Toronto Public Health [13] points out some evidences relating the incidence of heart diseases among people disturbed by road or air traffic noise.

Land vehicles (especially cars and buses) are the most common form of commuting in cities, resulting in an intensive traffic flow and an increasingly congested street network. Some large cities also have a metro service running underground or at ground level. In the latter case, it constitutes a major source of noise pollution. Many Brazilian cities have grown in disorderly fashion, with almost no urban planning, generating an array of environmental problems, including noise pollution.

Relster‡ concluded that seeking psychological care, using tranquilizers and receiving treatment at psychiatric facilities were significantly more likely among residents of noisy neighborhoods than residents of quiet areas in Copenhagen. Formal complaints also become more numerous as noise levels rise. Fyhri and Aasvang [15] models produced results that lead to similar conclusions for the city of Oslo. Thus, a study conducted by the Civil Aviation Institute [16] in Rio de Janeiro proposed cut-off values predictive of complaints from communities exposed to different noise levels (Table 1).

In a study on teacher-student communication, Oliveira Nunes and Sattler [17] evaluated the interruptive effect of periodical flyovers. All the interviewed teachers reported being seriously annoyed by the noise and having to raise their voice in the classroom. Likewise, 79% of the

† In this study A-weighted sound levels were adopted in order to evaluate the Leq values.

‡ E. RELSTER 1975 Trafic Noise Annoyance: the Psychological Effect of Trafic Noise in Housing Areas. Polyteknik Forlag, Lyngby. *apud* [14]

students reported having to raise their voice during flyovers, and 72% experienced difficulties understanding the teacher. The teachers agreed the noise had a negative influence on student performance.

Table 1: Noise levels and expected reactions.

Level	Reaction
≤53 dB	No reaction expected
53- 60 dB	Moderately noisy environment. Many complaints expected.
>60 dB	Extremely noisy environment. Complaints expected from nearly all residents. Community action expected.

Source: IAC [16]

Based on 149 measurements, Alves Filho [18] found Brazilian vehicles to emit louder sounds than British vehicles, as measured by Crompton and Gilbert [19]. The deleterious effects of environmental noise on the health and behavior of urban populations are conceivably more relevant in Brazil than in Europe and the US, highlighting the importance of the present study.

3 Methods

Three public schools (a kindergarten, an elementary school and a high school) were selected for a case study, covering children and adolescents between 3 and 18 years of age. The facilities were located in areas with different environmental noise profiles.

The international airport of Fortaleza (Pinto Martins) is located in the geometrical center of the metropolis, with the runway oriented along an east-west axis. The adjacent areas are subject to special municipal by-laws of occupation and noise protection, but this is not always complied with. In addition, most of the metro track (which runs north-south) is at ground level or elevated, producing a considerable acoustic impact on the immediate surroundings.

Figure 1 shows the location of the three schools, the metro tracks and the airport approach/departure corridor. The streets in the vicinity of the schools were classified as local, collector, arterial or highway, in accordance with the terminology employed by the law instituting the city's master plan [20].

- School #1 is for children aged 3-9 years. It is located in a quiet residential neighborhood, surrounded by local streets with low traffic flow (Figure 2).
- School #2 is attended by students aged 11-15 years. It is located in an area strongly impacted by street, metro and air traffic, along an airport approach corridor (flyovers at 200 m altitude). The building abuts on an arterial with medium traffic flow. The external wall behind the building is a few meters away from the metro track (Figures 3 to 6).
- School #3, the largest of the three schools, is attended by adolescents aged 11-18 years. It is located on an urban highway with intense traffic flow, along the airport departure corridor, though a little farther removed from the airport than School #2 (Figures 7 to 9).

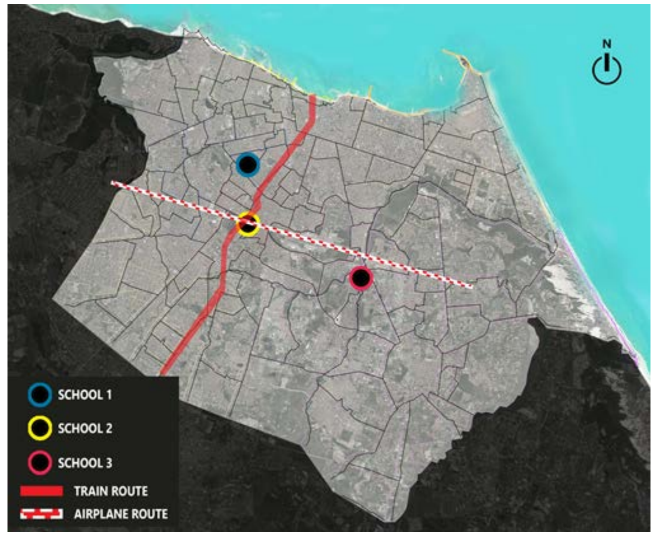

Figure 1: Map of Fortaleza showing the location of the three schools, the metro track (solid red line) and the airport approach/departure corridor (red/white dotted line).

Figure 2: External view of School #1.

Figure 3: External front view of School #2.

Figure 4: External back view of School #2. Note the proximity to the metro tracks.

Figure 5: View from school #2

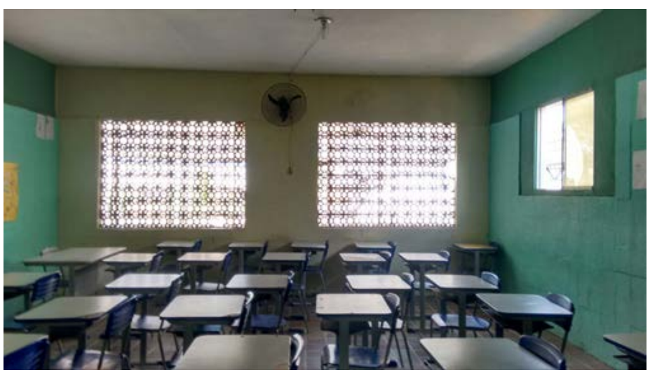

Figure 6: Classroom in School #2. Note the windows/vents.

Figure 7: External front view of School #3.

Figure 8: Another external view of School #3, left of the highway.

Figure 9: Noise measurement equipment deployed in a classroom in School #3.

Urban legislation

The WHO [1] recommends an external noise limit of 55 dB for playgrounds and schools, but according to Maschke [21], a limit of 65 dB is more realistic in densely urbanized areas. Canadian environmental noise guidelines [22] establish a limit of 50 dB for Class 1 areas (urban centers with mostly street traffic-related environmental noise) between 7 am and 11 pm, and 55 dB for outdoor living areas with greater exposure to external noise.

In Fortaleza, Law #8097 [23] specifies a limit of 55 dB (daytime) or 50 dB (nighttime) for noise emitted by machines, engines, compressors and stationary generators. For other types of noise (e.g., loudspeakers), 70 dB (daytime) or 60 dB (nighttime) is permitted. Vehicle noise emissions are regulated by federal law. Brazilian noise level regulations [24] are based on zoning criteria. Thus, School #1 is located in a zone classified as "mixed but predominantly residential", while Schools #2 and #3 are located in "mixed areas (residential and commercial) with commercial and administrative vocation" (Table 2).

Noise maps

The noise level was modeled and predicted using noise maps, as described by Garavelli et al. [25], Costa *et al.* [26], Guedes [27] and Souza Filho *et al.* [28], among others. Noise maps were produced with the software package Computer-Aided Noise Abatement (CadnaA) [29] displaying sound levels at 5 dB intervals, with color coding according to international standards [22]. They were subsequently validated by on-site measurements. The maps allowed to conduct individual and multiple analyses of the impacts of each noise source (street traffic, metro traffic, industry and other linear and punctual emissions).

Table 2: Criteria for maximum acceptable noise levels in external environments, according to NBR 10151/2000.

Environment	Daytime (dB)	Night (dB)	School
Country houses and farms	40	35	
Strictly urban areas, hospitals, schools	50	45	
Mixed, predominantly residential	55	50	#1
Mixed, commercial and administrative vocation	60	55	#2 #3
Mixed, recreative vocation	65	55	
Predominantly industrial	70	60	

Basemap and landscape

Each of the selected schools was localized within a 400 m x 400 m block on the 2010 basemap of Fortaleza, and information on the immediate surroundings was gathered, including the height of buildings and major noise sources. The landscape was subsequently corrected and updated based on Google street views (2016). Perforated/porous surfaces (e.g., vents, windows, perforated bricks) were considered void (classrooms in public schools have permanently open vents or windows due to high temperatures and lack of air conditioning).

Street traffic flow

To collect information on street traffic flow we adopted the methodology used by the authors of the Acoustic Map of Fortaleza [30]. Traffic flow was quantified on weekdays between 9 and 10:30 am and between 2 and 4 pm, coinciding with school hours, during the first term of 2017, by counting circulating motorcycles, cars, trucks and buses for 15 minutes. Hourly traffic flow was then estimated by multiplying the number of observed vehicles by 4. The vehicles were classified according to weight: light (motorcycles, cars, pick-ups, minivans) and heavy (trucks and buses). The street classification was updated according to the observed traffic flow (Table 3).

Air traffic flow

Information on the number of commercial airliners flying over School #2 during the study period (Table 4) was retrieved from the database of the government agency operating the airport [31]. At Schools #2 and #3, air traffic-related noise was recorded according to frequency range and expressed in LAeq (mean frequency for the sampling period) using a sound meter (DEC 5030 Class 2, Instrutherm, Brazil). The temperature was 30-31ºC and the air velocity was ~2 m/s.

Table 3: Street traffic flow outside the three schools.

Number of vehicles circulating in 15 min			
	Motorcycles	Cars	Trucks
School #1	17	41	1
School #2	163	308	53
School #3	505	1656	115
Number of vehicles in the period			
	Type of street	light vehicles	heavy vehicles
School #1	Collector	231	2.32%
School #2	Arterial	1871	12.3%
School #3	Highway	8604	5.82%

Table 4: Average number of flights at the international airport of Fortaleza (Pinto Martins)

Period	**n**
6 am to 9 am	5
9 am to 12 am	20.6
12 am to 3 pm	36
3 pm to 6 pm	9.8
6 pm to 9 pm	13.4
9 pm to 12 pm	25
12 pm to 6 am	9

Source: INFRAERO [31]

Metro traffic flow

Information on the flow of the north-south metro line (most of which is at or above gound level) was retrieved from reports provided by the government agency running the service (Metrofor). The 80-m long trains run at 21-min intervals each way between 6:34 am and 8 pm, at up to 70 km/h. Metro traffic-related noise frequency ranges were recorded at School #3.

Data management and software

The collected data was stored in a database generated with the software CadnaA [29]. Several factors interfering with sound propagation were considered, including vegetation, absorption in the atmosphere, reflection and diffraction, in order to quantify attenuation caused by barriers and reflection from opposite surfaces, as recommended by Quartieri *et al.* [32].

The model RLS90 was used in the analysis of hourly vehicle flow. The streets were processed as linear sources divided into segments processed by the program as punctual sources with noise levels in accordance with the characteristics of the traffic and the physical environment. Inputs included street name, width, pavement type, flow direction, and hourly daytime flow of vehicles (volume, composition and speed).

The SRM II model was used in the analysis of metro traffic flow by entering noise levels for frequency ranges between 31.5 and 8000 Hz (Table 5). Inputs included train type (with noise levels predetermined by the program), maximum speed at the study location, hourly flow, wheelset, track structure, and the presence of expansion joints.

Questionnaire and interview

Seven teachers from each school filled out standardized questionnaires containing nine questions focusing on the impact of noise pollution on occupational health and student performance. Subsequently, a short interview was conducted to give the teachers the opportunity to make additional observations relevant to the problem. The interviewees represented 88%, 58% and 55% of the teaching staff at Schools #1, #2 and #3, respectively.

Table 5: Distribution of traffic-related noise measured at Schools #2 and #3 according to frequency range.

			Oktave Spectrum (dB)									
School	Traffic	Time	31.5Hz	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	L
#2	street	fast	13.9	30.8	39.0	38.0	40.0	43.5	43.1	42.5	30.4	64.5
#2	street + air	fast	22.5	36.7	54.7	62.5	65.5	67.3	67.8	63.9	54.3	81.6
#2	street + metro	fast	28.0	47.6	62.7	68.0	65.7	58.7	52.5	45.5	33.5	87.2
#3	street	fast	23.4	39.3	49.6	55.1	52.7	58.1	56.3	50.7	40.4	75.8
#3	street + air	fast	21.3	40.5	48.2	54.4	57.6	59.9	57.8	49.9	39.1	75.8

4 Results and discussion

The results of the study are presented in two sections: analysis of on-site measurements and noise maps, and analysis of the teachers' responses to the questionnaire and interview.

4.1 On-site measurements and noise map analysis

The results of the noise maps were validated by on-site measurements (Table 6). At each sampling point, 10 measurements were taken at 30-s intervals. The LAeq values were calculated using Equation 1 (from a handbook on measurement and calculation of acoustic fields issued by a program for the recovery of learning environments sponsored by the University of São Paulo [33]):

$$LAeq = 0.01(L90 - L10)^2 + 0.5(L90 + L10) \quad (1)$$

Table 6: Comparison between noise levels modeled with the software CadnaA and on-site measurements.

Traffic		School #1	School #2		School #3
			Front	Back	
Street	External	62.6	67.8	59.1	67.2
	CadnaA	64.0	68.0	59.0	70.0
Metro	External		71.3	73.1	
	CadnaA		71.0	71.0	
Air	External		67.2	69.3	
	CadnaA		70.0	74.0	

The Brazilian legislation provides no guidelines for this type of measurement. We therefore adopted the criterion of the Portuguese Environmental Agency, according to which a difference of up to +/- 2 dB between simulated and measured values is acceptable [34]. Silva [35] points out that more flexible criteria (up to +/- 4 dB) may be used in urban settings. The points on the noise map selected for validation were those providing technically adequate measurement conditions. The data obtained on calibration confirmed the values obtained with the noise map modeling.

The street noise map for School #1 (Figure 10) indicates low traffic flow and quiet surroundings, especially inside the blocks. Noise levels were 60-64 dB on local streets and up to 73.7 dB on the nearest collector. According to Brazilian regulations, the average noise level of "mixed, predominantly residential areas" should not exceed 55 dB. The façade of the building was exposed to noise at 64 dB, but behind the building, on the same side as the patio, the level of external noise was only 43 dB. Figure 11 presents the results for this school of a three-dimensional modeling (3D) of the noise levels at the building facade and patio.

Figure 12A is a street noise map for School #2, showing a noise level of 75 dB in front of the building (facing an arterial) and 62 dB behind the building (facing a local street, and closer to the elevated metro tracks). Figure 12B shows the combined effect of street and metro traffic-related noise (front=76 dB, back=71 dB). Figure 12C combines all three sources of traffic-related noise (front=79.8 dB, back=74 dB). The frequency of metro runs (interval=21 min, each way) and commercial flights (interval=12 min) was confirmed by on-site observation.

A broader view of School #2 area and the noise impacts of street traffic are presented in Figure 13. These effects only are well above the legal limits. During flyovers and metro passings, noise levels in the most exposed classrooms peaked at 76.4 dB and 80 dB, respectively, on the side facing the arterial, and 78.9 dB and 83.1 dB, respectively, on the side facing the tracks. These levels are well above the ideal (≤45 dB) and acceptable (≤65 dB) levels recommended by Thiery and Meyer [36] for classrooms. The 3D modeling of the noise impacts on School #2 facade and patios is presented in Figure 14.

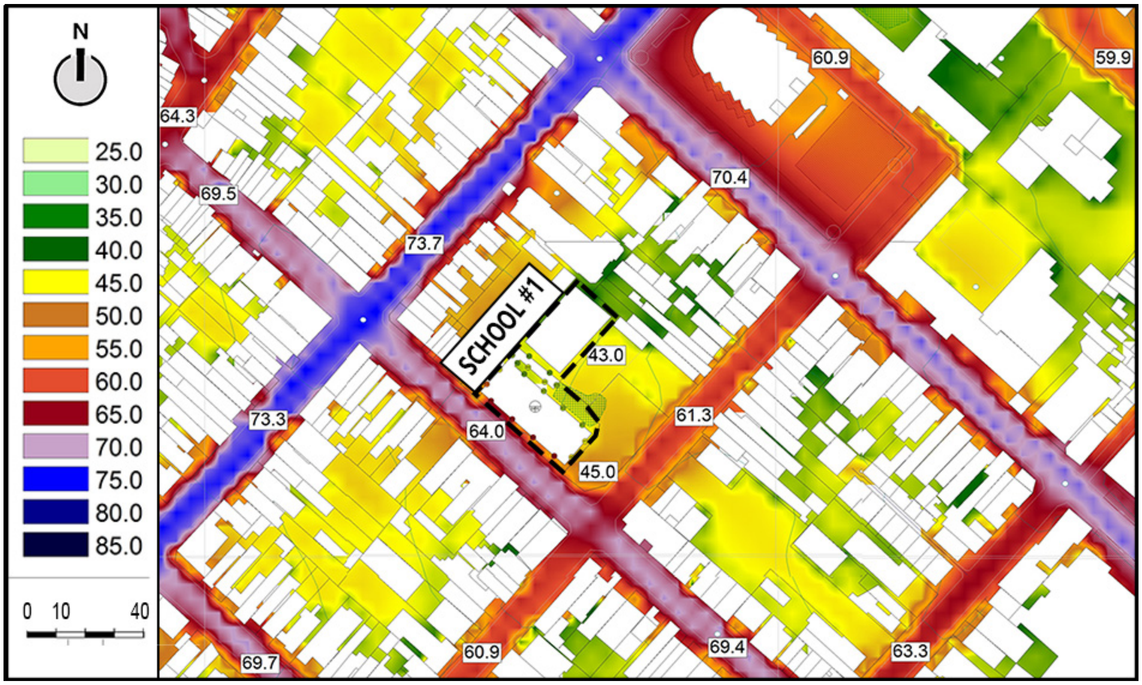

Figure 10: Street noise map of area surrounding School #1.

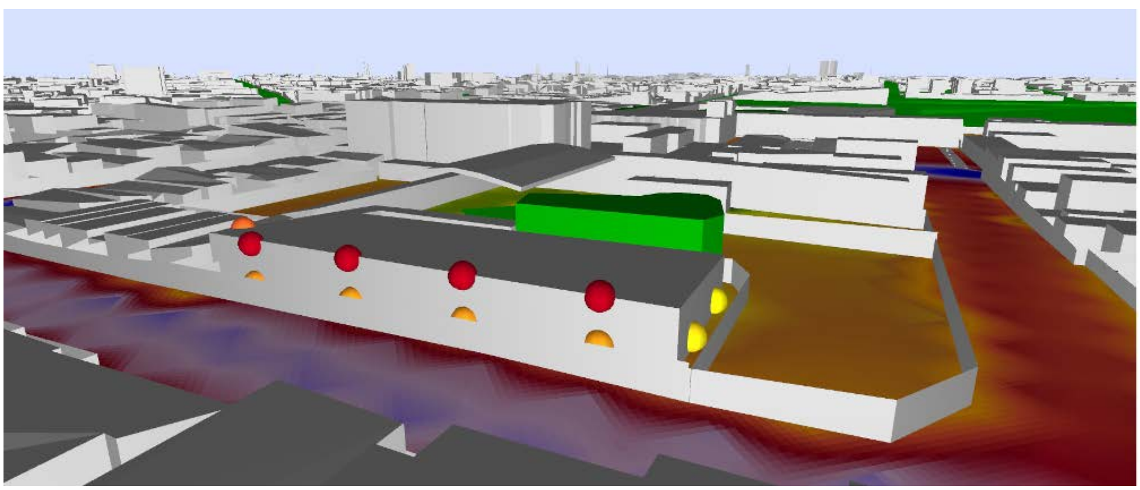

Figure 11: 3D modeling of street traffic noise for School #1

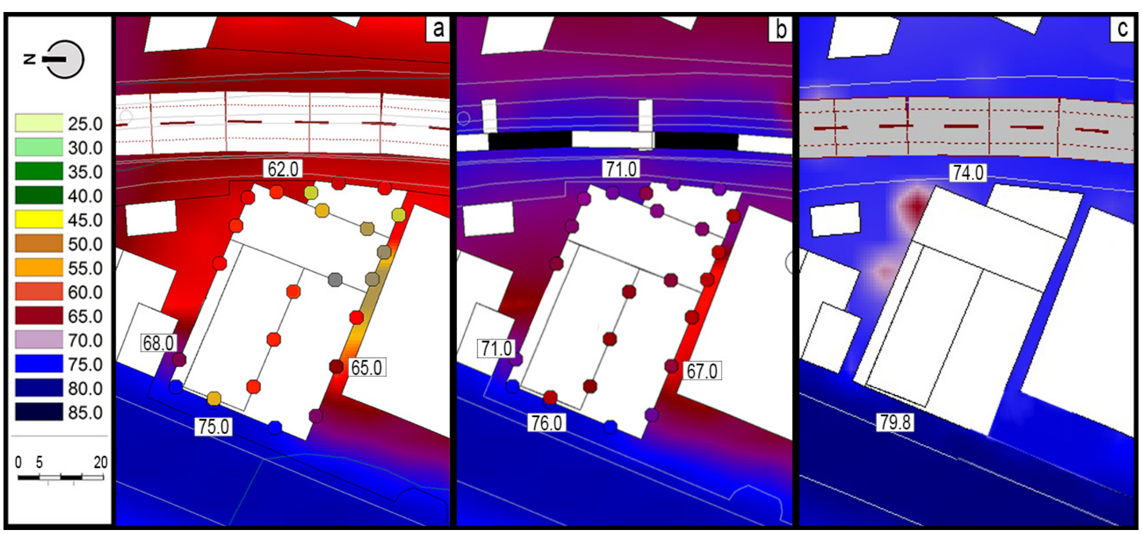

Figure 12: Interference of traffic-related noise at School #2. A: street traffic, B: street + metro traffic, C: street + metro + air traffic.

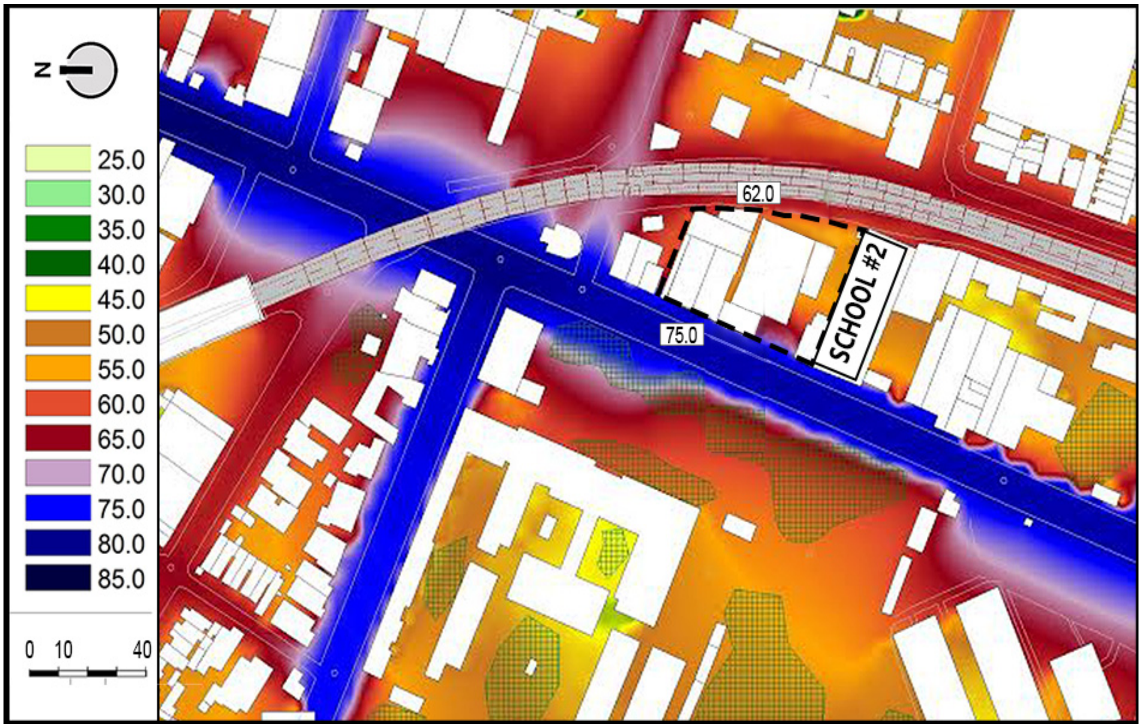

Figure 13: Street noise map of area surrounding School #2.

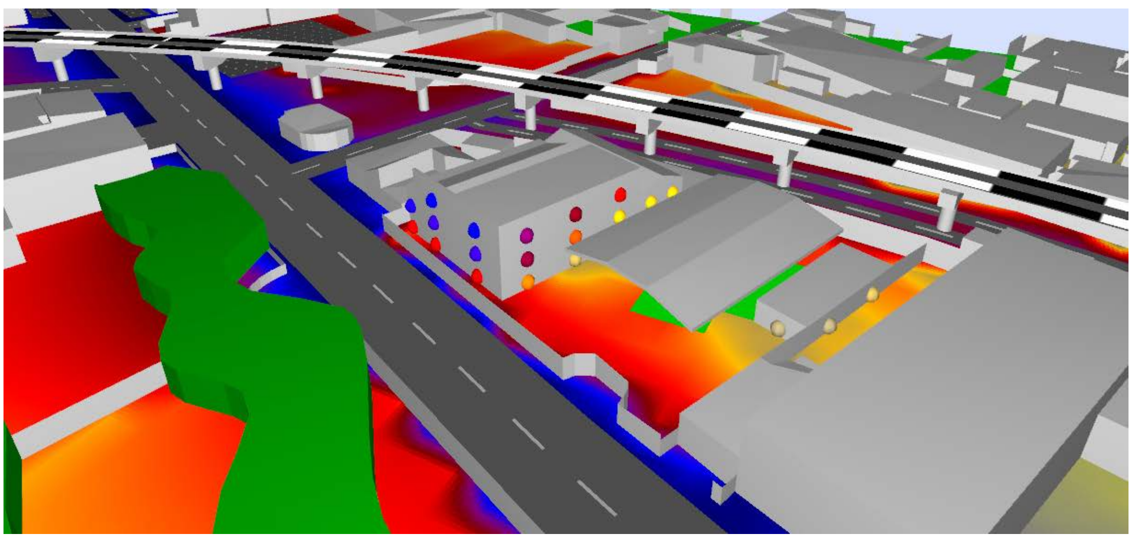

Figure 14: 3D modeling of street traffic noise for School #2

On the highway outside School #3, noise levels reached 83.5 dB. Due to the absence of acoustic barriers, the school façade was impacted at 70 dB. Inside the building, on the side facing the highway, the level was 67.8 dB, the highest value observed in the study when considering street traffic alone (Figure 15).. Both School #2 and #3 are located in zones classified as "mixed areas with commercial and administrative vocation", for which regulations specify an external noise limit of 60 dB. The WHO has concluded that undesirable sounds, such as noise generated by passing trains and airplanes, compromise the intelligibility of oral communication, with negative impacts on concentration, attention and well-being.

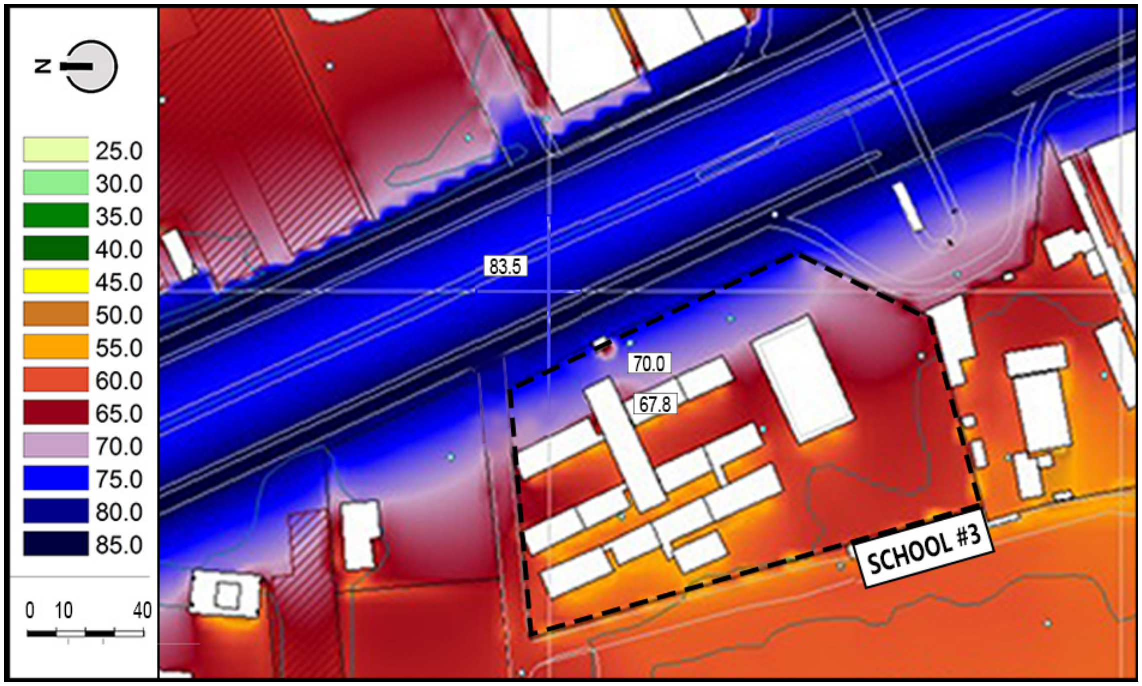

Figure 15: Street noise map of area surrounding School #3.

4.2 Analysis of questionnaires and interviews

School #2 was the oldest in the sample. Not surprisingly, the average time of employment of the teachers at this school (6.1 years) was longer than at School #1 (4.2 years) or School #3 (1.9 years) (Figure 16). Most teachers considered the work environment very or extremely noisy, with no significant difference between the schools (Figure 17).

The responses to Question #3 (Figure 18) revealed that the impact of external noise was much smaller at School #1 than at School #2 or School #3. Since all three schools were exposed to high noise levels, it follows that the noise perceived by the teachers at School #1 was from internal, non-traffic-related sources. School #1 is for children aged 3-9 years, and space is very limited. In fact, all teachers at School #1 observed a very significant difference in student behavior between classrooms facing the patio (higher noise level) and classrooms facing the street (lower noise level). The internal noise was generated by student activities during breaks. The teachers reported frequent problems with distraction, agitation and loss of concentration during classes, making it necessary to raise the voice.

School #2 was impacted by all three forms of traffic. Over half the teachers considered the noise from street and metro traffic very or extremely annoying, but only 20% were annoyed by noise from airplanes. This is supported by the finding that peak noise values were higher for metro traffic than for air traffic.

In School #3, over 80% of the teachers attributed high or extreme relevance to noise from buses, cars, trucks and, above all, motorcycles. Our measurements did not show high levels of air traffic noise, but some of the teachers reported being annoyed by it (Figure 19).

Over half the teachers at School #2 had not observed relevant differences in student behavior between classrooms with high and low noise levels (Figures 19 and 20). According to some, differences in behavior were primarily associated with socioeconomic background and immaturity. In contrast, at School #3, where students are over 15 years old (thus more mature), over half the teachers reported a big or extreme difference in behavior between classrooms with high and low noise levels.

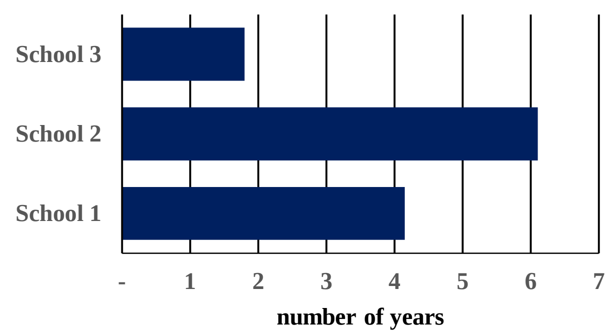

Figure 16: How long have you worked at this school?

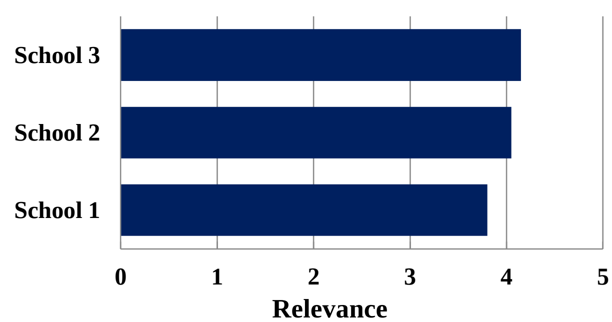

Figure 17: How relevant is noise in the workplace?

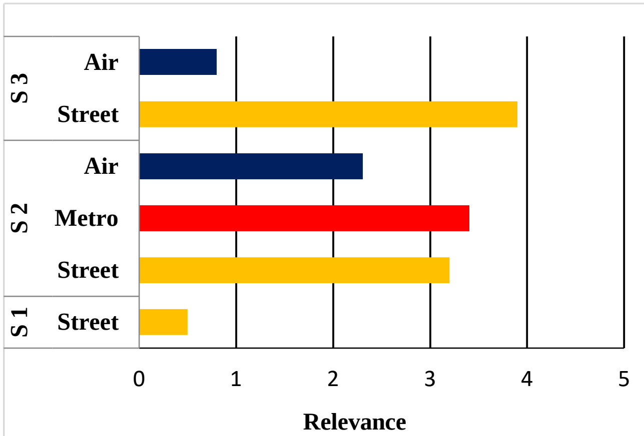

Figure 18: How relevant is external, traffic-related noise?

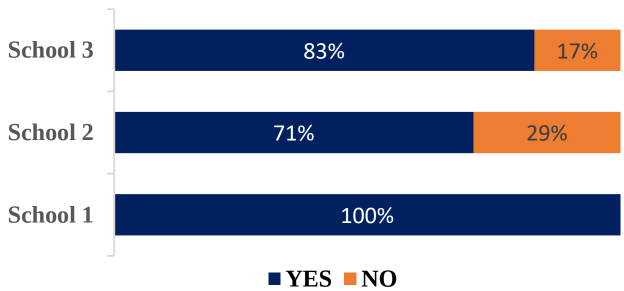

Figure 19: Do you perceive any difference in student behavior between classrooms with high and low noise levels?

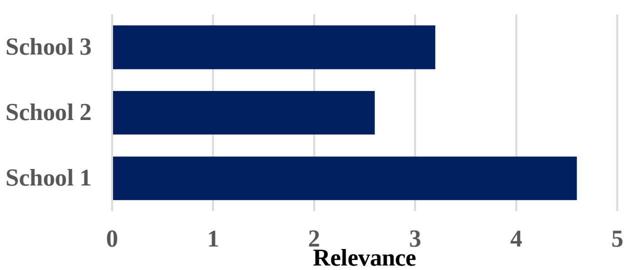

Figure 20: What is the relevance of this difference?

In addition to loss of concentration associated with traffic noise, the students also suffered from visual distraction (Figures 21 and 23): the street was visible through the open window/vent, which served as a source of light and ventilation due to high daytime temperatures and the prohibitive cost of air conditioning. Unsurprisingly, the students farthest removed from the blackboard had greater difficulties understanding the teacher. To mitigate this difficulty and prevent vocal fold injury, some teachers resorted to using microphones during class.

The questionnaire included items about health problems associated with high noise levels in the work environment (Figures 12 and 24). Problems such as hoarseness, sore throat, stress and hearing loss were reported by all teachers at School #1, and by some of the teachers at the other two schools. Two teachers at School #1 were receiving treatment for vocal fold injury.

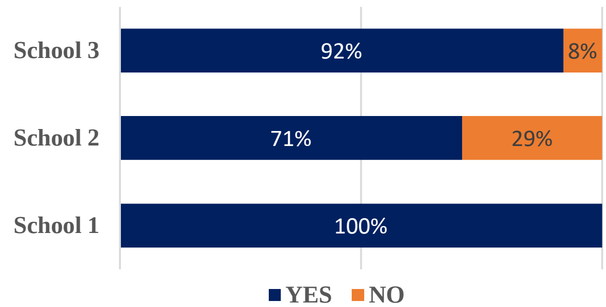

Figure 21: Is teaching more difficult in noisy classrooms?

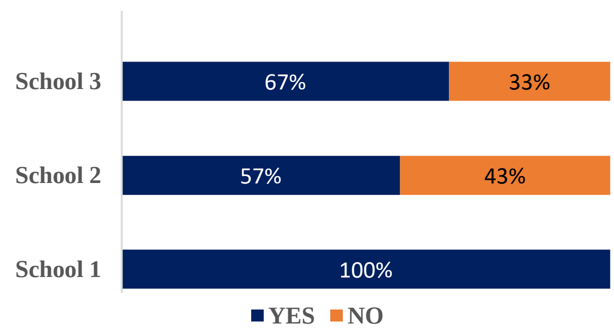

Figura 22: How you observed any health problems associated with noise in the workplace?

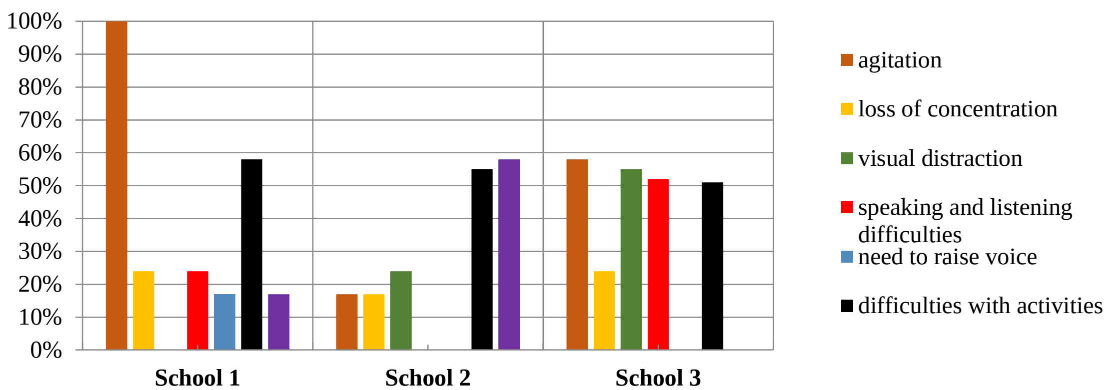

Figure 23: What are the teaching difficulties?

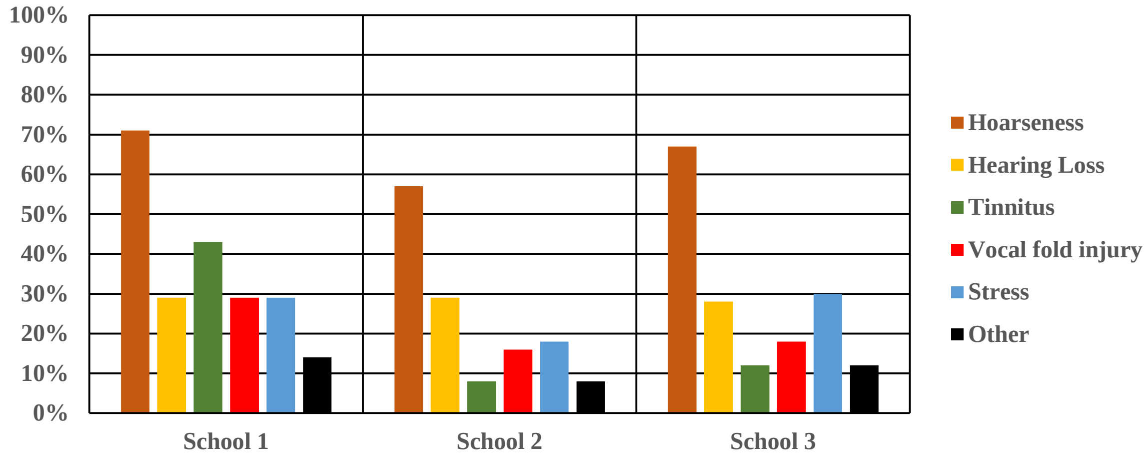

Figure 24: What noise-related health problems have you observed?

5 Conclusion

In this study we found three public schools in Fortaleza to be highly impacted by traffic-related noise pollution. The observed noise levels were above the maximum limits allowed by national and international legislation, as shown by the noise maps produced.

The limits were exceeded even at School #1, which is located in a relatively quiet neighborhood. In this case, the noise was from internal rather than external sources, due to questions of architecture and grade (age). The most severe impacts were observed at School #2, which was exposed to intense noise pollution from street, metro and air traffic. School #3 was mostly affected by noise from street traffic, but noise levels were higher than at the other schools due to the intense highway flow and the absence of acoustic barriers.

The teachers' responses to the questionnaire revealed the existence of health problems, such as hoarseness, stress and vocal fold injury, attributable to noise pollution in the work place. The students displayed noise-related behavior changes, including agitation, learning difficulties, loss of concentration and visual distraction during classes, potentially compromising academic performance.

Our results highlight the importance of implementing stricter public policies for protecting school children against environmental noise pollution. To do so efficiently, urban development plans and regulations should be carefully revised, and more funds should be allocated to endow urban infrastructure and public schools with acoustic protection. The problems identified in this study may also be mitigated by stronger enforcement of noise emission regulations for public transportation, a major source of environmental noise pollution.

Public schools play a crucial role in emerging economies like Brazil. However, many schools lack adequate physical infrastructure and protection. The children and adolescents attending such schools are highly vulnerable, biologically and psychologically, to the noise-related health problems observed in this study.

References

[1] Berglund B, Lindvall T, Schwela DH. Guidelines for community noise. Geneva: World Health Organization; 1999.
[2] Azevedo AP de M de. Efeito de produtos químicos e ruído na gênese da perda auditiva ocupacional [Dissertação de Mestrado]. [Rio de Janeiro]: Fundação Oswaldo Cruz; 2004.
[3] Powazka E, Pawlas K, Zahorska-Markiewicz B, Zejda JE. A cross-sectional study of occupational noise exposure and blood pressure in steelworkers. Noise and Health. 2002 Oct 1;5(17):15.
[4] Berardi U, Ramakrishnan R. The Acoustic Research in the Department of Architectural Science Ryerson University. Canadian Acoustics. 2016;44(2):12–13.
[5] Asuquo U, Onuu M, Asuquo A. Effects of exposure to loud noise on the hearing of the residents of calabar, nigeria. Canadian Acoustics. 2012;40(3):48–49.
[6] Angelo KLH, Zannin PHT. Sound Pressure Levels measured in Fitness Gyms in Brazil. Canadian Acoustics. 2015;43(4):19–23.
[7] Oliveira TCM de. Relações das condições de trabalho, qualidade de vida e percepção da voz em professores do ensino médio da rede municipal de Belo Horizonte. 2005 Mar 29 [cited 2017 Jul 8]; Available from: http://tede2.pucsp.br/tede/handle/handle/12071
[8] Fiorini AC, Matos EC. Ruído na escola: queixas de saúde e o incômodo em professores do ensino público. Distúrbios da Comunicação. 2009;21(2).
[9] Calixto A. O ruído gerado pelo tráfego de veículos em "rodovias-grandes avenidas" situadas dentro do perímetro urbano de Curitiba, analisado sob parâmetros acústicos objetivos e seu impacto ambiental [Dissertação de Mestrado]. [Curitiba]: Universidade Federal do Paraná; 2002.
[10] Gilbert JD. The problem of noise associated with road traffic. Lecture notes presented at: Intercollegiate M.SC. course in Transports. Imperial College - University College; 1985; London.
[11] Griffiths ID, Langdon FJ. Subjective response to road traffic noise. Journal of Sound and Vibration. 1968 Jul 1;8(1):16–32.
[12] Langdon FJ. Noise nuisance caused by road traffic in residential areas: Part I. Journal of Sound and Vibration. 1976 Jul 22;47(2):243–63.
[13] Toronto Public Health. Health effects of noise. Toronto: City of Toronto; 2000. 24 p.
[14] Öhrström E. Psycho-social effects of traffic noise exposure. Journal of Sound and Vibration. 1991;151(3):513–517.
[15] Fyhri A, Aasvang GM. Noise, sleep and poor health: Modeling the relationship between road traffic noise and

cardiovascular problems. Science of The Total Environment. 2010 Oct 1;408(21):4935–42.
[16] IAC. Métodos de avaliação dos níveis de ruído e de incômodo gerados pela operação de aeronaves em aeroportos. Rio de Janeiro: Instituto de Aviação Civil; 1981 p. 107. Report No.: IAC 4102-0581.
[17] Oliveira Nunes MF de, Sattler MA. Percepção do ruído aeronáutico em escolas da zona I do PEZR do Aeroporto Internacional Salgado Filho. Engevista. 2010;6(3).
[18] Alves Filho JM. Influência da composição do tráfego sobre o ruído gerado por rodovias [Dissertação de Mestrado]. [Florianópolis]: Universidade Federal de Santa Catarina; 1997.
[19] Crompton DH, Gilbert JD. The predictive bases used to determine environmental capacities. Lecture notes presented at: Intercollegiate M.SC. course in Transports. Imperial College - University College; 1985; London.
[20] Prefeitura Municipal de Fortaleza. Lei Complementar N^{o}. 062, de 02 de fevereiro de 2009. Institui o Plano Diretor Participativo do Município de Fortaleza e dá outras providências. 2009.
[21] Maschke C, Hecht K, Balzer H. Preventative medical limits for chronic traffic noise exposure. The Journal of the Acoustical Society of America. 1999 Jan 25;105(2):1374–1374.
[22] Ministry of the Environment and Climate Change. Environmental Noise Guideline - Stationary and Transportation Sources - Approval and Planning (NPC-300) [Internet]. 2013 [cited 2017 Aug 16]. Available from: https://www.ontario.ca/page/environmental-noise-guideline-stationary-and-transportation-sources-approval-and-planning
[23] Prefeitura Municipal de Fortaleza. Lei no. 8097 de 02/12/1997. Dispõe sobre medidas de combate à poluição sonora e dá outras providências. 1997.
[24] ABNT. NBR. 10151. Acústica - Avaliação do ruído em áreas habitadas, visando o conforto da comunidade – Procedimento. Associação Brasileira de Normas Técnicas; 2000.
[25] Garavelli SL, Moraes ACM, Nascimento JRR, Nascimento PHDP, Maroja AM. Mapa de Ruído como ferramenta de gestão da poluição sonora: estudo de caso de águas claras – DF. In Minho: Universidade do Minho; 2010.
[26] Costa CA, Garavelli SL, Silva EFF, Melo WC, Maroja AM. Barreiras acústicas como medida de mitigação dos ruídos gerados pelo trafego rodoviário: Setor Noroeste, DF. In 2013: ANTP; 2013.
[27] Guedes ICM, Bertoli SR. Mapa acústico como ferramenta de avaliação de ruído de tráfego veicular em Aracaju - Brasil. Pesquisa em Arquitetura e Construção. 2014;5(2):40–51.
[28] Souza Filho JJ de, Steffen JL, Andreasi WA, Zannin PHT. Urban Noise Assessment Based on Noise Mapping and Measurements. Canadian Acoustics. 2015;43(1):3–10.
[29] Datakustik. CADNA Manual V3.4. Greifenberg: Datakustik; 2005.
[30] Brito FAC, Bento Coelho JL. Carta Acústica de Fortaleza [Internet]. 2017 [cited 2017 Aug 16]. Available from: http://cartaacusticadefortaleza.com.br/
[31] INFRAERO aeroportos. Aeroporto Internacional Fortaleza - Pinto Martins [Internet]. 2017 [cited 2017 Aug 16]. Available from: http://www4.infraero.gov.br/aeroportos/aeroporto-internacional-de-fortaleza-pinto-martins/
[32] Quartieri J, Mastorakis NE, Iannone G, Guarnaccia C, D'Ambrosio S, Troisi A, et al. A Review of Traffic Noise Predictive Models. In: Recent advances in applied and theoretical mechanics. Puerto de La Cruz, Tenerife: WSEAS; 2009. p. 72–80.
[33] USP. Manual de Medição e Cálculo das Condições Acústicas. São Paulo: Universidade de São Paulo; 2003.
[34] Guedes M, Leite MJ. Directrizes para elaboração de mapas de ruído. Agência Portuguesa do Ambiente; 2011.
[35] Silva AMC. Mapa de ruído do bairro "Vila Universitária" Bauru, Brasil - Situação de pico [Dissertação de Mestrado]. [Braga]: Universidade do Minho; 2010.
[36] Thiery L, Meyer-Bisch C. Hearing loss due to partly impulsive industrial noise exposure at levels between 87 and 90 dB(A). The Journal of the Acoustical Society of America. 1988 Aug 1;84(2):651–9.