



Noise mapping and acoustic evaluation of different pavement surfaces in the city of Fortaleza, northeast Brazil.

Nara Gabriela de Mesquita Peixoto¹
Universidade de São Paulo (USP)
Rua do Lago, 876 - Butantã, São Paulo-SP-Brazil

Carla Marília Cavalcante Alecrim²
Universidade Federal do Ceará (UFC)
Campus do Pici, Bloco 703, Fortaleza-CE-Brazil

Gleidson Martins Pinheiro³
Laboratório de Desenvolvimento de Software
Av. Treze de Maio, 2081, Benfica, Fortaleza-CE

Paulo Henrique Trombetta Zannin⁴
Universidade Federal do Paraná (UFPR)
Av. Cel. Francisco H. dos Santos, 100 - Jardim das Américas, Curitiba – PR- Brazil

Veronica Teixeira Franco Castelo Branco⁵
Universidade Federal do Ceará (UFC)
Campus do Pici, Bloco 703, Fortaleza-CE-Brazil

Leonardo Marques Monteiro⁶
Universidade de São Paulo (USP)
Rua do Lago, 876 - Butantã, São Paulo-SP-Brazil

ABSTRACT

The Climate Action Plan developed by the city of Fortaleza encouraged public and active mobility. Recent interventions in avenues replaced Asphalt Concrete (AC) surface layers by Interlocking Concrete Pavers (ICP) and Porous Friction Course (PFC). This work aims to evaluate the impact of these infrastructure changes on environmental noise levels. As a case study, 25 measurements on an urban avenue were made on 6 road sections with AC, ICP and PFC. Noise levels were modeled in CADNA-A software and scenarios with different traffic conditions were compared. The results showed that the use of PFC led to a noise attenuation of 3.0 dB in L_{Aeq}

¹ nara.peixoto@usp.br

² cmariliac.civil@gmail.com

³ paulo.zannin@gmail.com

⁴ paulo.zannin@gmail.com

⁵ veronica@det.ufc.br

⁶ leo4mm@usp.br



when compared to AC. Reducing the maximum speed limit from 60 kmph to 50 kmph led to a noise attenuation of 1.2 dB. In the section with ICP, the measured data showed a reduction in speed and traffic flow when compared to other pavement surfaces. Thus, despite the higher tire/road noise caused by ICP, its application on urban roads led to a noise reduction of 1.5 dB. The authors conclude that the application of these alternative pavements surface, when accompanied by traffic calming strategies, can reduce road traffic noise.

1. INTRODUCTION

During COP26, Development Bank of Latin America (CAF) presented climate change vulnerability indices and action plans for several cities in Latin America. The Fortaleza Climate Vulnerability Index, published in 2019, analyzed data from the metropolitan region of Fortaleza (3.6 million inhabitants), in Northeast Brazil. The main risks that are expected to be faced by 2040 were identified and include: temperature increase, prolonged droughts, extreme rainfall and sea level rise (Figure 1). In this context, since 2016, the Fortaleza city government have been establishing agreements with international agencies as CAF, Local Governments for Sustainability/South America (ICLEI) and *Agence Française de Développement*. The Local Climate Action Plan (LCAP) [1] was created within the scope of the Urban- LEDS I Project and following the UN-Habitat principles. The urban mobility axis of the LCAP addresses the reduction of emissions from vehicles circulating through the city, encouraging the use of public transportation, and implementing and improving cycle paths and sidewalks. The main goal of the LCAP is to increase the tourism potential and competitiveness of the city, creating conditions to improve the social and economic development of the population.



Figure 1: Critical Risks for the City of Fortaleza elaborated by Local Climate Action Plan.

Regarding the pavement engineering, some changes in the traditional paving solutions have occurred in the city of Fortaleza. Road interventions, for instance 30 kmph zones, have been designed to improve traffic safety. It generally results in reduction of environmental impacts caused by the traffic, making some areas more pleasant for both residents and pedestrians. In the literature, combining the use of low noise road surfaces and traffic management measures, the overall potential for noise reduction on urban roads maybe from 3.0 to 8.0 dB in L_{Aeq} [2]. The use of two-layer porous asphalt achieved outdoor advantage of 5.0 dB and was related as potential solutions for reducing atmospheric temperatures in heat islands [3,4]. Recent studies in the city of Fortaleza [5,6] analyzed tire-pavement noise in traditional Asphalt Concrete (AC), PFC and ICP using the Controlled Pass-By (CPB) method. PFC offered a reduction in maximum noise levels (L_{Amax}) of up to 5.6 dB compared to AC. ICP offered higher noise levels at same velocities, as mentioned in other studies [7].

The present study aims to evaluate the potential of different pavement engineering solutions on sustainability from noise environmental impact perspective. An avenue in the city is used as a case study. The noise caused by traffic is evaluated using simulated scenarios in CADNA-A software. Strategic noise maps have been made since 2002 in the Fortaleza City Noise Map (FNM). The city was the first Brazilian city to adopt this strategy by a local government and nowadays the continuity of the project is being done in partnership with research projects [8]. FNM project was already used to analyze interventions in transportation systems due to the 2014 World Cup [9]. The maps indicate $L_{Aeq,T}$ as main evaluation parameter for community noise at daytime and nighttime. In the present work, FNM methodology is reviewed and the type of pavements analyzed are validated through 25 measurements in this avenue. The results are compared with thermal and drainage characteristic of the interventions and discussed in accordance with LCAP objectives.

2. METHODS

2.1. Location of study

The present work was carried out on an important avenue in the city of Fortaleza (Brazil). In 2020 a requalification intervention was completed on Desembargador Moreira Avenue, a commercial and administrative urban road. The project aimed to provide safe urban mobility necessary for everyone to circulate, creating a new corridor to induce economic growth. To evaluate noise impact of these intervention, measurements occurred at six points on the following sections of the avenue:

- Orange Section (P1 and P2): AC surface was replaced by ICP; speed limit was reduced from 60 to 40 kmph; insertion of rumble areas and signalization enforcing slow driving (Figures 2 and 3).
- Blue Section (P3): AC surface was maintained; speed limit was reduced from 60 to 50 kmph.
- Green Section (P4, P5 and P6): AC surface was replaced by PFC; speed limit was reduced from 60 to 50 kmph.



Figure 2: Study Areas and Type of Pavement Surfaces.

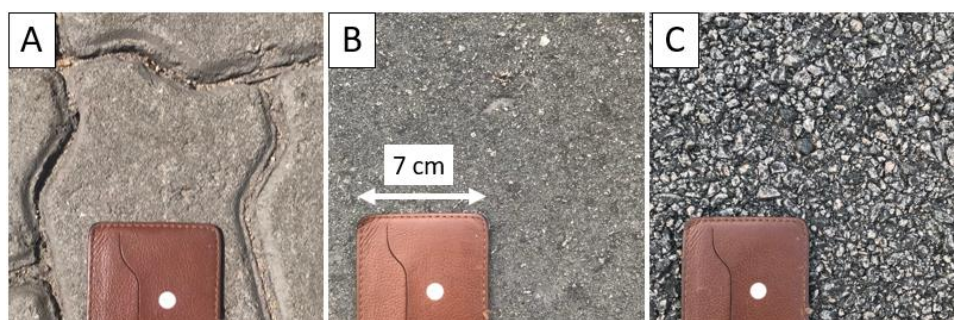


Figure 3: (A) ICP surface in P1 and P2; (B) AC surface in P3; (C) PFC Surface in P4, P5 and P6.

The ICP are concrete blocks with 16 faces (22×11×8cm), compressive strength of 35MPa, laid on a 20 cm compacted base of crushed stone. The material used for interlocking the blocks are medium sand and stone dust compacted over the pieces to finish the execution process. The PFC are asphalt mixtures containing polymer modified binder (PMB) in their composition. The implementation in the urban areas was due to improving resistance and durability.

The position of these six points intended to minimize the heterogeneity boundary conditions of the urban space (Figures 4 and 5). It because the focus of this study is the difference in noise values caused by pavements surfaces. All corners of this regions have traffic lights with the same cycle time. Despite that, point P2, P3 and P6 are near intersections with other avenues with high traffic flow, which influence the green time of traffic light. In these points the influence of acceleration or deceleration was more notable than in the other cases. A camera filmed the traffic to quantify this variable during the measurements and to allow estimation of the average speed of the vehicles by passing through reference points with known distances. To calculate medium velocity, 100 observations of light vehicles passages were sampled for each measurement point. Due to the low traffic at P1 the sample collected consisted only of 56 light vehicles. For the velocity of heavy vehicles, from three to five observations were considered for each point.



Figure 4: Points (A) P1 and (B) P2 with ICP surface.

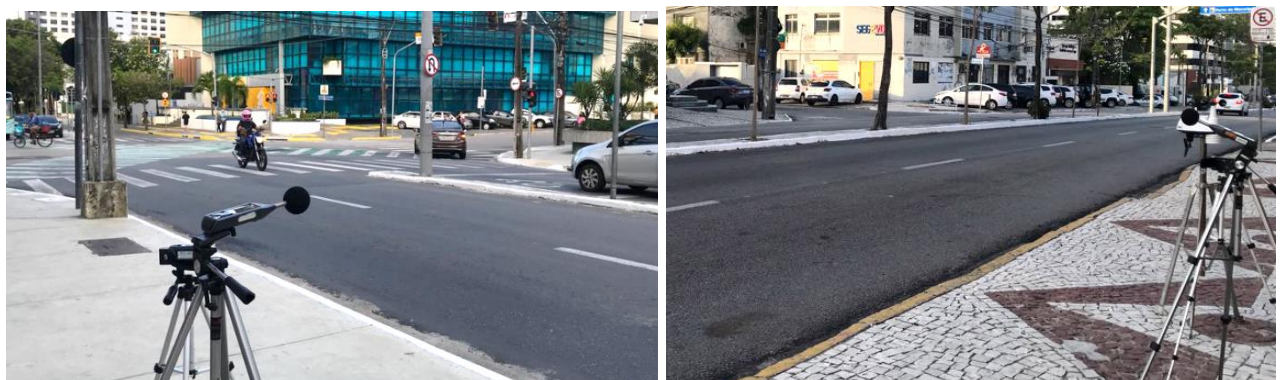


Figure 5: (A) Point P3 with AC surface and (B) point P6 with PFC surface.

The measurements took place in December of 2021 during daytime (14:00 to 17:00), when restriction due to COVID-19 have been decreased. NBR 10151 methodology [10] was followed and a KIMO class 2 sound level meter was used to perform the acoustic measurements, positioned 1.5 m above the ground and at least 2.0 m in radius free from obstacles. Two or three measurements of 10-



minute duration at each point were made. Vehicles were categorized as motorcycles, light (cars, SUVs) and heavy (trucks, buses, and minivans). A Davis Vantage Vue weather station was used to check wind speed and direction (NBR10151 recommends maximum wind speed of 4 m/s).

2.2. Modelling in CADNA-A

The area of study was modeled in CADNA-A software using the RLS-90 predictive model [11]. RLS 90 is a German calculation methodology widely used in Brazilian simulations [12,13]. One of the limitations of this model is to consider the reality of vehicle flow specific for other country. The FNM methodology assumes that 2% of motorcycles are heavy vehicles because in Brazil some motorcycles change the exhaust system causing higher noise levels.

The geometry of the roads and buildings were updated from the government cartography in AutoCAD software. It was the input to modelling on CADNA-A, with the configuration of barriers, buildings, curve lines, roads, and receipt points. The digital terrain model imports the direction and gradient of each road line. The heights of the buildings (H_{build}) were updated through satellite images from Google Earth (2020), defining a height of 3.5m for the first floor and 3m for the others. In the final model, the road width at the measured points varies between 29 m and 34 m, H_{build} vary approximately from 3.5 m to 45 m and the distance of the points at the edge of the road also varied between 1.7 m and 7 m (Figure 6). For calculation, the soil and building facades absorption was defined as zero. The number of reflections caused by parallel walls was defined as 1.

The definition of the road surface was a major question on the simulated tests. RLS90 doesn't refer to Brazilian types of pavements, but typical European pavements. The present study uses the visual inspection technique suggested by the European Good Practices Guide [14]. Configuration followed the CADNA-A manual for the RLS90 model [11], using Smooth mastic asphalt to AC surface, Pavement with a smooth surface for ICP surface and Open-Pore Asphalt to PFC surface (Table 1). D_{stro} parameter vary with type of pavement and vehicle speed. AC road surfaces are widely validated in Fortaleza Noise Map and ICP was validated in some Brazilian cities [13,15].

Table 1: D_{stro} in dB(A) at the maximum permissible speed.

kmph	30	40	50	≥ 60
Smooth mastic asphalt*	0	0	0	0
Pavement with a smooth surface*	2.0	2.5	3.0	3.0
Openpore asphalt*	0	0	0	-3.0
NL02 Cnossos porous surface**	-1.0 to -3.0			
Porous Friction Course***	No data	No data	- 4,6	- 4,4

* CADNA-A manual for RLS90 predictive model [11].** CNOSSOS-EU Road Equivalence [16].

*** Difference between PFC and AC in L_{Amax} for 1 passenger car [5].

The CADNA-A manual refers to D_{stro} as minus 3.0 dB for low noise road surfaces at permissible speeds > 60 kmph. This speed is not reached in Fortaleza urban areas, so another D_{stro} value were tested. The Cnossos-EU predictive model considerer -1.0 to -3.0 for porous surface, depending on speed [16]. Research conducted in Finland evaluated the noise reducing properties of SMA5 (stone-mastic asphalt with 5 mm maximum aggregate size) and reached 3.0 dB noise reduction at 50 km/h in relation to the original asphaltic pavement [17]. In Fortaleza, the difference between AC and PFC reached 4.6 dB and 4.4 dB at speeds of 50 and 60 kmph, respectively (Table 1). This result shows similar attenuation for the speeds compared, although these values could not be used because it refers

to L_{Amax} instead of L_{Aeq} . Considering this, the parameter D_{stro} were tested as -3.0 dB and -2.0 dB for PFC surface. The model was validated with 25 measured (table 2) using +/- 2.0 dB margin of error.

After validation, three scenarios were defined with a range of typical speeds in urban areas (30 kmph to 60 kmph). In the case of ICP, another scenario was used considering an 18% reduction in traffic flow, as will be discussed later. For the scenarios comparison, 20 random receipt points were positioned 2 m from the building facades in the model (Figure 6). The height of these points was set as 4 m, which corresponds to the height adopted by the European Directive for noise maps [18]. The value considered for analysis was the average of L_{Aeq} at the 20 receipt points.

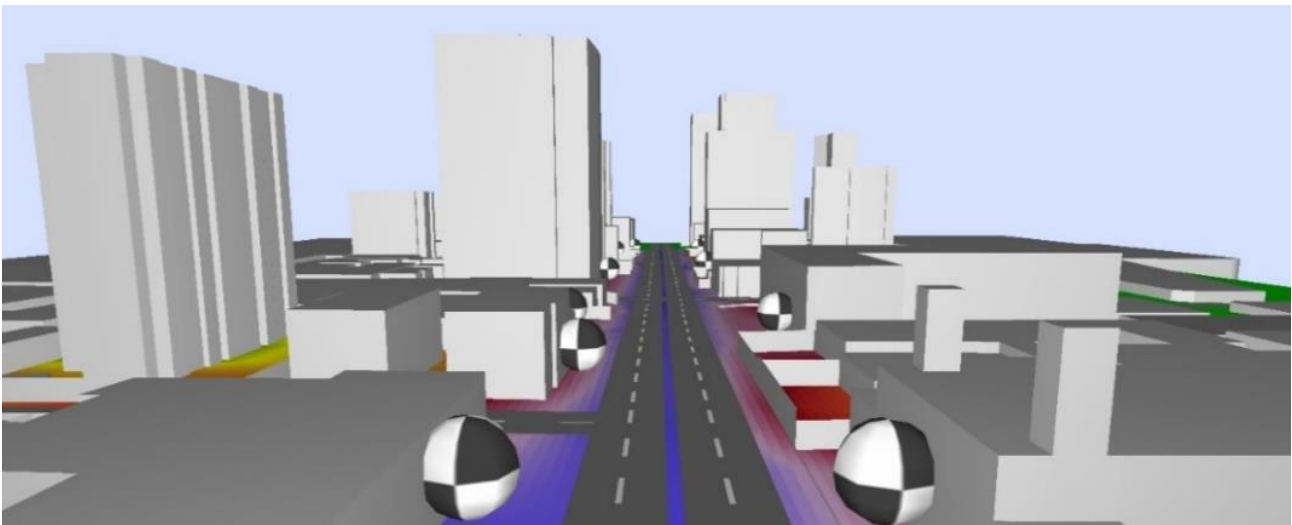


Figure 6: 3D model in CADNA-A software.

3. RESULTS

3.1. Volume, speed, and traffic composition

The percentages of heavy vehicles (PHV) and motorcycle (PM) were similar in all measured points, with 5% of PHV and PM ranging from 10% to 30%. From Table 2 and Figure 7A it is notable that the hourly traffic on the ICP sections (1345 veicph) is 18% lower than on AC and PFC sections (1810 veicph). It could be related to lower speed limit of vehicles in the ICP section and the resistance of vehicles to go through roads with many traffic calming interventions. The reduction in speed and volume in the ICP sections leads to L_{Aeq} ranging from 67.6 to 72.1 dB. These results are not very different from the range of AC (68.7 to 70.8 dB), although these values are difficult to compare due to differences in boundary conditions. Comparing AC to PFC points, both have similar volumes and speed of vehicles and PFC points showed lower L_{Aeq} levels.

The results of PFC were in accordance with previous studies performed in the city of Fortaleza for the L_{Amax} parameter, obtained from the passage of a single car (CPB method) in three types of pavement surfaces (Figure 7B). These studies used a different vehicle in ICP tests than the one used in the AC and PFC tests. However, at any speed, ICP surface implies in higher noise levels than AC and PFC surfaces. It indicates that if only the type of road surface is considered the ICP surface has the worst acoustic performance. On the other hand, when other aspects such as speed and volume are considered, this road surface could show similar results to others.

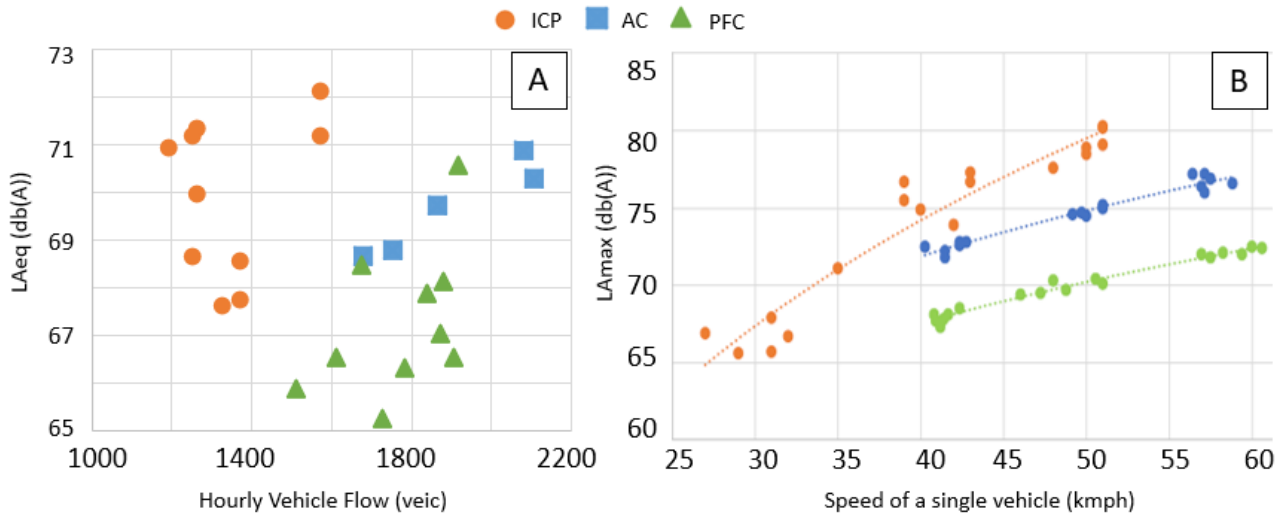


Figure 7: (A) L_{Aeq} results obtained under different boundary conditions. (B) L_{Amax} results obtained from [6] for ICP and from [5] for AC and PFC for the passage of a single car.

Table 2: Data measured, and input data used for validation.

	Point	Medium Speed	Vcar	Vtruck	Hourly traffic	PHV	L_{Aeq} Measured	L_{Aeq} Modeled	Δ
1					1326	3,6%	67,6	67,9	0,3
2	P1 (ICP)	32,7	30	30	1374	7,2%	68,5	69,7	1,2
3					1254	6,8%	68,6	69,5	0,9
4					1374	7,2%	67,72	69,9	2,2
5					1254	6,8%	71,17	71,8	0,6
6					1194	4,0%	70,9	70,6	-0,3
7	P2 (ICP)	27,6	30	30	1266	4,1%	71,3	70,2	-1,1
8					1572	5,1%	72,1	72,1	0,0
9					1266	4,1%	69,94	69,9	0,0
10					1572	5,1%	71,16	71,9	0,7
11	P3 (AC)	35,7	40	30	1752	7,2%	68,75	71,3	2,5
12					1680	5,5%	68,65	70,8	2,1
13					1860	6,3%	69,71	71,9	2,2
14					2105	3,4%	70,25	71,3	1,0
15					2076	2,3%	70,84	71	0,2
16	P4 (PFC)	35,4	35	30	1511	3,5%	65,86	66,3	0,4
17					1674	2,5%	68,48	65,6	-2,9
18					1723	3,6%	65,22	65,9	0,7
19					1608	4,4%	66,52	66,1	-0,4
20	P5 (PFC)	45,5	45	40	1902	2,8%	66,51	68	1,5
21					1782	2,7%	66,30	67,3	1,0
22					1872	4,4%	67,00	68,3	1,3
23	P6 (PFC)	41,3	40	40	1878	3,5%	68,12	68,5	0,4
24					1836	3,6%	67,85	67,6	-0,2
25					1914	4,5%	70,55	69,1	-1,5

3.2. Model Validation

To model validation, some input variables were tested. RLS90 uses maximum road speed limit, which generally cause more errors than using average speed [13]. A preliminary analysis of the data indicates that the average speed of the light vehicle category was 10 kmph below the allowed speed limit. For example, in ICP road section, the allowed speed limit is 40kmph, and the average speed collected was 32,7 kmph in P1 and 27.6 kmph in P2. In modeling using average speed, as expected, the medium error between modeled and measured values was 2.2 dB when using maximal allowed speed and 0.5 when using medium speed (Figure 8). It occurs because the model generally overestimates the L_{Aeq} values. Thus, for the scenario evaluation, it will be used an average speed that is 10 kmph lower than the maximum speed limit.

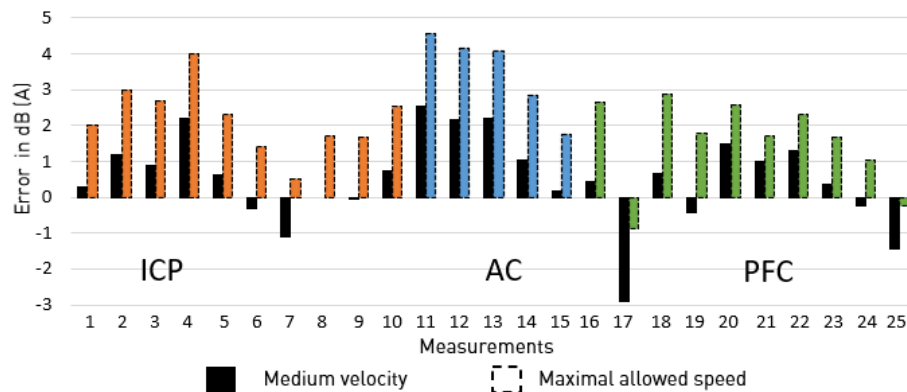


Figure 8: Comparison of modeling errors when considering maximum or average speed.

The acceleration and deceleration effect in RLS90 are related to the distance of points from traffic lights. The model adds +1.0 dB, +2.0 dB and +3.0 dB to points distant from traffic 70 m to 100 m, 40 m to 70 m and lower than 40m, respectively. The medium error between modeled and measured values was 2.1 dB when considering traffic lights and 0.5 when not considering it. Studies in city of São Paulo and Dublin recommended not to use traffic lights to produce noise maps because their application does not improve the accuracy of results [13, 19]. Thus, traffic lights were not used as input parameter. With this recommendation, only five errors were superior to +/- 2.0 dB and most of these are related to AC section, which is the traditional surface validated in Fortaleza Noise Map. The mean absolute error values were $\Delta = 0.73$ dB to ICP surface, $\Delta = 1.6$ dB to AC surface and $\Delta = 1.03$ dB to PFC surface. When considering -2.0 dB attenuation for D_{stro} parameter for PFC, the mean absolute error was $\Delta = 1.5$ dB. Thus, for PFC surface it was considered the value of -3.0 dB for D_{stro} .

3.3. Analysis of Scenarios

In the modelling scenarios, the reduction in maximum allowed and average speed causes reduction on average noise levels (L_{Aeq}). For the AC surface, reducing speed from 60 kmph (scenario without intervention) to 50 kmph (scenario 1), results in 1.2 dB reduction (Figure 9). This type of intervention generally causes a positive effect on traffic safety but can cause noise levels to rise when speed reduction measures result in driving patterns where vehicles are completely stopped. In the case of heavy vehicles, it could lead to more frequent gear changing and increase body rattle noise due to acceleration in low gears.

The PFC surface showed the highest L_{Aeq} attenuation, corresponding to 3.0 dB in the D_{stro} . The noise levels in this pavement surface at 60 kmph speed limit is lower than AC at 40 kmph and ICP

at 30 kmph. In the scenario similar to Blue section of the road, with PFC and 50kmph speed limit (scenario 2), the L_{Aeq} in receiving point at 4 m height is 65 dB. Brazilian standards NBR 10151 define values of 60 dB at daytime (06:00 to 22:00) and 55 dB at nighttime (22:00 to 6:00) in L_{Aeq} as recommended for mixed outdoor areas with commercial and administrative vocation. To achieve this, other interventions should be done to obtain more pleasant areas.

The combined use of traffic management measures and noise reducing pavements can offer an optimized solution for noise abatement. Table 3 summarizes the potential effects of different types of traffic management measure in noise attenuation. The authors indicate that true effects of the different measures depend very much on the precise design of the measures, how they are implemented and the reaction to them by vehicle drivers. When only speed signalization was used to enforce slow driving in a 30 kmph zone, it could achieve -2.0 dB, but when combined with other intervention it could achieve - 4.0 dB. It can generally be concluded that average noise levels can be reduced by up to 4.0 dB, although higher reductions may be achieved with some special measures.

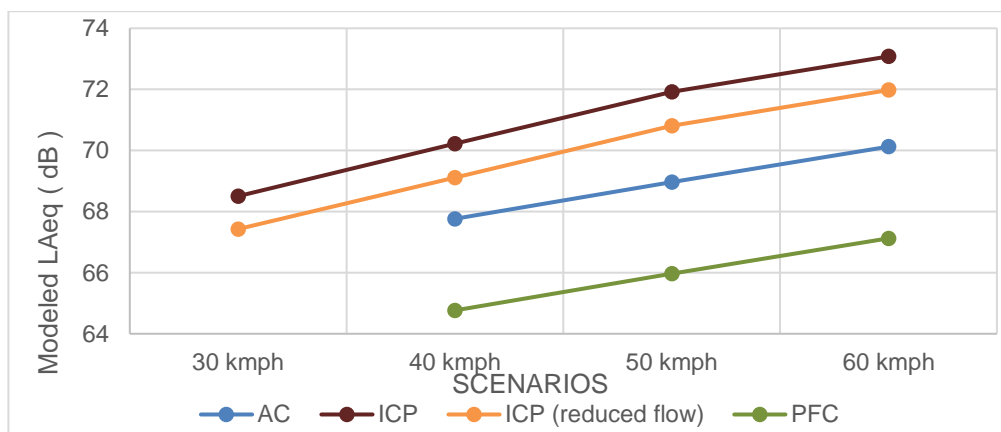


Figure 9: Scenarios of pavement surfaces at different velocities.

Table 3: Traffic management measures and corresponding noise reducing

Traffic management measure	Potential change in L_{Aeq}
Traffic calming/Environmentally adapted through-roads	0 to -4.0
30 kmph zone	0 to -2.0
Flat-top road humps	0 to +6.0
Speed limits combine with signs warning of noise disturbance	-1 to -4.0
Rumble areas (paving stones)	0 to +3.0

The use of uneven surfaces, rumble zones, block paving and cobblestones can increase noise levels if is an isolated measure. The +3.0 dB in Table 3 is similar to value of D_{stro} adopted by CADNA-A for the ICP surface. If only speed reduction is considered, the resulting L_{Aeq} is higher than L_{Aeq} in other scenarios. However, the avenue evaluated was redesigned with implementation of road markings that were useful to reinforce the information conveyed by traffic signs. These traffic calming strategies combined with the new pavement were appropriated for the intended reduction on speed and traffic flow. When this reduction is considered (scenario 3), the L_{Aeq} resulting from the intervention on ICP section with 30kmph is similar to that on the AC section with 40kmph. Figure 10 shows the noise maps of the four described scenarios on the avenue of this study.

3.4. Sustainable benefits of interventions

Other sustainable aspects of the pavements were evaluated in order to highlight integrated urban planning. For Temperature (Ts) parameter, the AC and PFC reached 62°C when measured 30 cm above the pavement surface on a sunny day in the city of Fortaleza [6]. The Ts registered for ICP at the same hour (1 pm) was 55°C for both red and white paving stones colors. This difference may be due to the darker or lighter color of the surfaces, which can change the material's reflectance when exposed to solar radiation. It is important to highlight that Ts is a result of combined factors, including albedo, pavement thickness, material type and subgrade properties [3]. In relation to drainage properties, some Brazilian experiments considered both PFC and ICP as low or medium permeability [20]. It is worth mentioning that the studies were done in different locations, thus the pavements surfaces had different conditions of use, joint spacing, state of conservation, age, traffic volume. Another issue is the loss of infiltration capacity over time, especially in the PFC due to clogging of the pores.

Considering these results, the three types of scenarios have specific benefits (Table 4). In terms of short-term measures, reducing the speed limit could cause reduction in noise levels (scenario 1). This is almost the same gain as applying the ICP surface instead of AC surface (scenario 3) and reducing the maximum speed limit to 40kmph. However, it will probably offer benefits in temperature and some drainage benefits, depending on the characteristic of the stone, size of aggregate and soil characteristic. In the scenario 2 there is no thermal benefit over the AC surface, but in this case traffic noise achieved the lowest levels compared the other scenarios.

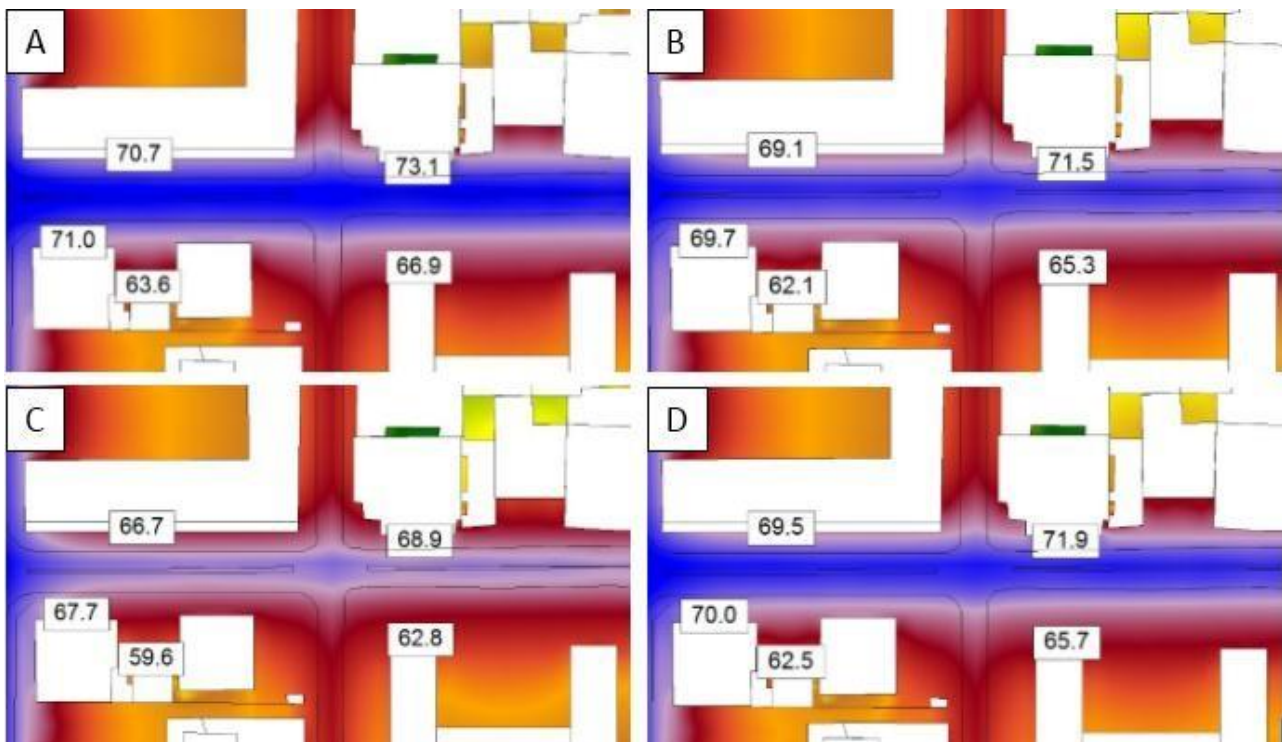


Figure 10: Noise Map in dB of scenarios around point 3: (A) Before intervention, with AC surface and 60kmph speed limit; (B) Scenario 1, with AC surface and 50kmph speed limit; (C) Scenario 2, with PFC surface and 50kmph speed limit; (D) Scenario 3, with ICP surface and 40kmph speed limit.



Table 4: Comparison of interventions in terms of sustainable benefits.

Intervention	Characteristic	Acoustic (dB)	Thermal (Ts)	Drainage
Scenario 0*	AC _ 50kmph	68.96	62°C **	low
Scenario 1	AC _ 40kmph	- 1.2	0	low
Scenario 2	PFC _ 40kmph	- 4.2	0	Low to medium
Scenario 3	ICP _ 30kmph	- 1.5	- 5°C	Low to medium

*Reference values** Temperature measured 30 cm above the pavement surface on a sunny day [6].

4. CONCLUSIONS

The present work proposes an integrated evaluation of urban interventions from noise controlling perspective and the relationship with thermal, drainage and road safety aspects. In the case study, AC, PFC and IC pavement surfaces were used in a recent requalification project in the city of Fortaleza. The evaluation of these interventions occurred through modeled scenarios in CADNA-A software. Validation of field measurements achieved better results without traffic lights and considering average speed instead of allowed speed limit. For IC surface the surface parameter (D_{stro}) depends on the vehicle speed, while for PFC surface D_{stro} -3.0 dB was set for all speeds.

All three types of intervention showed benefits that are aligned with the objectives of the Local Climate Plan. Reducing the allowed speed limit caused a reduction in average speed and therefore noise levels. When considering facility of implementation, the speed limit reduction caused - 1.2 dB in traffic noise levels (scenario 1). It does not represent gains in thermal and drainage aspects, which are vulnerabilities of the city. The combined use of traffic management measures and porous surface offered an optimal solution for noise attenuation. Both actions can cause reduction of the noise emitted at the source, while the latter can also act on sound propagation. By reducing the speed limit on a porous road, such as PFC, there was a gain in the acoustic and drainage environmental aspects (scenario 2). In the case study, using PFC and reducing the speed limit from 60kmph to 50kmph caused - 4.2 dB in noise levels.

When the priority is to reduce thermal discomfort to pedestrian and avoid traffic accidents, the use of ICP surface instead of AC can be very effective (scenario 3). This pavement surface is known to cause a 2.0 dB to 3.0 dB increase in noise levels, so its application should be combined with other traffic management measures. In the case study, the road and sidewalks were redesigned with the implementation of road markings that were useful in reinforcing information conveyed by traffic signals. Modifying the physical layout and reducing the speed limit to 40kmph caused a reduction in average speed to 30kmph and an 18% reduction in traffic flow. In the modeled scenario, this combined effect showed -1.5 dB compared to scenario 0. Thus, despite the higher tire/road noise caused by ICP surface, its application on urban roads led to a similar L_{Aeq} as other interventions.

5. ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

6. REFERENCES

1. Prefeitura de Fortaleza. Plano Local de Ação Climática. Fortaleza, 2020. In Portuguese.
2. Morgan, P. Sustainable road surfaces for traffic noise control. Guidance Manual for the Implementation of Low-Noise Road Surfaces. FEHRL Report 2006/02.
3. Stempihar, J.J., Pourshams-Manzouri, T., Kaloush, K.E. & Rodezno, M.C. Porous Asphalt



- Pavement Temperature Effects for Urban Heat Island Analysis. *Transportation Research Record* 2293, pp.123–130. 2012.
4. Coseo, P. & Larsen, L. Cooling the Heat Island in Compact Urban Environments: The Effectiveness of Chicago's Green Alley Program. *Procedia Engineering*, (118), 691–710 (2015).
 5. Alecrim, C.M.C., Castelo Branco V.T.F.C, Peixoto N.G.M, Alves A. & Pinheiro G.M., Avaliação do Desempenho acústico e das características de superfície de camada porosa de atrito em meio urbano, *Transportes*, v. 30 (1), 2022. (In Portuguese).
 6. Ribeiro Filho, I.A.N. Análise Socioambiental da Pavimentação Utilizando Blocos de Concreto Intertravados: Um Estudo de Caso. Graduation Project. Fortaleza, CE. 2021. In Portuguese.
 7. Freitas, E., Mendonça, C., Santos, J.A., Murteira, C., & Ferreira, J.P. Traffic noise abatement: How different pavements, vehicle speeds and traffic densities affect annoyance levels. *Transportation Research Part D*, 17 (4), 321-326 (2012). In Portuguese.
 8. Ary Junior, I. J. Azevedo Filho, M. A. N., Mota, F. S. B. , Peixoto, N. G. M. & Brito, F. A.C. Impact of traffic-related, environmental noise on school children and teachers in a Brazilian city. *Canadian Acoustics*, v. 46, p. 15-26 (2018).
 9. Prefeitura Municipal de Fortaleza. Carta Acustica de Fortaleza. Available in: <https://cartaacusticadefortaleza.com.br/> (in Portuguese).
 10. NBR 10151:2019 – Acústica — Medição e Avaliação De Níveis De Pressão Sonora Em Áreas Habitadas — Aplicação De Uso Geral. Rio De Janeiro, 2019. In Portuguese.
 11. Datakustik GmbH. CANDA-A Reference Manual Release 3.8: State-of-the-art noise prediction software, Greifenberg, Germany, 2008.
 12. Guedes, I.C.M.; Bertoli, S.R. & Zannin, P.H.T. Influence of urban shapes on environmental noise: A case study in Aracaju - Brazil, *Science of The Total Envir.*, V. 412–413, P. 66-76 (2011).
 13. Pozzer T. & Holtz, M. The pilot noise map of São Paulo: first findings and next steps. *Proceedings of Internoise 2018 – Impact of Noise control engineering*. Chicago, USA. 2018.
 14. Hinton, J., & Bloomfield, A. A Good Practice Guide for Strategic Noise Mapping and The Production of Associated Data on Noise Exposure. *Acoustics Bulletin*, 18-21 (2004).
 15. Peixoto, N.G.M., Desenvolvimento de Método de Mapeamento do Ruído de Tráfego Rodoviário em Áreas Urbanas Utilizando Sig De Acesso Aberto e Validação na Cidade De Fortaleza. Master in Science, Federal University of Ceará, 2020. In Portuguese.
 16. Shilton, S.J., Ledeé, F. A. & Leeuwen, H. V. Conversion of existing road source data to use CNOSSOS-EU. *Proceedings of 10th Euronoise - European Congress and Exposition on Noise Control Engineering*, Maastricht, Netherlands, June 1-3, 2015.
 17. Valtonen J, Hyyppä I & Sainio P. *Noise reduction vs wearing properties*. *Proceedings of the Ninth International Conference on Asphalt Pavements*, Copenhagen, Denmark. 2022.
 18. END. Directive of the European Parliament and of the Council of 25 June 2002 Relating to the Assessment and Management of Environmental Noise, Directive 2002/49/EC. 2002.
 19. Murphy, E., Faulkner, J.P., Rice, H. & Kennedy, J.,. Transitioning to Strategic Noise Mapping under CNOSSOS-EU (Noise-Adapt) EPA Research Report. Environmental Protection Agency, Wexford, Ireland, 2021.
 20. Ono, B. W., Balbo, J. T., & Cargnin, A. Análise da capacidade de infiltração em pavimento permeável de bloco de concreto unidirecionalmente articulado. *Transportes*, 25(3), 90–101 (2017). In Portuguese.