

Research Article

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Rio de Janeiro noise mapping during the COVID-19 pandemic period

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Abstract: This paper presents a comparison between the acoustic scenario at the Rio de Janeiro city center, before and during the COVID-19 pandemic. Undergoing one of the most important pandemics of the recent history, the social isolation led to a new acoustic scenario for Rio de Janeiro. The study was realized at the city center, an area of historical, economic and cultural relevance. The comparison consisted of analyzing measured data and noise maps produced for the city center area. The maps were created according to measured and collected data of the respective time periods. The acoustic scenario prior to the pandemic time was reconstructed based on previous measurements and data collection, while the pandemic one was built with data survey during the highest social isolation index on July 2020. The comparative analysis showed a considerable noise reduction, between 10 and 15 dB, for areas where the traffic noise was not intense and where the human activities were predominant on the streets. However, there was no substantial noise decrease for the areas around the major avenues. This occurred due to the traffic intensity drop to 50% during the pandemic, which meant a noise reduction between 3 and 5 dB.

Keywords: Noise pollution, sound diagnosis, COVID-19 noise

1 Introduction

SARS-CoV-2 VIRUS (COVID-19) pandemic changed life in most of the cities in the world. Firstly emerged in late 2019, as a mysterious illness reported in Wuhan, China, coronavirus infection was recognized as a global pandemic by WHO on March 11 of 2020. Due to its high potential for contagion through interpersonal contact, social distance has been adopted as a measure to reduce the transmission speed.

Most of outdoor human activities were drastically reduced, which restricted people from displacement over the cities. This impact on the transportation system also changed the noise panorama, since the transport modes are the major contributors to the overall urban noise environment [1, 2]. Not only land transportation has decreased, but also air traffic. Therefore, the majority of acoustic sources that people were used to listening in the urban environment have been drastically reduced or even ceased. When the residual or “background” noise decreased, people could hear sounds which were masked by the urban noise. Besides, with lower background levels, peak noise events are more sensitive and could become an annoyance factor, especially when the amplitude difference between peak and background noise was smaller. Similar noise reduction results were found in a research based on short-term measurements in the United Kingdom [3].

It is a consensus that excessive noise exposure degrades population life quality. Its psychological and physiological effects are commonly cited by the academic community, indicating auditory impairment, interference in communication, sleep disorder [4], cardiovascular and psychological effects [5–8], among others negative effects to the population health [9]. Therefore, it seems to be relevant to study noise behavior also in such specific and rare conditions.

The noise reduction due to lockdown, quarantine or even under more flexible activities restriction was perceived mainly in the big cities. A project called SONYC recorded the audio clips from several microphones, located closed to the streets, over the last three years, to monitor noise

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pollution patterns in the New York city [10, 11]. This project has shown a decrease about 6 dB in the pandemic day noise pattern and the “ordinary” nightly one, when comparing April 2019 to the same month of 2020. It corresponds to a sound energy reduction of 4 times.

For Rio de Janeiro, a city about 6.7 million inhabitants, it was not different. When the pandemic started in Brazil, the social isolation index in the Rio de Janeiro city reached about 30%. Later, between April and July 2020, this index was kept steady in about 40%.

Rio de Janeiro is a large city, with dozens of neighborhoods, with several morphological and environmental characteristics, such as flood areas, urban forests, slums or beach areas with high buildings.

The Central Zone of Rio de Janeiro is the historic, cultural, financial and administrative core of the city, where corporate towers share the space with historical buildings, museums and cultural centers. Wide avenues are connected with narrow tortuous roads or pedestrian streets taken by popular commerce. The intense road traffic and human activities occurs mainly during the working days. Cultural and leisure activities, as the famous sambas in Arco do Teles and Ouvidor Street, are specific and occur more frequently at night on the historical center [12, 13].

Figure 1 exhibits the map of Rio de Janeiro city center, highlighting in red the most important area, considered for this study. This area includes most of the historical and cultural buildings, as well as the major roads and famous streets due to their cultural activities. The main roads were also important landmarks for the urban evolution of the city of Rio de Janeiro.



Figure 1: Map of Rio de Janeiro city center and study area highlighted in red

Due the historical and economical relevance of this city area, several noise studies were conducted by researchers from Federal University of Rio de Janeiro (UFRJ), at Architecture and Engineering Schools, before the pandemic time, in order to assess the noise climate for different perspectives and purposes.

This paper presents the results of a joint research conducted by both groups, in order to evaluate the changes in the sound environment of the central Zone of Rio de Janeiro. As reference parameter, the authors rebuilt recent scenario - prior of pandemic, based on earlier noise measurements and traffic flow data. A new data collection was conducted in July 2020, when the people isolation and social distance was at the highest level in Rio, due to the quarantine measures.

2 Study area description

The selected area for comparison between the acoustic scenarios of the pandemic with the “normal” situation has about 776 m² and is located in the Central Zone of Rio de Janeiro. Figure 2 presents the study area, which comprises the two main avenues and several secondary streets.

The morphological diversity of the area reflects 455 years of history over which successive interventions have left their mark on the urban form, architecture and even the natural profile of the site. The urban morphology and the relationship between street width and buildings length have strong impact over the acoustic landscape, due to wave phenomena such as sound diffraction and reflection [14–16].



Figure 2: Study area, including traffic counting and noise measuring locations

Originally, the city was implanted at the top of Morro do Castelo (later devastated), but its expansion was made by the occupation of the floodplain by a mesh of streets whose main axis was “Rua Direita” (now Primeiro de Março Street). During the colonial period this was the most important street in the city where located churches, townhouses and the Imperial Palace. The Palace Square opened up to the port, the markets and the wholesale trade in the immediate vicinity. Nowadays, most of the buildings of Primeiro de Março Street are occupied by museums and cultural centers. Such buildings preserved its architectural characteristics and configure the oldest and most important historical site of the city.

The primacy of Primeiro de Março street ends at the beginning of the 20th century, with the opening of “Avenida Central” (now Rio Branco Av.). The road – inspired by the Haussmann’s Renovation Plan for Paris – crossed the City Central Zone in a straight line, which demolished a considerable portion of the remaining blocks from the colonial period. The modern avenue, whose width was considerable for the time, had lanes in both directions, wide and tree-lined lateral and central sidewalks. In line with the urban planning, the Municipal Theater and the other buildings that occupied the margins of the road presented a refinement and grandeur that contrasted with the dominant simplicity of the rest of the central area.

The third traffic road in the study area, is the President Vargas Avenue: the major road axis which connects the Central, North and West Zones. Constructed in the 1940s, the opening of its four traffic lanes, with four tracks each, as responsible for the demolition of a large part of the houses along the Mangue Channel. The Avenue is crossed by Primeiro de Março Street and its connection to Rio Branco Av. is marked by the Candelaria Cathedral.

In the spaces between arterial roads, there are several secondary traffic streets and a network of tortuous roads and alleys, where the buildings are occupied by bars, restaurants, popular formal and informal commerce and itinerant trade.

Rio de Janeiro city center has suffered several infrastructure changes, for the international events of the World-Cup (2014) and the Olympic Games (2016), which greatly affected the entire city population dynamics. The inclusion of a Light Rail Vehicle (VLT), the changes in city bus lines, the demolition of an extensive viaduct at the port area, new tunnel constructions and the enlargement of the main streets in the Rio de Janeiro historic center, clearly altered the way that citizens used the public and private transports. Figure 3 shows the Rio Branco Av., where the historical buildings contrast with the commercial skyscrap-



Figure 3: Architecture and road system at Rio city center. Left: Rio Branco Av. shared road by pedestrians, VLT and cars. Right: VLT and historical buildings

ers and the new tram shares the road with pedestrian and cars.

The VLT city tram model used is the “Citadis 402”, with seven sections, 100% low floor, manufactured by the French company Alstom and also available in several cities such as Bordeaux, Dublin, Grenoble, Lyon, Paris T3 and Dubai. According to the administration consortium VLT Carioca, the operational average and maximum tram speed are 15 km/h and 50 km/h, respectively. This low speed assures very low noise levels, including the “rolling noise”. Measurements conducted along 2016 and 2017, over the same and similar tram models, to evaluate grinding rail noise shows that broadband equivalent level, energetically averaged over 2 years ($L_{Aeq,T}$), is about 76 dB(A), at a distance of 2 meters for a speed of 30 km/h [17]. This noise is equivalent to, or even lower than, the noise emitted by a car (light vehicle) on the surroundings. Therefore the main noise contribution is given by the light and heavy vehicles on the street. The most “prominent” noise, particularly from the Rio de Janeiro VLT system, is a bell ring (similar to the 19th century ones) emitted by the tram, during its movement to alert the pedestrians. This particular sound was, up to that time, “incorporated” to the avenue noise panorama.

Nevertheless, if, by one side, more public transportation was offered, the main streets enlargement also brought more vehicles, especially the heavy ones. The actual noise landscape of the Rio city center (as well as most of other areas) is consequence of several years of misguided urbanization process and, in order to provide more silent environment, the noise characteristics and new goals should be taken into account by the city planners [18, 19].

3 Scenarios Description

In this section, is presented a brief description of the acoustic scenarios found during measurements, as well as the human activities in the streets.

3.1 Before pandemic

During studies realized before the pandemic period, the authors concluded that the Rio Branco Av. was the unique road which had benefits with the transport system renovation [20]. A reduction about 3 dB was observed and measured in 2019, mainly due to the drastic decrease of the heavy vehicles. However, such reduction could be more expressive if the number of light vehicles would not have increased. Another relevant characteristic of this street is the “canion” morphology along its 2 km length. High buildings with more than 20 floors with acoustic reflexive materials, such as glass and concrete, also contribute to increase sound reflections and noise level.

Unfortunately, the noise reduction benefits observed at Rio Branco Av. do not compensate the issues found at the surrounding streets. After the renovation, part of the Rio Branco Av. was narrowed and, consequently, part of the original traffic was distributed to the transverse streets, which increased the noise level at that areas. Such streets have, in general, a single and narrow lane, which contribute to traffic jams and noise increase.

On the other hand, the demolition of a huge viaduct, as part of a plan to revitalize the port area, had a strong impact on Primeiro de Março St. The route was connected to a tunnel, which crosses the foot of the historic Morro de São Bento hill, towards the North Zone of the city. As



Figure 4: Primeiro de Março av. crossing Presidente Vargas, near to Candelária Cathedral before pandemic (close to measuring location B)

a result, a significant part of the vehicle flow, including buses and heavy trucks, started to be carried out through the historic center of the city, as shown in Figure 4.

Besides that, the short time equivalent noise levels ($L_{Aeq,5min}$), previously measured at Rio Branco Av., were higher than the 60 dB(A) defined as the maximum noise level by Brazilian Standard for such commercial urban area [21], not only at ground level but also at higher elevation at the façades. On the other hand, the block internal areas are protected from the street noise by the barrier effect promoted by the high and dense building configuration.

3.2 Pandemic scenario

According to a Brazilian information service provider [22] the Social Isolation Index in Rio de Janeiro, since February 2020, started about only 25% of people isolated, raised up to the top on March 22th, with 64% isolation index and started decreasing slowly up to 35% in the beginning of September. The Isolation Index is a measuring tool, developed jointly by the brazilian authorities and a few enterprises, based on the distance between people, according to their mobile phone location. The system consists in a geo-referenced database which collects cellphone position by the antenna triangulation and evaluate the proximity and mobility between people. During the measurements conducted in June 18th, the social isolation index was approximately 40%. It means that almost 60% of Rio State population was moving and developing economic and social activities. Figure 5 presents the isolation index for Rio de Janeiro.

During the measurements period, it was observed a considerable reduction of pedestrians and vehicles. Some secondary streets were practically empty, with almost all street shops and stores closed. This was observed in streets such as Ouvidor, Carmo and Sete de Setembro, and clearly reflected on the measurements. Figure 6 illustrates the commerce streets on the central area of study.

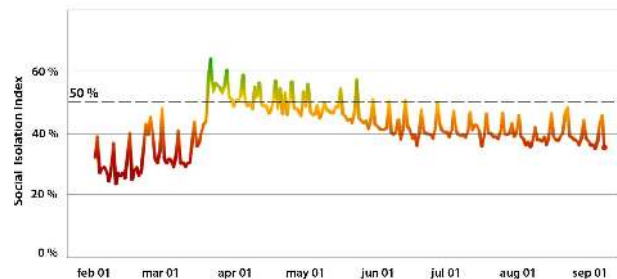


Figure 5: Isolation index for Rio de Janeiro city [22]



Figure 6: On the left, intense activity on the streets of popular commerce, before the pandemic. on the right, closed shops and deserted streets during the pandemic

However, in other streets there were still considerable number of cars, compared to the situation outside the pandemic, such as Presidente Vargas Avenue (near the Candelária Church) and Primeiro de Março Street at the two measuring points. In general, the traffic counting averaging revealed a flow reduction of 52% of the regular one at the pandemic period. Traffic noise prediction models, such as ISO 9316, RLS90, NMPB-Routes or the on-going CNOSSOS directives [16, 23–25], consider as the main noise components the traffic flow, in vehicle per hour, and the average speed, in Km/h. Except from CNOSSOS, which calculated separately noise from engine, rolling and other sources, in the other methods the speed and the number of vehicles are directly related to the predicted noise, i.e., the higher is the speed or the traffic flow, higher is the noise. Assuming that the average speed did not increase considerably during the pandemic time, a reduction of 3 dB would be expected, simply by taking the logarithm of half of number of vehicles.

4 Scenario comparison

In order to provide scenario comparison, data collected in 2019 were used to generate the pre-pandemic noise map, while pandemic map was build based on data obtained in July 2020. For both scenarios, the geometric model was created based on municipality CAD files and exported to the software Predictor LimA Type 7810 (version 9.10). Twelve location points were selected for maps validation. On each location, simultaneous vehicle counting and noise measurements were performed. Traffic data is used to input road acoustic power, according to ISO 9613.1/2-Road method for noise prediction. Noise produced by the VLT tram was not simulated due to the small contribution to the overall noise

level and because the standard ISO 9613.1/2-Road, available at Predictor LimA version, did not include rail traffic. Alternative approaches, such as line sources, simulating the tram path, could be implemented, but would require specific measurements for calibration, which was not recommended during the pandemic time.

Noise measurements were conducted in accordance to the Brazilian standard NBR 10.151 [21]. The noise descriptor evaluated was the Average Equivalent Level $L_{Aeq,T}$, given by

$$L_{Aeq,T} = 10 \log_{10} \left[\frac{1}{T} \int_{t_1}^{t_2} \frac{p_A^2(t)}{p_0^2} dt \right], \quad (1)$$

where $p_A(t)$ is the sound pressure, weighted by “A” curve [26] – for frequency compensation of non-equal loudness characteristics of human hearing, p_0 is the reference sound pressure, related to the minimum audible sound ($20\mu\text{Pa}$) and $T = t_2 - t_1$ is a generic period of time between the starting and the ending time instants, t_1 and t_2 , respectively. The $L_{Aeq,T}$ is usually calculated from discrete pressure values, with sampling period of 1 second. Brazilian standard defines a minimum period of 30s. The Day-Night equivalent level (L_{DN}) or individual long term noise periods, such as L_D and L_N , were not considered, due to previous short term measurements from 5 to 10 minutes on each location and to the difficult to proceed long term measurements during the pandemic and social distance period.

Traffic data was obtained by directly counting vehicles pass-by or through video recordings made during the measuring periods. *In loco* vehicle counting was done by visual inspection and hand counter (click machine), along the recording time. The samples were taken in different periods of the day over the location points.

Depending on the $L_{Aeq,T}$ integration period on each location, a projection of the average number of vehicles per hour was made by linear proportion. The vehicle categories were separated in motorcycles, light cars, light and heavy trucks [19]. Buses were included in heavy trucks due to their characteristics in Rio de Janeiro. The average road speed was set according to the road hierarchy (arterial, collector or local road) and to the vehicle category. In the arterial and collectors streets, speed flow was set to 50 km/h for motorcycles and light vehicles, while for light and heavy trucks, the speed was set to 40 km/h. For the local roads, the speed was set to 40 km/h for motorcycles and light vehicles, while for light and heavy trucks, it was set to 30 km/h. There are no significant slope on the streets to be relevant to noise level. The arterial and collecting roads are paved and the local roads are covered with cobblestone or stone. Table 1 shows the street characteristics at the evaluation points.

Table 1: Street characteristics at the evaluation points. (*) Point B is at the corner of two main streets

Point	Lanes		Covering	Width (m)	Type
	road	VLT			
A	7	-	Asphalt	35	Main
B*	4	-	Asphalt	19	Secondary
	6	-	Asphalt	32	Main
C	1	-	Asphalt	4	Collector
D	3	2	Asphalt	18	Secondary
E	1	-	Cobblestone	4	Local
F	1	-	Cobblestone	5	Local
G	4	-	Asphalt	18	Secondary
H	1	-	Cobblestone	4	Local
I	1	2	Stone	8	Local
J	4	-	Asphalt	17	Secondary
K	2	-	Asphalt	10	Collector
L	3	2	Asphalt	18	Secondary

Table 2: $L_{Aeq,5min}$ comparison between measurement (M), along 5 minutes per location, and simulation (S) for both scenarios, in dB(A), and the absolute error (E)

Point	Pre-Pandemic			Pandemic		
	M	S	E	M	S	E
A	76.9	75.2	1.7	72.2	72.3	0.1
B	73.0	74.9	1.9	72.7	72.5	0.2
C	72.6	73.9	1.3	63.6	65.1	1.5
D	73.0	74.7	1.7	67.2	68.1	0.9
E	77.7	75.9	1.8	64.1	64.8	0.7
F	72.2	71.1	1.1	59.9	61.4	1.5
G	76.0	76.3	0.3	71.9	71.5	0.4
H	71.6	70.3	1.3	63.8	64.8	1.0
I	73.0	73.8	1.3	60.2	59.6	0.6
J	76.9	77.2	0.3	72.7	72.2	0.5
K	76.9	75.1	1.8	65.9	66.9	1.0
L	73.0	73.6	0.6	69.3	68.3	1.0

All calculation grids considered an spacing of 20×20 m between receivers.

Using the collected traffic data for the main streets and most of the secondary ones, the acoustic models were validated by comparing the measured $L_{Aeq,5min}$ with the simulated ones, for each scenario. The equivalent noise level was measured using single class 2 sound meter on each location, with average time of 5 minutes. There are common uncertainties related to the sound meter class and also related to the measuring location point.

The comparison is presented in Table 2 for the 12 control points illustrated on Figure 2. The small errors found between simulation and measured data, for distributed points over the study area, suggests that the generated maps are representative of both scenarios.

Figure 7 presents the collected 5 minutes equivalent noise level data ($L_{Aeq,5min}$), for both periods. From Figure 7 it can be noticed that the smallest differences between scenarios were achieved at location points A, B, G, J and L. The smallest difference occurred at Point B, at the Cathedral square, which collects all the traffic flow from Primeiro de Março St. and cars returning from the main Presidente Vargas Avenue. During pandemic time, this corner practically did not presented changes in the traffic flow, with very similar number of cars (approximately 1600 vehicles/h). This behavior explains the same levels measured at that location. Points A, D and L belong to the Rio Branco av., which shares VLT with pedestrian area and does have vehicle flow in part of the path (see Figure 3). Points G and J are located at main street Primeiro de Março. For these 5 measuring points (A, D, G, J and L) the noise reduced between 3 and 5

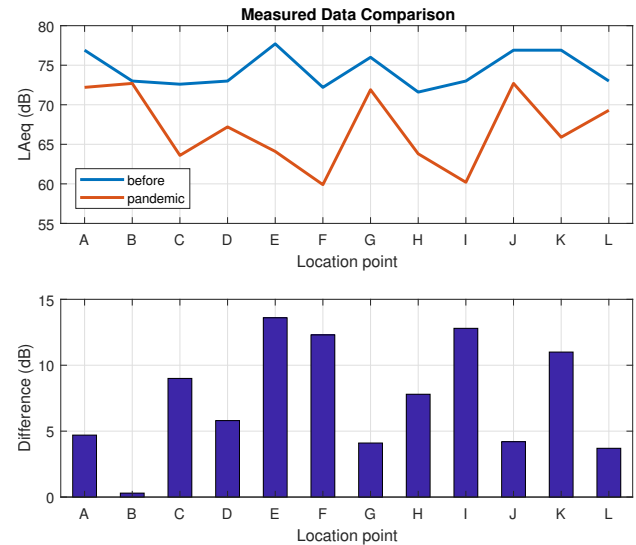


Figure 7: Measured levels comparison before and during pandemic period

dB, which is in agreement with the expected drop of 50% of traffic flow at these streets.

The largest noise reduction occurred at the center of the study area (Figure 2), where the points C, E, F, H, I and K are located. In these places the vehicle traffic is very small, due to the narrow streets. Therefore, at these streets, the predominant noise was not related to the traffic, but to the human activities. Before pandemic, there were several informal street sellers, people walking, speaking at cellphones or talking and stores with loudspeakers advertisements. In the pandemic period all of these shops were closed and

almost no one was at the streets. It justifies the a large noise reduction from 11 to 13 dB for such locations.

The noise maps for the scenarios before and during the pandemic are presented, respectively, in Figures 8 e 9. Comparing the maps, it is observed that the main avenues are responsible for the highest levels, as expected. The difference between before and during the pandemic is a range reduction – from 75-80 to 70-75 dB, lowering from 3 to 6 dB, on average, as observed in Figure 7. Around the Candelária Cathedral there was also the same reduction, but the levels are still between 70 and 75 dB(A), which is much above the indicated by brazilian standard. On the other hand, an area which had benefited was the 15 de Novembro Square (east side on both figures), with a decrease between 5 to 10 dB.

Traffic noise on this square is mainly influenced by Primeiro de Março Av. and the buildings act as a barrier. At this square there is a transportation port, connecting Rio de Janeiro city center to Niterói city, on the other size of the Guanabara bay. The noise produced by boat were not considered on both scenarios, but taking into account that the boat traffic was very restricted during the pandemic, the noise reduction on this area might be larger than 10 dB.

The central area, surrounded by the 3 main avenues, was benefited in terms of noise during the pandemic, by a level reduction of about 10 to 15 dB, especially as it approaches to the Cathedral (left upper part on Figs. 8 and 9).

In “normal” situations, traffic on Primeiro de Março St. in front of 15 de Novembro Square is usually quite problematic, due to the sum of the flow from Presidente Antonio Carlos Av. (which is the natural extension) with that of Assembleia St. (for which is the only alternative). It also receives the outflow from the garage building. In the square there are usually fairs that attract a lot of public and pedestrian traffic, which cross the square towards the terminal of boats. During the pandemic, in addition to reducing the flow of vehicles and pedestrians, the space is favored for its open space characteristics, in contrast to the profile of Primeiro de Março St., narrow and with a line of façades almost continuous on both sidewalks.

Figures 10 and 11 present the cross-sections indicated on Figure 8, where the same color legend are used. It is interesting to notice the influence of the city center morphology, and the relationship between streets width and buildings height, into the noise landscape. Figure 10 presents the

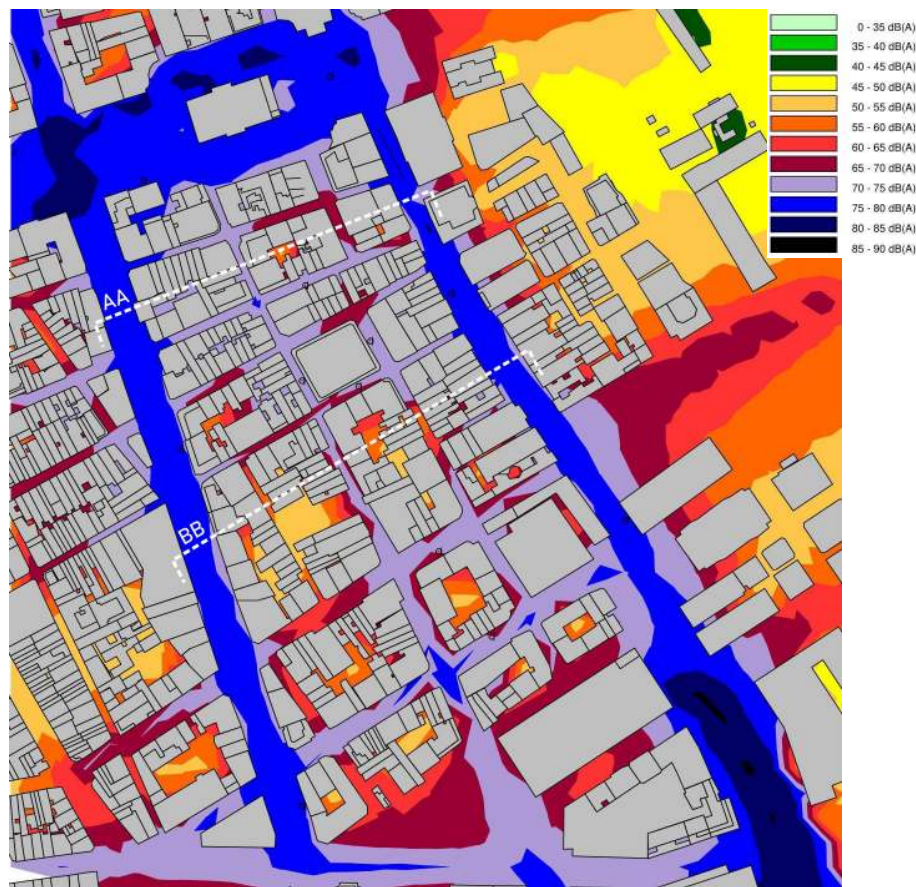


Figure 8: Noise map for scenario before pandemic.

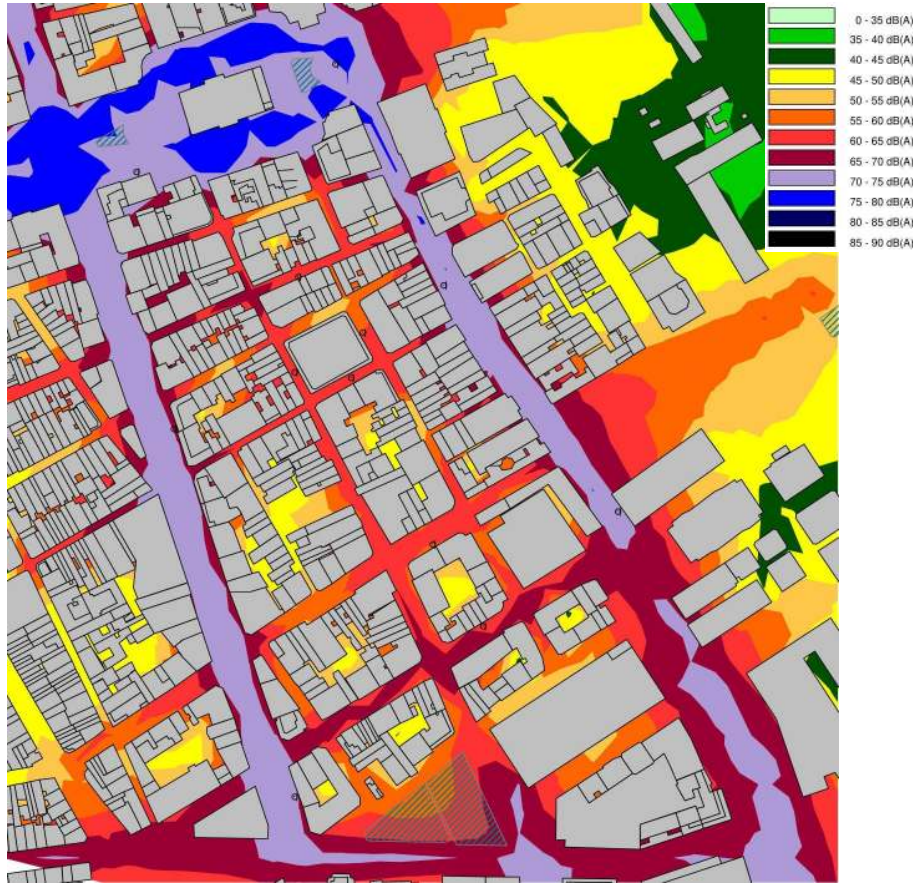


Figure 9: Noise map for the pandemic scenario.

cross-section AA of Figure 8, where the highest levels correspond to the Rio Branco Av. (left side) and Primeiro de Março St. (right side). The noise produced at these streets propagates vertically and reflects at the façades. At the pre-pandemic scenario (Figure 10(a)) a noise level ranging for 75 to 80 dB is propagated to higher height than the tall buildings. During the pandemic, the vertical noise propagation characteristic is nearly the same, except by the level reduction at the sound source, i.e., acoustic power of the

linear sources (streets). At the central area, noise differences are not so noticeable through this section due to the noise barrier effect promoted by the area buildings. Such noise protection holds for both scenarios, blocking most of noise that reaches the façades. Similar behavior occurs to section B at Figure 11.

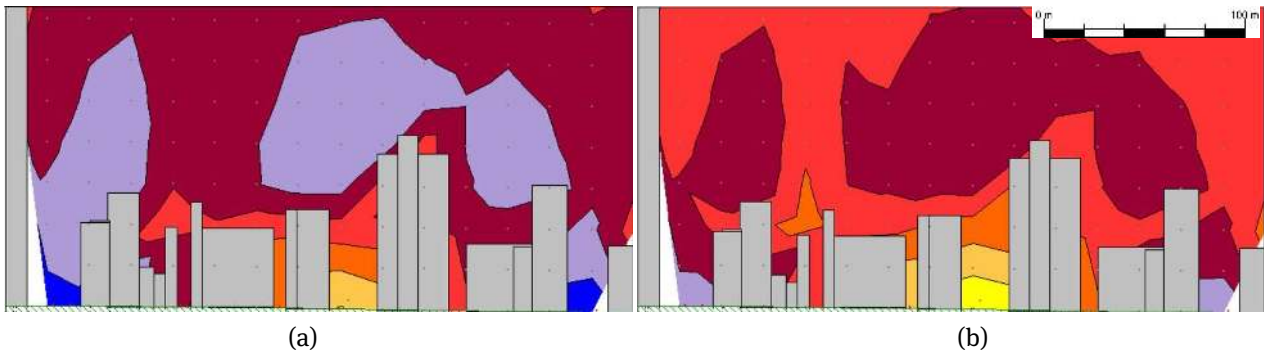


Figure 10: Cross section A, as indicated on Figure 8: (a) Pre-pandemic scenario and (b) pandemic one on the right.

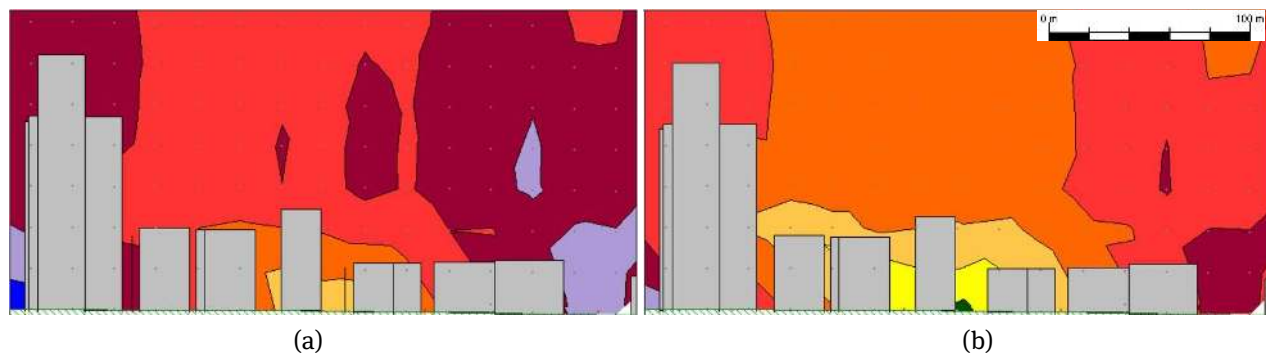


Figure 11: Cross section B, as indicated on Figure 8: (a) Pre-pandemic scenario and (b) pandemic one on the right.

5 Conclusion

This work presented a comparison between the acoustic scenario at the Rio de Janeiro city center, before and during the COVID-19 pandemic. During one of the most important pandemics of the recent history, the social isolation led to a new acoustic scenario for Rio de Janeiro. The study was realized at the city center, an area of historical, economic and cultural relevance for the city. The acoustic scenario prior to the pandemic time was reconstructed based on previous measurements and data collection, gathered by the research group. The pandemic scenario was built with data survey during the highest social isolation index, on July 2020. The comparative analysis showed a considerable noise reduction, between 10 and 15 dB, for areas where the traffic noise was not intense and where the human activities were predominant on the streets. However, for the areas around the major avenues of the city center there were no substantial noise decrease. This occurred due to the traffic intensity has dropped to 50% during the pandemic, which meant a noise reduction between 3 and 5 dB.

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