



Mitigation of the Sound Impact of Outdoor Concerts through Computational Simulations and Solutions for Community Acoustic Comfort

Andrew Rafael de Freitas¹

Rafael Schmitt²

Fábio Becker Beck³

Scala Acústica

Rua Prof. Joaquim de Sales, 45 – Itoupava Seca, Blumenau, SC, Brazil

ABSTRACT

Outdoor concerts have become increasingly common, bringing cultural and economic benefits, but also challenges related to their acoustic impact on surrounding communities. Acoustic comfort is essential for quality of life, and mitigating noise generated by musical events remains a significant challenge. This study presents a combination of computational simulations and field measurements to assess sound propagation during a musical event held in Colombo/PR, with the goal of informing improvements for the 2025 edition. The main focus was to evaluate the effectiveness of interventions aimed at reducing the sound impact on the São Rafael Arcanjo Hospital, located near the event site. Solutions such as repositioning the stage, installing acoustic barriers, and analyzing sound directivity were simulated using IMMI software, based on the ISO 9613-2:2024 standard. Field measurements were also conducted to assess the effectiveness of these interventions. The results indicated a reduction in noise levels at the hospital compared to the 2024 edition, demonstrating the effectiveness of the proposed strategies, even though some were not implemented due to budget constraints. The study demonstrates that it is feasible to hold outdoor events with appropriate acoustic planning, highlighting the importance of targeted studies to ensure community acoustic comfort.

1. INTRODUCTION

Over the years, outdoor music events have become increasingly common around the world. These events not only promote cultural dissemination, but also stimulate the local economy. However, the practice of these events in urban spaces, such as public parks, raises important questions about the noise impact on the surrounding areas. In order to contribute to these issues, the Brazilian standard ABNT NBR 10151:2019 [1] presents limits to be met in order to guarantee the acoustic comfort and quality of life of local inhabitants.

¹andrew@scaladb.com.br

²rafael@scaladb.com.br

³fabio@scaladb.com.br

According to Lima et al. (1994), the definitions of “open space” and “leisure area” are often debated, and the lack of a common language can hinder the planning and management of these places [2]. In this regard, the lack of an adequate study to ensure acoustic comfort can be detrimental, not only in terms of noise, but also in balancing the well-being of the various functions that these spaces offer, such as recreation and conservation of natural resources [3].

For events like these, acoustic planning is essential, as the sound emitted spreads and impacts the surrounding community. However, holding these festivals presents major challenges, mainly related to the sound impact emitted. Loud sound can be a significant source of discomfort and stress for individuals in the communities near the event venues, affecting residents’ quality of life and, in more critical cases, impacting the functioning of noise-sensitive institutions such as hospitals and schools.

The aim of this article is to demonstrate that acoustic comfort at large events can be achieved through specific studies. The study was based on a nationwide music festival taking place in Colombo, Paraná, with special attention to the noise impact on the São Rafael Arcanjo Hospital, located a few meters from the venue.

The study included field measurements before the event, followed by computer simulations to analyze current conditions and explore acoustic interventions. Scenarios such as the strategic repositioning of the stage, the installation of acoustic barriers and the study of sound directivity [4] were simulated. Following the ISO 9613-2:2024 [5] standard, the software IMMI was used to perform sound propagation calculations. Finally, measurements were taken during the event to assess the effectiveness of the solutions implemented.

2. FUNDAMENTALS

Outdoor music events, such as concerts with large sound systems, generate significant levels of noise that propagate in a complex way in urban environments. Noise is transmitted as a mechanical wave through elastic media such as air, solids or liquids. In this context, propagation occurs mainly through the compression and rarefaction of air molecules [6]. To measure noise levels accurately, it is necessary to use a sound pressure level meter, which records the intensity of the sound waves emitted during the event. This calculation is represented by Equation 1.

$$L_p = 20 \log \left(\frac{P}{P_0} \right), \quad (1)$$

where P , represents the sound pressure generated by sound waves in the medium (usually air), measured in pascals (Pa), P_0 is the reference sound pressure, defined as $20 \mu\text{Pa}$ (2×10^{-5} Pa).

When analyzing sound propagation outdoors, it is important to consider three main components: the sound source, the propagation medium and the receiver. The sound level decreases with distance from the source, partly due to sound absorption in the air, which attenuates the sound along its path. Ground reflections also interfere with direct sound, resulting predominantly in attenuation and, in less frequent cases, amplification. Various factors can influence the propagation of noise.

A sound source that has no preferred directions of radiation is classified as omnidirectional; otherwise, it is considered directional. When the wavelength is much longer than the size of the source, the waves generated are spherical. On the other hand, when the wavelength is the same or smaller, propagation tends to be directional. [7].

For omnidirectional sound sources radiating in a free field, away from reflective surfaces, the relationship between sound power and sound pressure at a distance r from the source is described by Equation 2.

$$L_p = L_{w_o} - 20 \log r - 11 \text{ dB}, \quad (2)$$

where L_{w_o} is the sound power of the omnidirectional source.

When a sound source is directional, Equation 2 must be adjusted to include the parameters of the sound source’s emission direction. Equation 3 is presented incorporating the directionality variable.

$$L_{p\theta} = L_{W_d} + DI_{\theta} - 20 \log r - 11dB, \quad (3)$$

where $L_{p\theta}$ is the sound pressure level in the θ direction, L_{W_d} is the sound power level of the directional source, and DI_{θ} is the directivity index of the source in the θ direction, in decibel.

The directivity index, DI_{θ} , is represented by polar diagrams in octave bands. These diagrams show that, in general, loudspeakers tend to have a higher degree of directivity at low frequencies. The DI_{θ} is calculated by measuring sound pressure levels and applying Equation 4.

$$DI_{\theta} = L_{p\theta} - \bar{L}_{p_{esf}}, \quad (4)$$

where $L_{p\theta}$ is the sound pressure level measured at distance r , in direction θ and $\bar{L}_{p_{esf}}$ the spatial sound pressure level, calculated.

The basic equation for describing sound propagation outdoors is derived from Equation 3, with the addition of two new parts, resulting in Equation 5.

$$L_p(r, \theta) = L_W + DI_{\theta} - 20 \log r - 10 \log \frac{\pi}{4\pi} - A_{combined} - 11dB, \quad (5)$$

where π is the solid angle available for free propagation and $A_{combined}$ is the combination of all significant sound attenuation mechanisms between the source and the receiver.

At outdoor music events, loudspeakers are the main sources of noise, with their unique directionalities affecting the way sound propagates in the neighborhood. Understanding the behavior of each sound source and its interaction within the overall system is crucial for studying the acoustic impact. Although this represents a complex study, the digital age provides us with facilitating tools.

In order to minimize the impact on the surroundings, strategic planning is essential. This makes specialized software indispensable, helping with complex analyses at various stages of planning, from the initial acoustic design to the execution of the event [8].

The software must comply with the ISO 9613-2024 standard [5], which represents an engineering method for predicting outdoor sound pressure levels. This standard details how to calculate sound attenuation in different scenarios, such as reflections from surfaces and obstacles, taking into account meteorological factors.

This technology makes it possible to simulate current scenarios, identify critical issues, and properly configure sound settings. It makes it possible to predict the behavior of sound, calculate its propagation and assess how changes in the configuration of the stage or equipment can improve sound distribution through noise maps, which are graphic representations using a color scale that express the respective sound pressure levels calculated. In addition, these simulation studies help to minimize the impact of sound on the neighbourhood and ensure that events tend to comply with the limits established by law, even when the zoning limits are very restrictive.

The Resolution of the Conselho Nacional de Meio Ambiente, CONAMA Resolution number 001, of March 8, 1990 [9] establishes standards, criteria and guidelines for noise emissions as a result of any industrial, commercial, social or recreational activities, including political propaganda. It also defines that measurements must be carried out in accordance with ABNT NBR 10151:2019 [1].

The Brazilian standard that defines acceptable sound pressure levels for different types of land use zones is ABNT NBR 10151:2019 [1], which also describes how to conduct noise measurements and assessments in inhabited areas, ensuring that the sound environment remains within the acoustic comfort limits established to protect residents' quality of life.

With the commercial software IMMI, used in this study, it is possible to evaluate all these variables accurately, allowing for effective acoustic planning in order to improve the acoustic experience of outdoor events and minimize unwanted impacts on the neighborhood.

3. DEVELOPMENT

This study was carried out during a traditional event that takes place every year in the Municipal Park of the city of Colombo/PR, which attracts thousands of people and features concerts by national artists. This event causes a significant increase in traffic, the concentration of large crowds and, above all, high noise levels due to the live performances. In addition, a critical aspect is the site's proximity to a hospital unit, located just 100 meters from the nearest boundary of the park targeted by the study. These factors represent major challenges, mainly because they directly impact the local community.

As the event takes place over four consecutive days, there is a need to implement effective measures to control noise and mitigate environmental impacts. This need is accentuated by the fact that, in previous editions, excessive noise was the community's main complaint.

The study was therefore structured in four main stages. The first stage was based on gathering data for the simulations and defining essential information to guide the study. In the second stage, sound propagation software for outdoor environments was used to model and insert the data and definitions obtained in the first stage, with the aim of calculating sound levels and obtaining a diagnosis of the initial sound impact scenario. In the third stage, solutions were designed after calibrating the initial scenario, with the aim of developing strategies to minimize noise levels, especially in the hospital. Finally, the fourth stage was the validation of the study, carried out by measuring sound pressure levels during the event in 2025, ensuring the effectiveness of the proposed interventions, as well as measuring residual sound at the point in front of the hospital.

To ensure the relevance of the proposed strategies, data collection was carried out with specialists experienced in organizing large-scale national concerts. This consultation aimed to understand how major events are typically structured and to develop noise mitigation solutions that are not only effective but also realistic and applicable to the specific context of the event. In addition, to support the study, various pieces of information were gathered from site floor plans, contour maps, and detailed records from the most recent edition of the festival, allowing for an analysis of the existing acoustic conditions.

The acoustic simulation was carried out using acoustic modeling with IMMI v2024 software, developed by the German company Wölfel Engineering GmbH & Co. KG [10]. For the calibration, a sound level of 106 decibel was considered in the house mix, located 35 meters from the stage, which is a relevant parameter for estimating the sound pressure on the audience. In addition, a density of three people per square meter was simulated in the audience area, including the sound emission of female voices at a high level (raised) throughout this region. Figure 1 shows the spectrum used to configure the audience as a sound source [11].

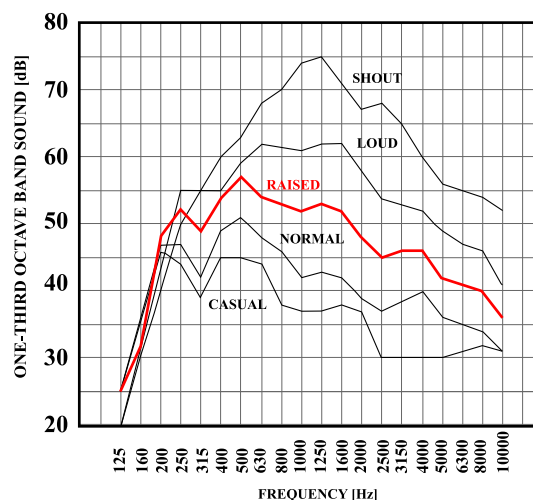


Figure 1: Frequency spectrum of the female voice at different intensities, measured in a free field at 1 meter. (Image adapted by the author [11])

In the 2024 edition, no specific acoustic study for noise mitigation was conducted. However, strategic control points were established, measured at 1.6 meters above ground level, to monitor the sound impact on the surrounding neighborhood, and these were used as a reference for this study.

Simulation was carried out in two main stages. The first stage involved creating a three-dimensional model in the computer software, which incorporated all the acoustically relevant obstacles, as well as the neighboring houses, in order to simulate the environment accurately. In the second stage, the sound sources were integrated into the model with their specific powers and directivities. To ensure the accuracy of the acoustic study, characteristics such as sound reflections, absorption by the ground, environmental conditions and the topography of the region were taken into account.

To calibrate the acoustic model, measurements obtained during the 2024 edition of the festival were used. It is important to highlight that the directionality function of the sound sources was applied. In the IMMI software, this feature allowed for directionality to be configured by frequency bands, enabling precise control over sound propagation in relation to the sound system setup.

To characterize the sound sources, the client reported that the sound system setup includes a total of 16 PA (Public Address) loudspeakers directed toward the audience, arranged on both sides of the stage (8 on each side), in addition to 2 subwoofers and 4 woofers on each side in the inner area, oriented toward the center of the stage and directed at the performers.

For the simulation, JBL VT4889 speakers (commonly used in concerts of this type) were used to configure the audio system. To ensure accuracy in the acoustic model, the emitter points in the software were configured with the specific directivities of the JBL VT4889 [12], according to the manufacturer's specifications, shown in Figure 2, allowing a simulation that faithfully reflects the acoustic behavior of the event. The audio spectrum simulated in the project was pink noise, emitting around 134 dB of sound power.

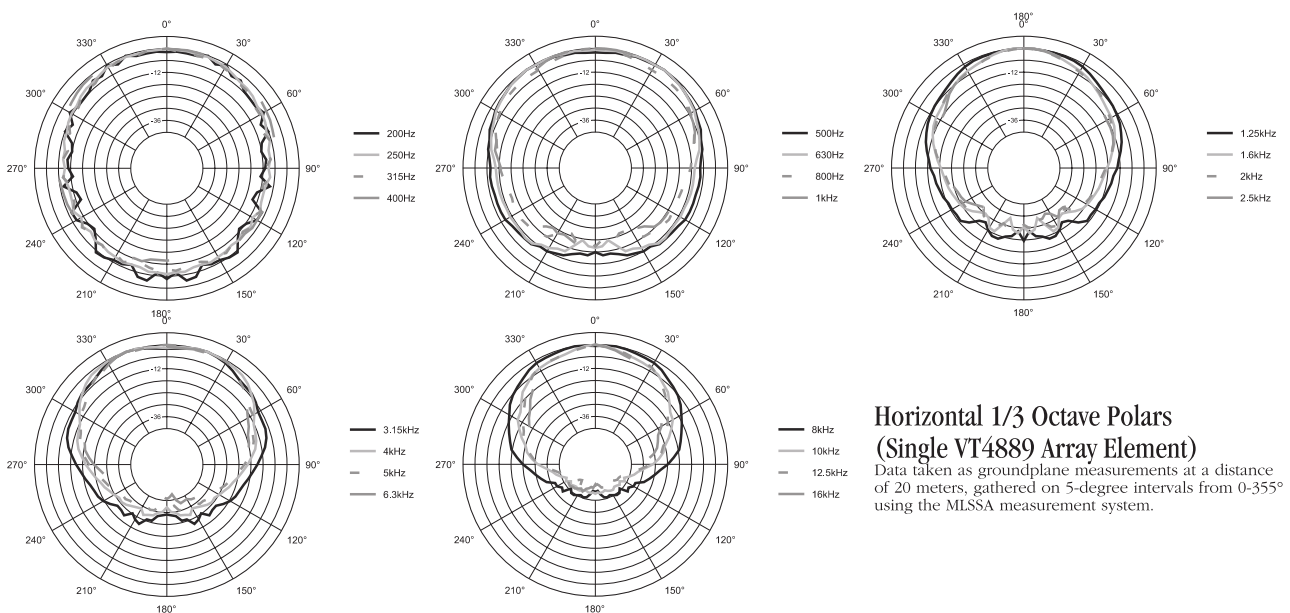


Figure 2: Frequency-dependent directivity of the JBL VT4889 loudspeaker [12].

In order to meet the limits set by ABNT NBR 10151:2019 [1], two types of inhabited areas were considered. In the hospital region, the area was categorized as “strictly urban residential area or hospitals or schools”, with limits of 50 and 45 dB for daytime and nighttime, respectively. For the other regions, which have a combination of residences, commercial establishments and some industries, the classification adopted was “Mixed predominantly residential area”, with limits of 55 and 50 dB for daytime and nighttime, respectively.

With the model adjusted, we moved on to the acoustic interventions phase, which included

repositioning the stage, installing acoustic barriers and analyzing sound directivity. The aim of these actions was to identify the most effective solutions for the 2025 edition of the event. Once the solutions had been detailed, the city council was responsible for implementing the simulated interventions, after which new measurements were carried out to check that the expectations generated by the simulation had been met.

After implementing various actions that will be discussed throughout this study, new acoustic measurements were conducted at the previously defined positions. In addition to measurements taken at a height of 1.6 meters above ground level, measurements at 4.0 meters height were also included.

4. RESULTS AND DISCUSSION

To obtain an accurate acoustic simulation, monitoring measurements conducted in the vicinity during the 2024 edition were used. With data on the stage location, sound system configuration, and measurement points, it was possible to calibrate the current scenario model. Figure 3 shows these measurement points, highlighting the hospital location in red and the stage in yellow, in addition to the simulation of sound emission from raised female voices. These points served as a reference for the computational simulation, helping to calibrate the current model and evaluate improvements after acoustic interventions.

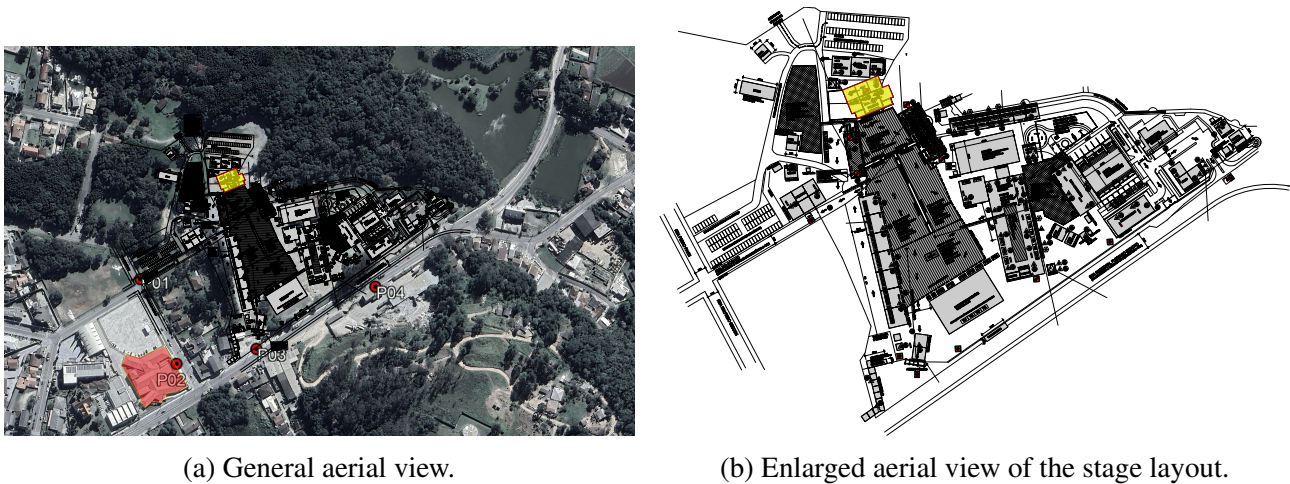


Figure 3: Map showing the location of measurement points and the stage.

In previous editions, the stage was located as shown in Figure 3b, resulting in noise propagation that directly affected the hospital and neighboring residences. Figure 4 presents the noise maps of the initial scenario, calculated at 1.6 meters. Figure 4a illustrates noise propagation in an aerial view, while Figure 4b shows a perspective to understand how noise affects the hospital. Figure 4c represents the cross-section from the stage to the hospital, which shows the vertical noise map calculated up to 50 meters in height.

Scenarios were simulated with the aim of identifying ways to reduce festival noise and mitigate the sound impact on the hospital.

Scenario 01: The first solution was the implementation of acoustic insulation on the side walls, ceiling, and back of the stage, and behind the projection screens. This intervention aimed to minimize sound dispersion towards the surroundings and reduce the acoustic impact in areas external to the event, in addition to improving sound quality on the stage, benefiting musicians and artists. This solution served as a premise for all subsequent scenarios.

The result is an insulation system capable of containing sound within the stage area, blocking sound energy and minimizing scattering outside the show area. Acoustic insulation was essential to reduce the sound pressure level propagating to areas behind the stage, decreasing the event's impact on the surrounding urban environment and directing the sound towards the target audience.

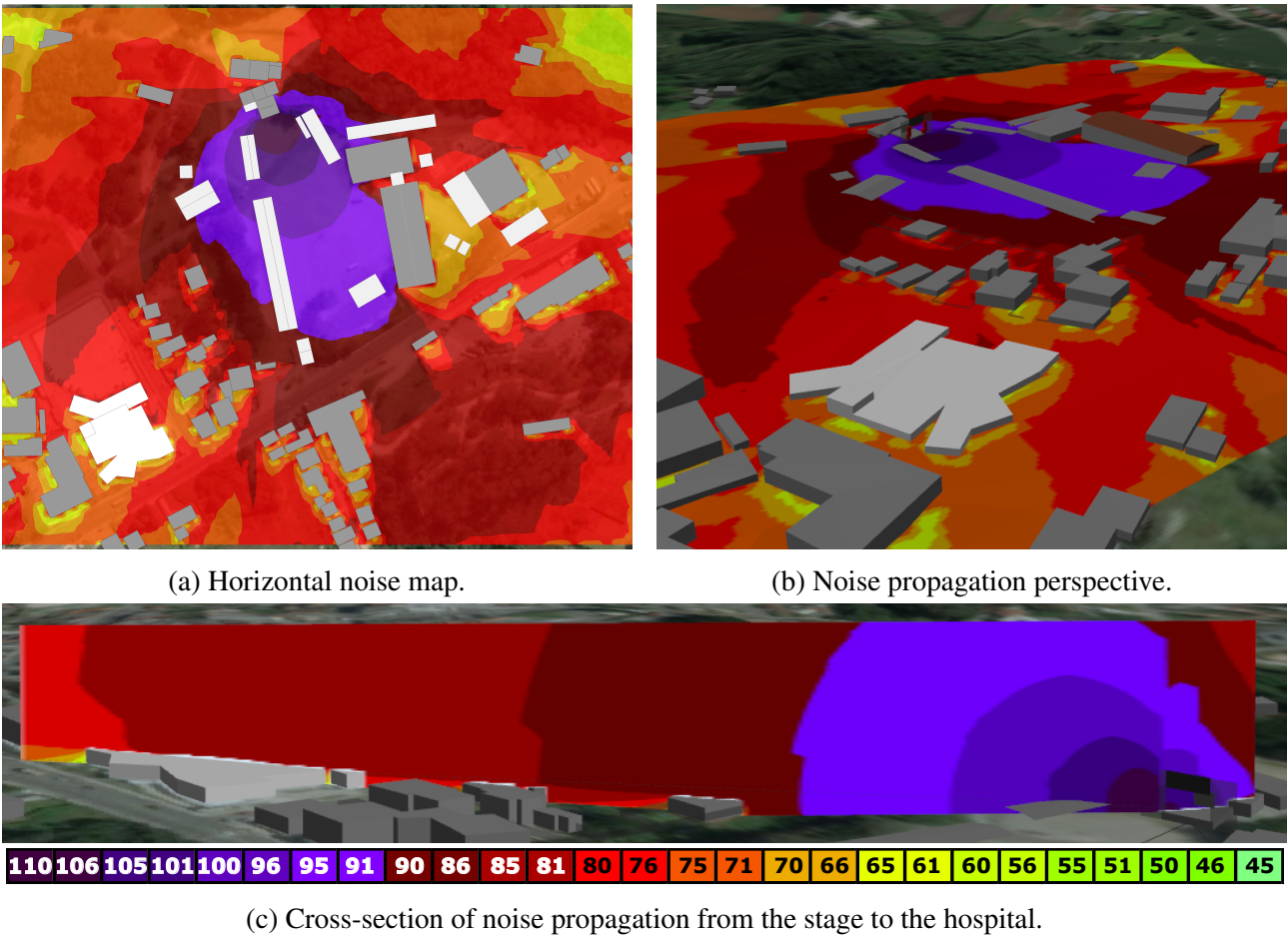


Figure 4: Initial Scenario - Noise maps from computational simulation in IMMI software, based on 2024 Edition measurements.

The implemented acoustic insulation measures were previously tested in acoustic simulations, which indicated a significant reduction in sound transmission to the back of the stage, as shown in Figure 5.

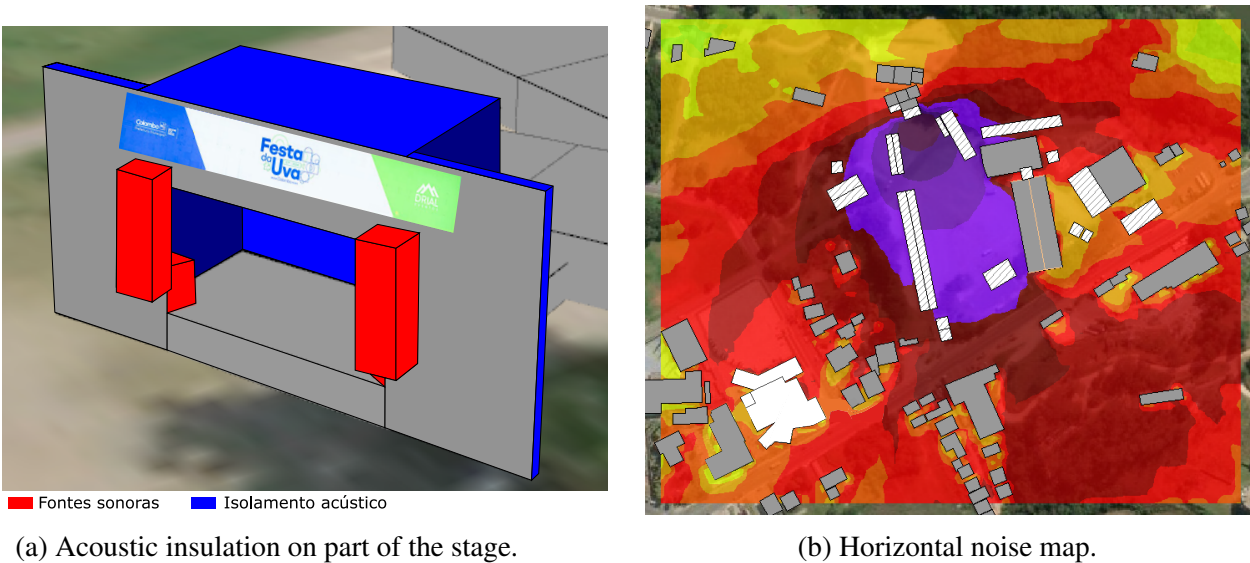


Figure 5: Scenario 01 - Configuration and noise map.

For this scenario, it is important to note that the focus of an insulation system is to contain sound within the stage area, blocking sound energy and minimizing scattering outside the show area.

Acoustic insulation was essential to reduce the sound pressure level propagating to areas behind the stage, decreasing the event's impact on the surrounding urban environment and directing the sound towards the target audience.

The implemented acoustic insulation measures were previously tested in acoustic simulations, which indicated a significant reduction in sound transmission to the back of the stage. As this intervention was only on the side opposite to the sound directionality towards the audience, the results obtained at the control points remained unchanged.

Scenario 02: Acoustic barriers were simulated between the main sound emission areas, considering different heights, positions, and materials with high absorption and acoustic insulation capacity. The barrier arrangement was designed to create a physical barrier to the propagation of sound waves, simulating ideal conditions for a significant reduction in sound pressure levels towards the hospital.

An overestimated barrier 12 meters high was simulated, located in the western region, between the stage/audience and the hospital. The height value was intentionally overestimated to simulate an extreme scenario and observe how this condition impacts the model, being used exclusively for analysis and testing purposes, as shown in Figure 6.

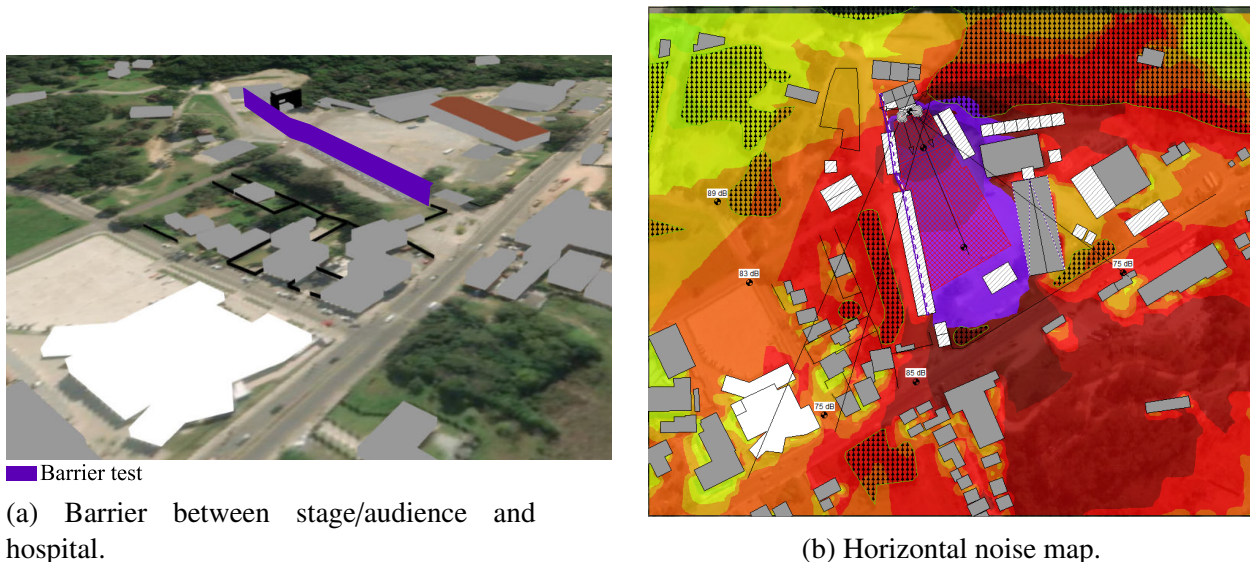


Figure 6: Scenario 02 - Configuration and noise map.

The simulation results indicated that the acoustic barriers were not effective in achieving the expected noise reduction levels. Data analysis revealed that several factors limited the effectiveness of the barriers. Firstly, the large open space of the festival allowed sound waves to propagate via indirect routes, bypassing the barriers. Furthermore, the presence of multiple noise sources at different points of the event contributed to sound diffusion, reducing the impact of acoustic barriers. Another relevant aspect was the dispersion of sound waves. This phenomenon resulted in a diffuse propagation of sound, which proved difficult to contain even with additional barriers.

Scenario 03: With the objective of reducing the incident noise on the Hospital premises, new positions for the stage were tested, seeking to minimize sound propagation towards the sensitive area. The simulations considered different orientations and locations of the stage within the available space, evaluating how each configuration influenced the direction and intensity of emitted sound waves.

Scenario 03.A: The first position simulated was close to the one adopted in the 2024 edition, shifted westward and redirected, aiming for less direct line of sight with the Hospital, as demonstrated in Figure 7.

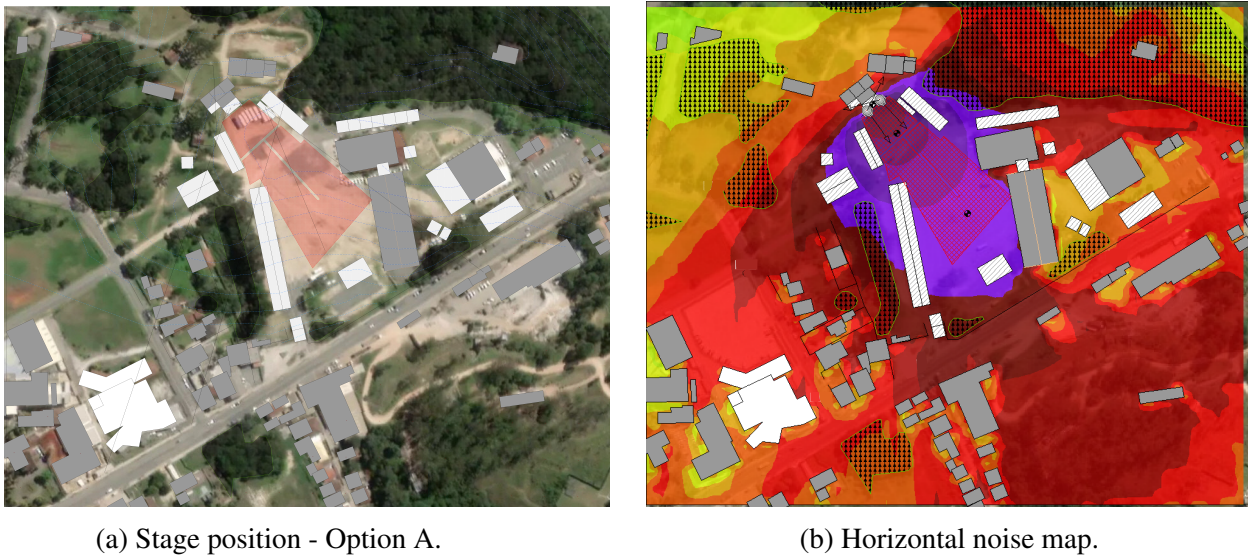


Figure 7: Scenario 03.A - Configuration and noise map.

Stage repositioning "A" yielded varied results: while in some points there was a small reduction in incident noise levels, other points showed a significant increase in sound exposure, which ended up intensifying the acoustic impact in certain areas. This behavior is due to the new distribution of sound waves, which directed the sound unevenly, creating "shadow zones" with lower noise, but increasing the impact in previously less affected regions.

Given this, it became clear that this stage repositioning alternative proved ineffective for consistent noise mitigation, as it continues to significantly impact the hospital area. Thus, repositioning "A", even with acoustic insulation on the stage, did not prove to be an efficient solution for reducing noise in the hospital's surroundings.

Scenario 03.B: The second position simulated was near the southern entrance of the Municipal Park (Parque Municipal da Uva), with the stage redirected northward, aiming to direct the noise in an indirect orientation towards the hospital, as demonstrated in Figure 8.

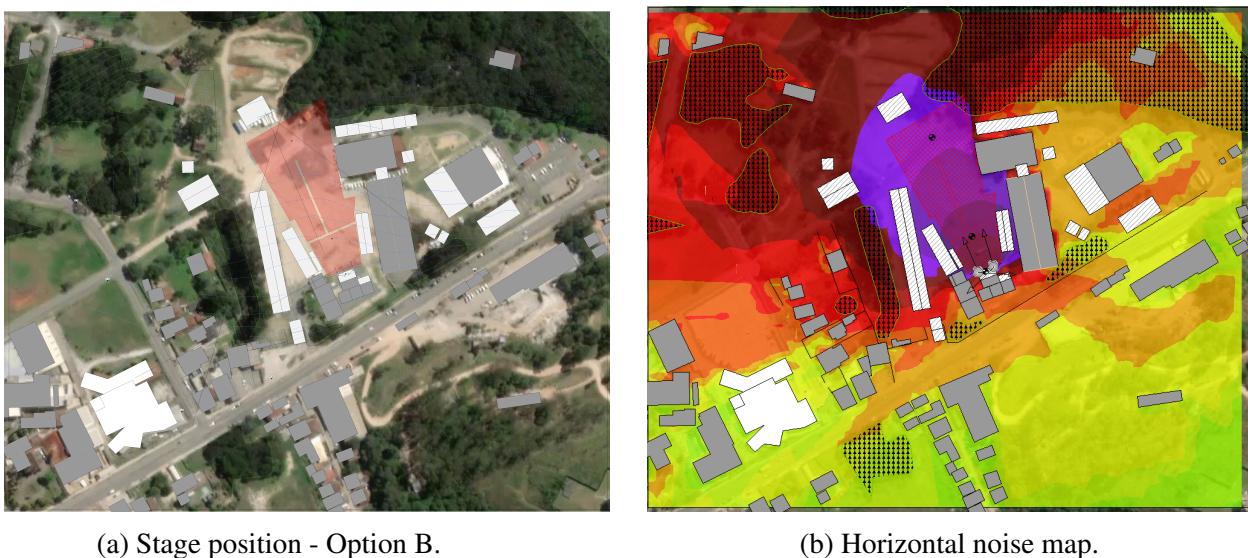


Figure 8: Scenario 03.B - Configuration and noise map.

Stage repositioning "B" brought an improvement in results, especially at the previously defined control points, where a more consistent reduction in noise levels was observed. This configuration proved to be a more effective alternative, providing greater control over the direction of sound

propagation and attenuating the impact on the hospital.

However, although the repositioning brought significant improvements at the receptor points, there are still indications that the noise may continue to interfere in the hospital areas under specific conditions, as the color map showed orange tones near the hospital, indicating higher levels in the parking lot, for example.

Scenario 03.C: The third position simulated was also near the southern entrance of the Municipal Park (Parque Municipal da Uva), with the stage redirected eastward, aiming to direct the noise in an orientation opposite to the hospital, as demonstrated in Figure 9. Furthermore, bass cancellation was studied for the opposite side of the stage, where the hospital is located.

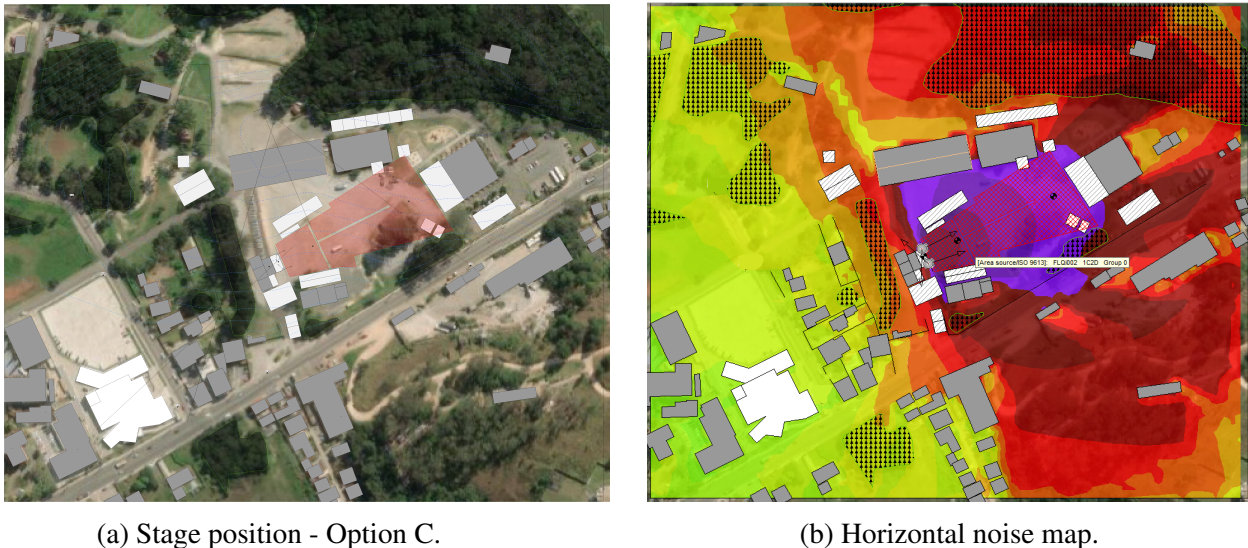


Figure 9: Scenario 03.C - Configuration and noise map.

Stage repositioning "C" yielded the best results, providing a significant reduction in noise levels at the control points near the Hospital. This repositioning directed the sound more effectively, significantly decreasing propagation to the area of interest and reducing the acoustic impact on the hospital.

In Scenario 03.C, interventions using acoustic barriers were simulated as part of the strategy to reduce the sound impact. However, due to budgetary constraints, the implementation of these barriers was not approved, despite significantly helping with noise in the hospital area. The high cost of these solutions is a challenge, especially because open environments and events that produce very high sound levels require more complex, robust, and large-scale solutions to efficiently attenuate noise.

The implemented solution was the stage repositioning, which previously had a direct line of sight to the hospital and demanded significant changes, impacting various aspects of the event. This included the relocation of various event areas, such as escape routes, cabling, parking areas, among others, which were previously in predefined locations. Furthermore, there was an improvement in the electroacoustics of the sound system, with special attention to low-frequency cancellation behind the stage. The main objective of these actions was to minimize the acoustic impact on the hospital as much as possible. Even with the stage repositioning, which ended up being closer to the hospital, the simulated and calculated interventions demonstrated a significant reduction in noise in this specific area.

In 2025, measurements were conducted during one night of the music event, without audible interferences from natural phenomena such as thunder and rain. Sound level measurements were performed at the same evaluation points presented previously, carried out according to the technique described in the Brazilian standard ABNT NBR 10151:2019 [1], which deals with the measurement and evaluation of sound pressure levels in inhabited areas. Residual sound was also collected at the hospital for comparison with the standard. Fusion and Black Solo sound level meters were used to

collect sound samples at heights of 1.6 and 4.0 meters from the ground, respectively. Measurements were performed at positions away from reflective surfaces (such as walls and barriers), ensuring a minimum distance of 2 meters, in order to avoid distortions in the results caused by sound reflection.

At the hospital, which constitutes the main object of this study and was evaluated at Point P02, the interventions resulted in a significant reduction in the sound pressure level, reaching 56 dB (L_{tot}) during the event. To evaluate the specific impact of the music event at this point, the difference between the total level (L_{tot}) and the residual level (L_{res}) was analyzed. It was verified that, for the measurements performed during the nighttime period, both at 1.6 and 4.0 meters above the ground, the arithmetic difference between L_{tot} and L_{res} was less than 3 dB. The measurements did not include impulsive or tonal characteristics, thus, evaluation was done using the simplified method. According to Section 9.2.3 Note 2 of standard ABNT NBR 10151:2019 [1], when this difference is less than 3 dB, it is concluded that it is not possible to attribute responsibility to the sound source (the event), as the residual sound level of the region is very close to the total measured level.

At Point P03, a value above the normative limit was verified. Despite this, it is important to note that this area is predominantly occupied by industrial establishments, without the presence of residences. The measurement results for each point at a height of 1.6 meters, conducted during the 2024 and 2025 editions, are presented in Table 1, in addition to the simulated results for each scenario.

Table 1: Comparison of measurement points: 2024 Edition with values simulated by acoustic simulation software and real values measured in the 2025 Edition.

Point	L_{tot} 2024 Ed.	C01	C02	C03.A	C03.B	C03.C	L_{res} 2025 Ed.	L_{tot} 2025 Ed.
P01	83	83	70	81	78	61	-	-
P02	75	75	69	76	60	55	54	56
P03	86	86	83	84	70	72	-	74
P04	77	77	77	78	66	88	-	-

where the scenario abbreviations: Ed, C01, C02, C03.A, C03.B, and C03.C correspond to Edition, Scenarios 01, 02, 03.A, 03.B, and 03.C. Furthermore, L_{tot} indicates the Total Sound Pressure Level and L_{res} the Residual Sound Pressure Level.

As measurements were performed at different heights from the ground for a more complete analysis of sound propagation, for measurements at a height of 4.0 meters, the values recorded were 57 dB for Point P02 and 78 dB for Point P04. However, for the specific evaluation of the impact on the hospital, the analysis focused on the data collected at 1.6 meters height. This evaluation approach was taken because the hospital is a ground floor building, with windows and reception areas located in this height range, which are the most relevant receptors for this study.

5. FINAL CONSIDERATIONS

The present study highlights the importance of ensuring an appropriate sound environment in urban areas, especially in regions near locations where outdoor music events occur, which can generate significant acoustic impacts. The analysis and mitigation of noise levels are fundamental not only for the comfort and well-being of the community but also to protect the health and quality of life of residents located in sensitive areas, such as near hospitals. This work demonstrated how calculated and well-planned interventions, based on accurate computational simulations, can effectively reduce the sound impact of these events on the neighborhood.

In the 2024 edition, the stage was positioned differently compared to the 2025 edition, which significantly altered the local acoustic scenario. Improvements were implemented in the directivity of sound propagation, as recommended by the study. These joint interventions led to a reduction in noise levels in the vicinity, with this decrease being particularly relevant to the São Rafael Arcanjo

Hospital.

In shows held in open parks with high sound pressure levels, meeting the limits of standard ABNT NBR 10151:2019 [1] presents significant challenges. In the specific case of this study, the 45 dB limit required by the most restrictive zoning for the nighttime period becomes unattainable given the nature of the event. Although the limits established by the standard were not fully achieved, the measures adopted resulted in a significant reduction in noise levels, providing better comfort to neighboring regions. Furthermore, the standard states that in situations where the residual sound level of the region is very close to the total measured level, it is not possible to attribute responsibility for the noise to the sound source in question.

In the planning phase of outdoor music events, the use of computational software is essential. It enables the performance of predictive studies and the dimensioning of effective solutions to avoid negative impacts during the realization of the events. Understanding how the noise from these events propagates and can be mitigated, through these tools, is crucial not only for the community's well-being but also to ensure the continuity of these events.

ACKNOWLEDGEMENTS

The authors would like to thank the Municipality of Colombo for supporting this study on noise mitigation at the Festa da Uva. Special thanks go to Júlio César Marquez for his fundamental help in carrying out this work, from beginning to end.

REFERENCES

1. Associação Brasileira de Normas Técnicas, Rio de Janeiro. *NBR 10151, Acústica — Medição e avaliação de níveis de pressão sonora em áreas habitadas — Procedimento*, maio 2019.
2. Ana Maria Liner Pereira Lima, Felisberto Cavalheiro, João Carlos Nucci, Maria Alice de Lourdes Bueno Sousa, Nilva de Oliveira Fialho, and Paulo Celso Dornelles Del Picchia. Problemas de utilização na conceituação de termos como espaços livres, áreas verdes e correlatos. In *Anais do II Congresso Brasileiro de Arborização Urbana*, pages 539–553, São Luís/MA, setembro 1994.
3. M. I. S. Escada. Utilização de técnicas de sensoriamento remoto para o planejamento de espaços livres urbanos de uso coletivo. Dissertação de mestrado, Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, 1992.
4. Open-air events from the point of view of sound immission control, <https://immi.woelfel.de/fileadmin/download/info/IMMI-Newsletter-2017-Q1-EN.pdf>, 2017.
5. International Organization for Standardization (ISO), Geneva, Switzerland. *ISO 9613-2:2024 - Acoustics — Attenuation of sound during propagation outdoors — Part 2: General method of calculation*, 3rd ed. edition, 2024.
6. L.L. Beranek. *Acoustics*. Amer Inst of Physics, 1986.
7. S.R. Bistafa. *Acústica aplicada ao controle do ruído*. Blucher, São Paulo, 3 edition, 2018.
8. Stefan Feistel, Janosch Blaul, Tobias Goldmann, and Andreas Nicht. Sound immission modeling of open-air sound systems. In *AES 157th Convention*, New York, NY, USA, October 2024.
9. Conselho Nacional do Meio Ambiente (CONAMA), Brasília. *Resolução CONAMA nº 001, de 23 de janeiro de 1990 - Dispõe sobre critérios básicos e diretrizes gerais para a avaliação de impacto ambiental*, 1990. Publicada no Diário Oficial da União de 24/01/1990.
10. Immi - Software for Immision Prognosis, Accessed on 25 May 2025. Available at: <https://immi.woelfel.de/en/>, 2025.
11. Marshall Long. *Architectural Acoustics*. Elsevier, San Diego, 2nd edition, 2014.
12. VT4889 Fullsize Line Array Element Specification Sheet. Accessed on 25 May 2025. Available at: https://jblpro.com/en/site_elements/vt4889-spec-sheet, 2025.