

Acoustic Behavior and Design of Large Urban Spaces – Canyon and Tunnel

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ABSTRACT

Residents of large urban centers are daily exposed to urban noise pollution, especially to noise generated by traffic of vehicles. Environmental noise may harm the environment and the population's quality of life. Therefore, studies that aim to reduce the effects of noise pollution are extremely relevant. In urban divisions, there must be spaces between or in buildings to ensure access for people and vehicles. However, regarding sound transmission, these spaces are considered "weak points" as they ease the passage of urban noise to other spaces that have housing. Thus, this study, carried out in the city of Stuttgart/Germany, evaluates the influence of urban spaces called tunnel and canyon on the transmission of traffic noise to residential facades posterior to these spaces. Two locations were selected: the first with the presence of a tunnel-like space and the second with a canyon-like space. Through measurements and acoustic simulations, the current sound environment of the places was measured. In acoustic simulations, variations of geometric aspects and sound absorption coefficients of the internal surfaces of open spaces were also considered. The results show that the dimensions of open spaces are significant in sound transmission, especially the parameters width and height. The data also show that the installation of coatings with sound absorption on the internal surfaces of spaces is a viable measure from a technical point of view, as it resulted in an attenuation of up to 22 dB(A) on posterior facades.

KEYWORDS: Ambient noise. Sound transmission. Urban Spaces.

1 INTRODUCTION

Currently, noise pollution is one of the main forms of environmental pollution. It is directly responsible for negative impacts on the environment and on the population's quality of life (GERAVANDI, 2015). In addition to the direct effects on society's health, noise pollution may also have negative economic impacts given that properties close to noisy areas may suffer devaluation in the real estate market (FURLANETTO, 2012, SOUZA, 2017).

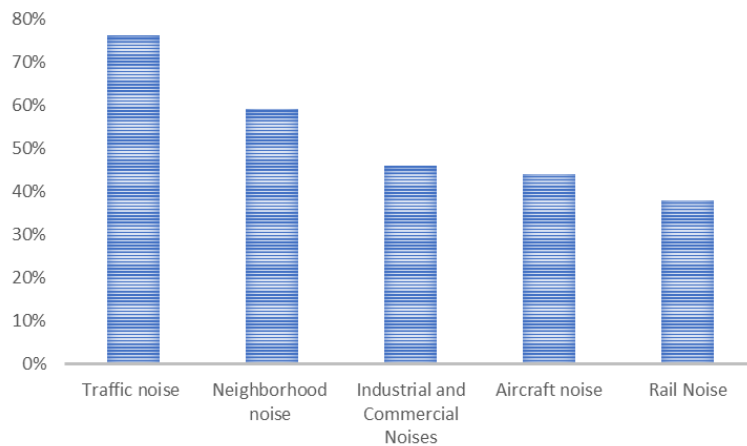
The combination of different sound sources in large urban centers, such as alarms, ambulance sirens, churches, civil construction works, traffic noise, and industries, have contributed to an increase in noise levels, which may make the urban environment unpleasant. Often the impact of sounds impairs the performance of different tasks, such as studying, working, and even resting (GUEDES et al., 2011; SZEREMETA, 2007; MILANEZ, 2013).

The characterizing agent of urban noise pollution is called urban noise or environmental noise, which is considered a complex noise as it is composed of several portions of secondary noise from different sources and activities (WHO, 2011). Therefore, to eliminate or attenuate this type of noise, it is necessary to intervene in each portion that composes it (WHO, 2011).

Among the several existing urban noise sources, noise from road traffic in large urban centers is the portion that most contributes to urban noise pollution, since, in terms of duration, it is permanent and not punctual, that is, it is not limited to a single area (KHAN et al., 2018; ZANNIN et al., 2019). Road traffic noise is a fraction of the noise generated and radiated laterally to a highway, which aggregates traffic sources whether they are performing transit functions (circulation and parking) or services (road works) (VDA, 1978; JOHNSON & SANDERS, 1968; GILES-CORTI et al., 2016).

Studies have shown that the negative effects of traffic noise are becoming more and more noticeable and that a large portion of the population feels annoyed by noise pollution. A survey conducted in 2016 by the *Bundesministerium Für Umwelt, Naturschutz, Bau Und Reaktorsicherheit Umweltbewusstsein* (BMUB) in Germany pointed out that more than 70% of Germans feel annoyed by traffic noise (Figure 1).

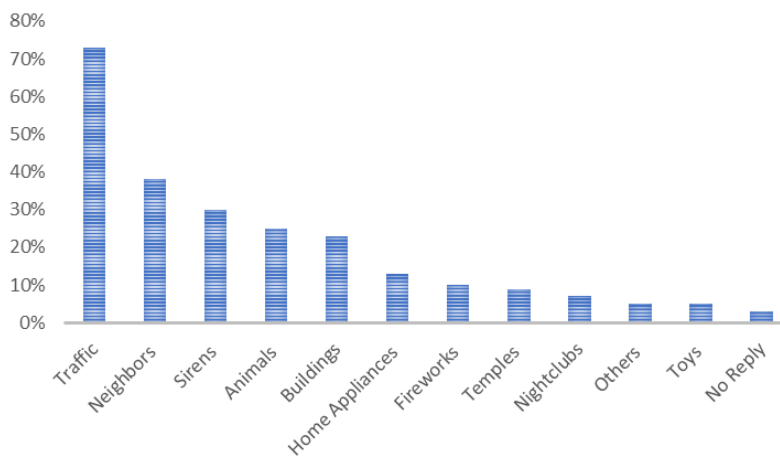
Figure 1: Perception of the German population to noise



Source: BMUB, 2016.

In agreement with the results obtained in Germany, a study developed by Zannin et al. (2002) traced the reaction of the population of Curitiba to environmental noise and pointed out that of the 863 people interviewed, 73% indicated urban traffic noise as the main source of discomfort (Figure 2).

Figure 2: Perception of the Brazilian population to noise



Source: Zann et al., 2002.

Due to the problems above, this study is an exploratory, case study research with collection and analysis of measured and simulated data. The objective is to investigate the acoustic behavior regarding the sound levels transmitted to facades posterior to spaces described as canyon and tunnel sections. The present work also presents the analysis of surfaces with sound absorption as a mitigating measure aiming to improve the population's acoustic comfort and compliance with the current environmental comfort standards in Brazil and in Germany.

2 OBJECTIVES

This research aims to evaluate the acoustic behavior of urban buildings in large open spaces described as canyon and tunnel sections in the city of Stuttgart, Germany.

2.1 Specific objectives

- Characterize first floor facades in urban buildings affected by environmental noise in the city of Stuttgart, Germany;
- Recognize the main urban source(s) of environmental noise in the city of Stuttgart, Germany;
- Identify the open urban spaces that are objects of study in the city of Stuttgart, Germany;
- Quantify current acoustic quality on facades located posterior to urban open spaces;
- Quantify the sound transmission between urban open spaces relative to their geometry and construction materials;
- Compare results according to guidelines specified in Brazilian and German standards;
- Evaluate the general panorama of the acoustic quality on the facades located posterior to urban open spaces;
- Propose mitigating measures aiming the acoustic comfort of the population and compliance with Brazilian and German acoustic comfort standards.

3 METHODOLOGY

For the analysis of sound transmission between urban open spaces, two locations were selected, both at the *Rotebühlstraße* in the city of *Stuttgart, Germany*. The first is a tunnel-like space (Figure 3a) and the second is a canyon-like space (Figure 3b).

Figure 3: Urban open spaces assessed – tunnel (a) and canyon (b)



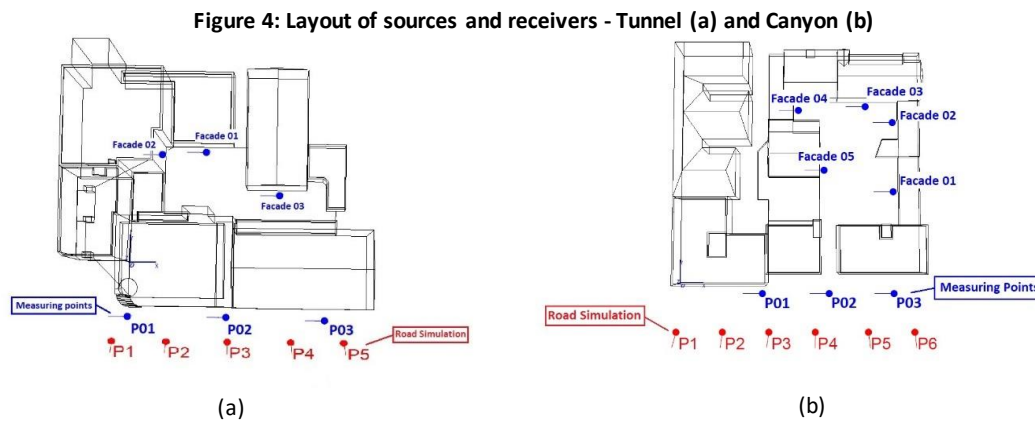
Source: The Authors, 2020.

A tunnel-type space is a superficial gallery in a building with a wide, extensive, and covered section used as a support structure, enabling or facilitating access to a given location. An urban canyon can be classified as the opening between two buildings with an extensive, wide, and uncovered corridor section that may or may not be used for passage to a certain location.

The study sites are characterized by constant noise impacts due to traffic noise generated by the intense flow of vehicles on the *Rotebühlstraße*. Thus, to characterize the noise in these places, measurements of sound pressure levels (SPL) *in situ* were made using a *Norsonic AS* type I sound meter, model NOR 140. Acoustic simulations were also carried out

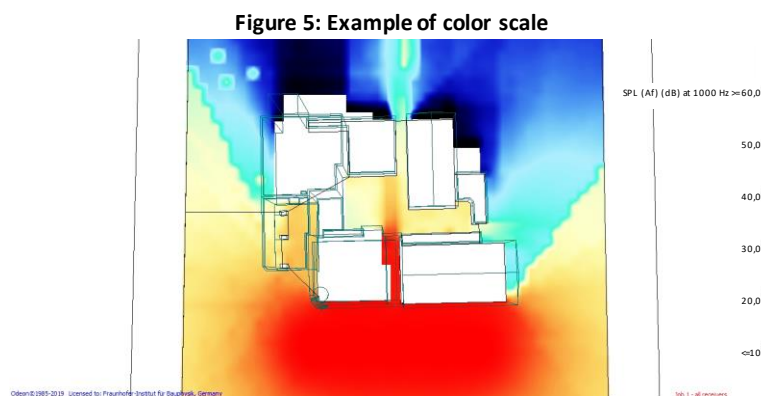
using the *software Sketchup®*, specialized in digital design, and *ODEON 15.15 Auditorium®*, used for calculations and mapping of sound dispersion.

Once the geometric bases of the models were created in the *Sketchup®* environment, they were exported to the *ODEON 15.15 Auditorium®*. Subsequently, the SPL sources and receivers of interest were defined in the acoustic mapping software (Figure 4).



Source: The Authors, 2020.

After adjusting the sound sources, receivers and materials, the calculation grid must be defined in ODEON, that is, the user must inform which surface(s) of interest can view the SPL results on the receivers and the color chart of the acoustic behavior in the evaluated locations. Therefore, the command to calculate all sound interactions present in the model was used, resulting in the acoustic map with color scale, as exemplified in Figure 5.



Source: The Authors, 2020.

To evaluate the influence of materials used on the internal surfaces of tunnels and canyons on SPL transmission, simulations were carried out with representative materials for the current situation, that is, masonry cladding. Subsequently, variations in the sound absorption coefficients of internal surfaces of the evaluated spaces were adopted, thus changing the sound transmission patterns between open spaces.

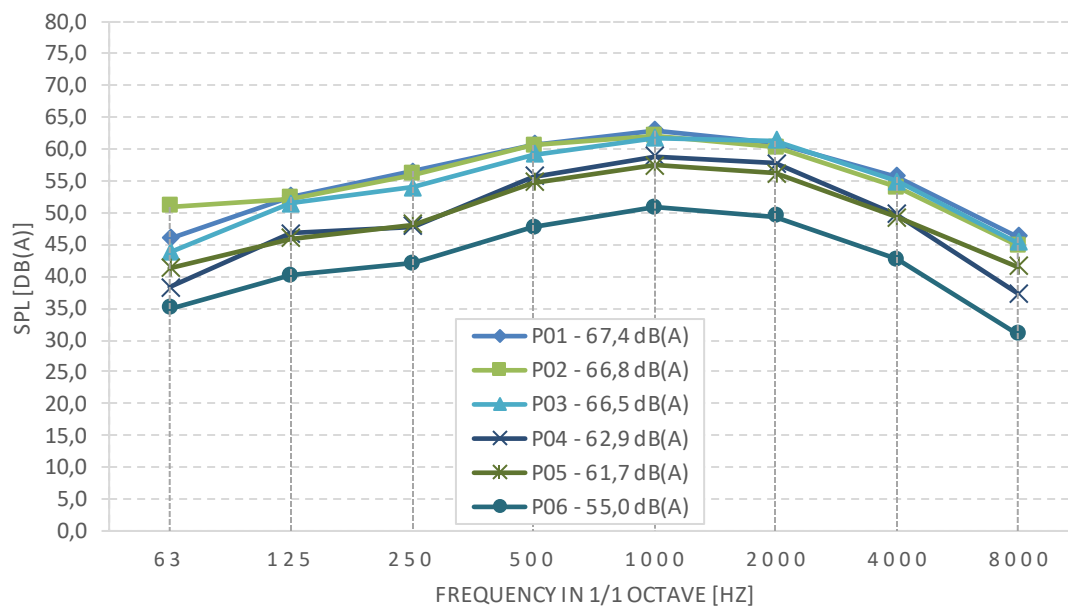
All results were compared with the limits stipulated by standards established by the German Technical Instruction for Noise Protection (*Technische Anleitung zum Schutz gegen Lärm*, TA Lärm) and by the norm of the Brazilian Association of Standards and Techniques (ABNT, NBR 10151/2020).

4 RESULTS

4.1 Acoustic Measurements

Acoustic measurements present sound pressure level values in dB with weighting on the A scale. By analyzing the results, it was firstly possible to verify the characteristics of urban road traffic noise at the site. The analysis of frequencies for all measured points presented higher values within the range of 500 and 2000 Hz (Figure 6).

Figure 6: Acoustic measurement results



Source: The Authors, 2020.

Furthermore, the measurements placed the places evaluated in disagreement with the maximum values provided for in the German TA Lärm legislation and the Brazilian standard ABNT NBR 10.151/2020, that is, areas such as health clinics, hospitals, nursing homes, and schools had a limit of 45 dB(A) and strictly residential areas had a limit of 50 dB(A).

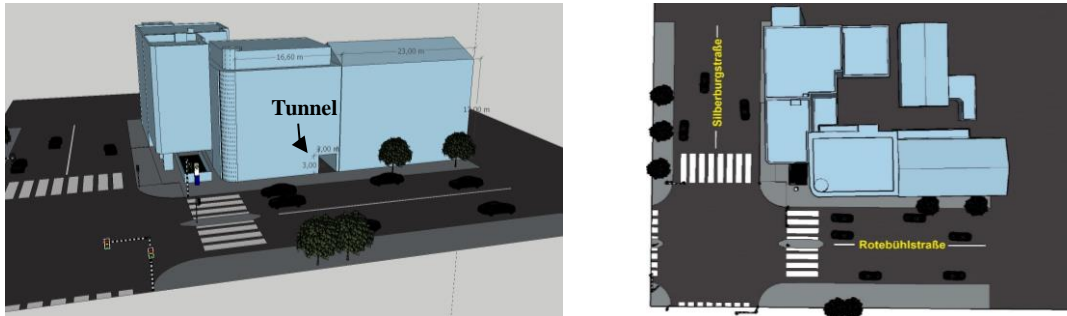
4.2 Acoustic Simulations

This item presents the results obtained with the acoustic simulations, firstly by observing the acoustic behavior in tunnels and urban canyons for the current scenario. Then, the results achieved with variations in geometric dimensions and materials used in the interior surfaces of the tunnel and canyon will be exposed and analyzed.

4.2.1 Architectural models

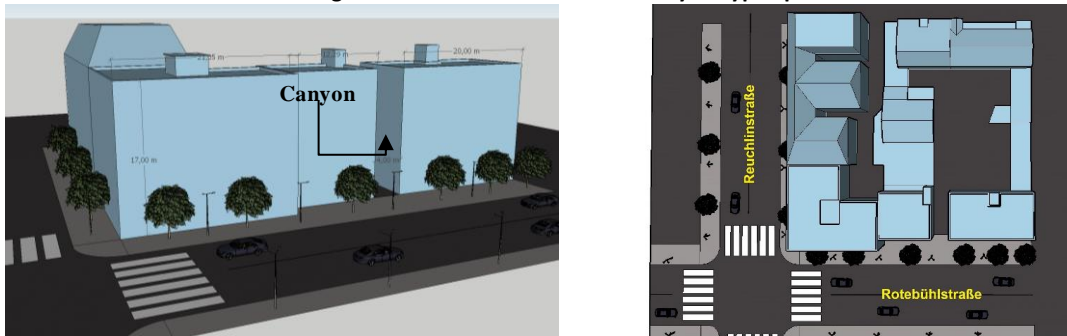
Using the software *Sketchup Pro 2019*[®], the architectural digital patterns of the evaluated spaces were generated (Figures 7 and 8).

Figure 7: Architectural model for tunnel-type space



Source: The Authors, 2020.

Figure 8: Architectural model for canyon-type space

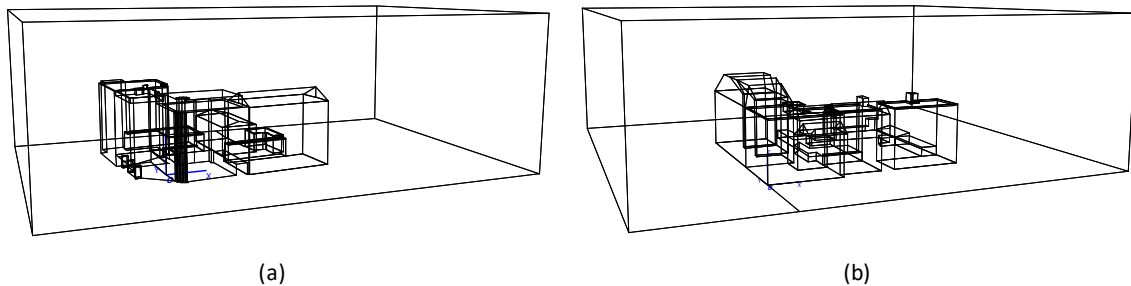


Source: The Authors, 2020.

4.2.2 Model for computer simulations

The export of the architectural models to the *ODEON 15.15 Auditorium*[®] obtains the models used in the acoustic simulations. They are recognized as spaces, voluminous, and geometrically closed, and it is possible to visualize the edges (Figure 9).

Figure 9: ODEON Model Grid - Tunnel (a) and Canyon (b)



Source: The Authors, 2020.

4.2.3 Acoustic simulations - Current situation

Acoustic simulations kept the original dimensions of the evaluated spaces and the materials used on their internal surfaces and presented simulated values for a real approximation of incident sound levels on facades (Table 1).

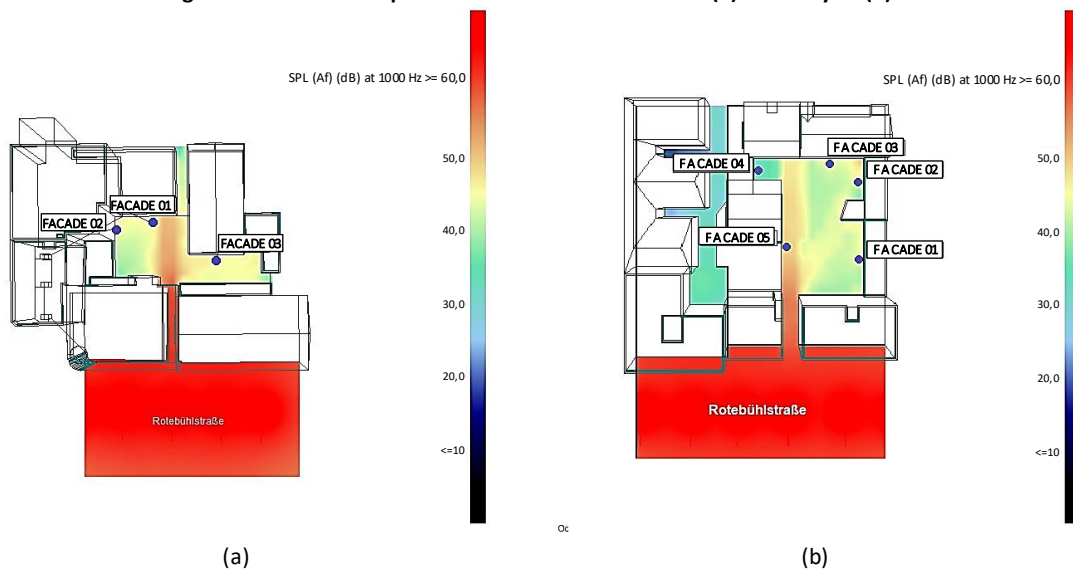
Table 1: Simulated results for the original situation of spaces

Facades	LAeq Results - dB	
	Tunnel	Canyon
Facade 01	51.9	50.5
Facade 02	50.9	48.5
Facade 03	51.3	44.6
Facade 04	--	36.1
Facade 05	--	50.9

Source: The Authors, 2020.

Figure 10 shows the acoustic maps for the frequency of 1000Hz, as it is the component that presents the highest sound levels. The color scale represents the simulated sound levels in the area of interest and the highlighted points resulted in the highlighted values in Table 1.

Figure 10: Acoustic maps for current situation - Tunnel (a) and canyon (b)



Source: The Authors, 2020.

It is evident that some of the post-tunnel and canyon facades are under the influence of traffic noise generated on the nearby road, that is, the sites evaluated do not meet the minimum requirements stipulated by the *TA Lärm* and the ABNT NBR 10.151.

4.2.4 Acoustic simulations - variations in space geometry

To assess the interference of dimensions of open spaces in the transmission of sound levels, geometric variations were considered in the length, width, and height of the tunnel and the canyon evaluated; however, the materials of the internal surfaces were the same.

Table 2 shows the calculated responses for the facades of interest in the tunnel-type space situation.

Table 2: Acoustic simulations with geometric variations - Tunnel

Variation	Simulated dimension (m)		LAeq Results		
	L x W x H		Facade 01	Facade 02	Facade 03
Length (L)	15 x 3 x 3		51.9	50.9	51.3
	12 x 3 x 3		50.1	48.8	51.2
	15 x 4 x 3		54.3	48.7	53.3
Width (W)	15 x 5 x 3		56.8	55.3	54.9
	15 x 6 x 3		57.4	55.8	54.1
	15 x 3 x 3,5		48.7	51.2	53.1
Height (H)	15 x 3 x 4		53.3	51.6	55.6

Source: The Authors, 2020.

Table 3 shows the calculated responses for the facades of interest in the canyon-type space situation.

Table 3: Acoustic simulations with geometric variations - Canyon

Variation	Dimensions		LAeq Results				
	(m) L x W		Facade 01	Facade 02	Facade 03	Facade 04	Facade 05
Length (L)	12 x 4		50.5	48.5	44.6	36.1	50.9
	15 x 4		48.9	42.1	48.1	34.0	52.9
	15 x 3		48.1	39.7	43.5	31.4	51.2
Width (W)	15 x 5		50.7	46.8	50.1	46.8	52.5
	15 x 6		51.3	48.4	51.1	48.9	54.6

Source: The Authors, 2020.

The assessment of the influence of geometric aspects of spaces showed more significant trends for the increase in the levels of sound pressure incident on facades behind tunnels as the measurements of width and height increased. For the canyon-type opening, a similar phenomenon occurred: by increasing its width, there were relevant increases in the sound levels on posterior facades.

The simulated results also showed that traffic noise transmitted between open spaces affect facades, since these facades presented sound level values in disagreement with the limits of the *TA Lärm* and the ABNT NBR 10.151/2020. Thus, mitigation measures were tested using materials with sound absorption capacity on the interior surfaces of tunnels and canyons.

4.2.5 Acoustic simulations - material variations as a mitigating measure

This item shows the results achieved in using surfaces with sound absorption capacity as a possible measure for attenuating environmental noise on facades. For this purpose, modeled situations considered the inner lining of tunnel and canyon, except for the paving surface, and tested for materials with a greater sound absorption. Thus, materials were selected for the internal surfaces with a sound absorption capacity of 10% ($\alpha = 0.1$), 30% ($\alpha = 0.3$), 50% ($\alpha = 0.5$), and 70% ($\alpha = 0.7$).

Table 4 shows the simulated results with variations in the absorption capacity of internal materials in the tunnel-type space situation.

Table 4: Acoustic simulations with material variations - Tunnel

Sound absorption	LAeq Results		
	Facade 01	Facade 02	Facade 03
Original	51.9	50.9	51.3
10%	51.6	50.1	50.5
30%	50.6	44.3	44.5
50%	50.2	38.9	37.2
70%	50.1	36.8	29.2

Source: The Authors, 2020.

Table 5 shows the simulated values with variations in the absorption capacity of internal materials in the canyon-type space situation.

Table 5: Acoustic simulation with material variations - Canyon

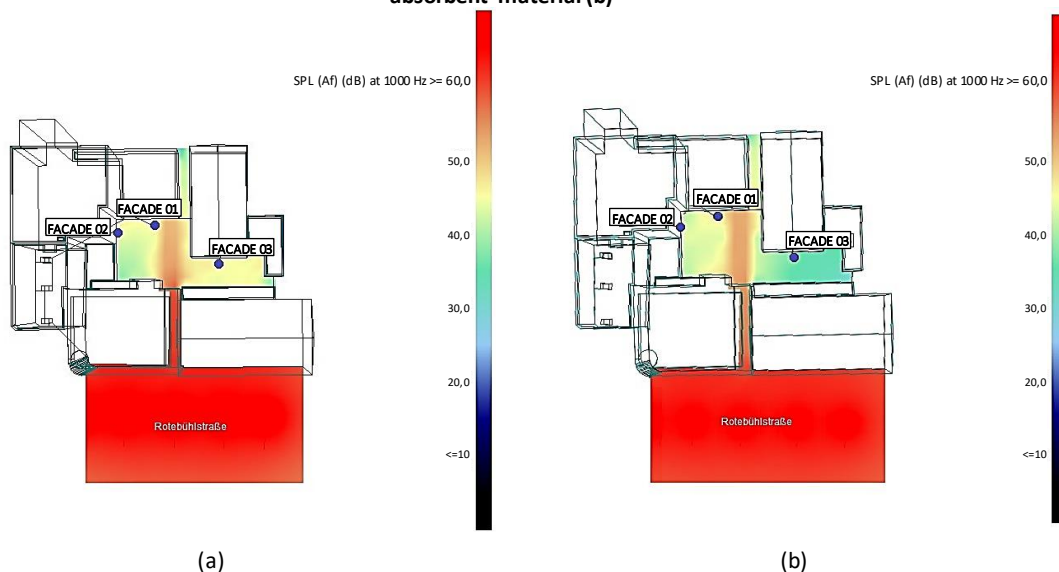
Sound absorption	LAeq Results				
	Facade 01	Facade 02	Facade 03	Facade 04	Facade 05
Original	50.5	48.5	44.6	36.1	50.9
10%	49.9	48.2	44.3	35.9	50.8
30%	45.4	46.1	42.4	34.7	49.8
50%	41.2	44.0	41.1	33.8	49.3
70%	39.3	42.0	40.5	33.2	49.0

Source: The Authors, 2020.

Figures 11 and 12 show the difference between the values obtained with acoustic simulations, considering sound absorption materials. Comparing the situation without the application of absorbent material in tunnel and canyon with the simulated scenario for materials with 70% of sound absorption shows the dispersion of SPL and the influence of materials used in the models.

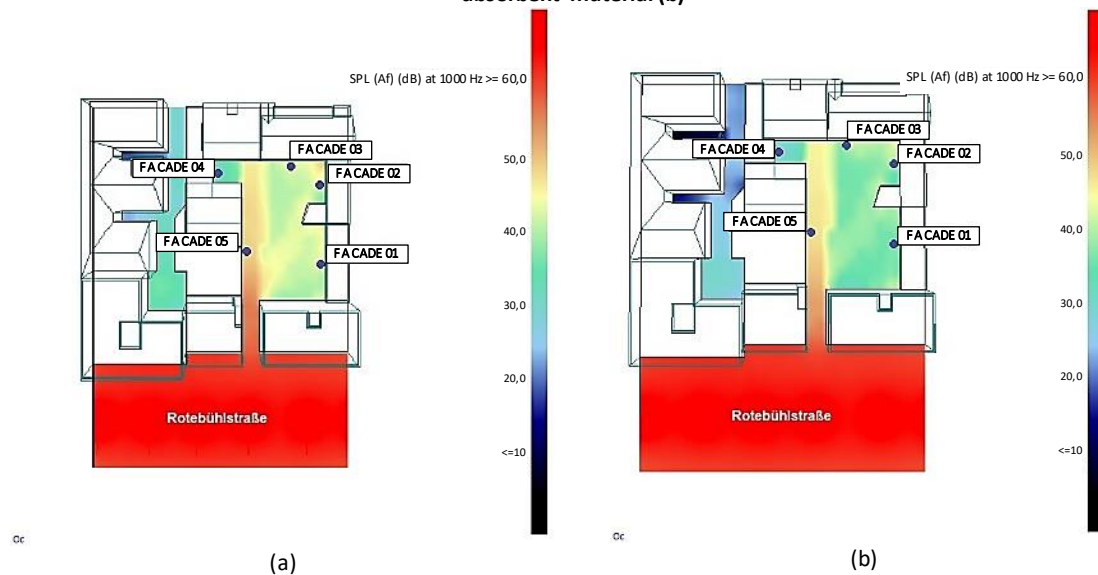
The color scale represents the simulated sound levels in the area of interest and the highlighted points resulted in the highlighted values for each facade, as shown in Tables 4 and 5.

Figure 11: Comparison between tunnel-type acoustic maps - original masonry situation (a) and with 70% absorbent material (b)



Source: The Authors, 2020.

Figure 12: Comparison between canyon-type acoustic maps - original masonry situation (a) and with 70% absorbent material (b)



Source: The Authors, 2020.

The acoustic simulations allowed verifying that, while the absorption capacity of the internal coverings of open spaces increased, there was a gradual reduction of the incident noise levels on posterior facades.

5 CONCLUSION

The acoustic measurements and simulations show that currently the SPL on facades close to the *Rotebühlstraße in Stuttgart, Germany*, are above the values recommended by the German legislation *TA Lärm* and the Brazilian standard *ABNT NBR 10.151/2020*.

Simulations with variations in dimensions show that all post-tunnel facades presented levels above the those recommended and part of the post-canyon facades presented values above the values prescribed by the legislation. Thus, facades, even located after buildings, are susceptible to SPL transmitted in spaces such as tunnels and canyons.

Another point is that, as the sound absorption capacity of the internal surfaces of spaces increased, there were gradual reductions in noise levels on the posterior facades of up to 22.1 dB(A). Therefore, the technique used is a viable alternative to mitigate sound levels.

It can be concluded that this study can support designers, public authorities, and the population in general in understanding the acoustic effects caused by open spaces, as it points out that the variation in width is the constructive parameter that most influenced the sound transmission for facades posterior to gaps. The present work also presents a proposal for a constructive solution to adjust the sound pressure levels in regions that are similar as those which were objects of this study. The study points out that the application of materials with a high capacity for sound absorption in tunnels and canyons, such as mineral wool, results in a significant attenuation in the transmission of sound levels.

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