SPL Monitoring Tool for Events on Campus: Improvement of the Methods to minimise Noise Exposure

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Introduction

At the Campus Inffeldgasse of the University of Technology in Graz about 20 to 30 outdoor events with electro-acoustic sound systems take place every year [1]. Although the university buildings partially form an acoustic shield to the neighbouring residential area, complaints from residents have increased in recent years. Therefore, the university has installed a noise monitoring system in cooperation with the city of Graz in 2019 [2]. A measurement microphone was set up on the roof of a building close to the affected neighbouring residential area (cf. Fig. 1). The sound pressure level, which can be accessed on an external website [3], is to be monitored by the organisers of the events and, if necessary, reduced to certain limit values in order to adhere to the permitted noise limit values on the facades of the neighbouring residential buildings.

In this paper, the legal guidelines that apply around campus will be discussed. Afterwards, the sound propagation on campus is simulated in software and after a subsequent measurement, the noise monitoring system is to be critically examined and improved in this paper.

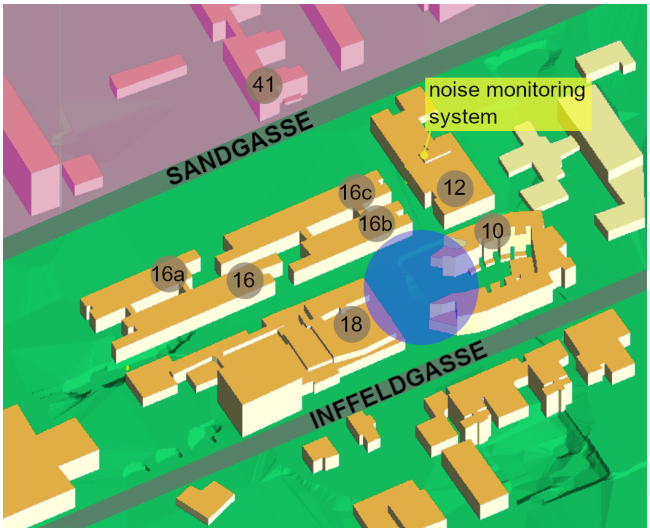

Figure 1: Location map of the Campus Inffeldgasse: event area (blue), noise monitoring system (yellow) and affected residential area (pink) [4].

Statutory guidelines

The limit values used in the noise monitoring system at the Campus Inffeldgasse are anchored in standards and guidelines for events [5]. These limit values mainly refer to the rating level L_r, which corresponds to the A-weighted energy-equivalent continuous level $L_{A,eq}$ with additional adjustment values. Under certain conditions these adjustment values can be neglected [5], resulting in $L_{A,eq}$ as evaluation parameter. Therefore the limit values used in the noise monitoring system refer to $L_{A,eq}$.

Frequency of events on campus

When evaluating noise pollution the used standards and guidelines distinct between frequent and infrequent events. For frequent events the limit values depend on the area where the events take place [5]. According to [6], the residential area around the Campus Inffeldgasse is defined as "general residential area", leading to the limit values shown in Table 1. For infrequent events, which are limited to a maximum of 10 events per year, higher sound pressure levels are tolerated. These limit values should be adhered to at the residents' houses facades and serve as a basis for the limit values used in the noise monitoring system at the Campus Inffeldgasse (cf. Tab. 1).

Table 1: Guideline based limit values depending on the frequency of events and resulting limit values at the noise monitoring system ([1]Events at the Campus Inffeldgasse are only permitted up to 2 am.).

	$L_{A,eq}$ in dB		
	> 10 events/year	≤ 10 events/year	resulting limits
06 am - 10 pm	55	70	70
10 pm - 06 am	40	50	60[1]

Separate consideration of the bass range

By using the A-weighted energy-equivalent continuous level $L_{A,eq}$ (or rating level L_r) to monitor the events on campus, the energy in the bass range is less considered. Since noise with an excessive bass range is perceived as particularly disturbing for residents, it is essential to consider low frequencies more carefully in the evaluation of event noise.

When it comes to spectral evaluation of sound events, the difference between the A- and C-weighting is mainly in the low frequency range (< 1000 Hz). As a result the difference $L_{C,eq} - L_{A,eq}$ is used as evaluation parameter for the energy in the low frequencies [7].

According to [7] bass-dominated music genres can be approximated by the reference spectrum for traffic noise, for which the difference $L_{C,eq} - L_{A,eq}$ is about 10 dB. Therefore this value is directly applied as limitation for the difference $L_{C,eq} - L_{A,eq}$ in the noise monitoring system to monitor the energy in the low frequency range.

Simulation in SoundPLAN

For the simulation in SoundPLAN [4] a 3D model of the Campus Inffeldgasse is created, with concrete selected as the ground covering. Special attention needs to be paid to the sound-reflecting exterior surfaces of certain buildings. For the reflection loss DL_{RI}, which is calculated according to Equation (1) [8], a value of $DL_{RI} = 0.07$ is assumed for the buildings Inffeldgasse 16, 16a, 16b and 16c and a value of $DL_{RI} = 0.5$ for the buildings Inffeldgasse 12 and 18. For all remaining buildings a value of $DL_{RI} = 1$ is assumed.

$$DL_{RI} = 10 \cdot \lg(1 - \alpha) \qquad \text{in dB} \qquad (1)$$

Hereby, α denotes the absorption coefficient.

Definition of the sound source

The sound source is defined using the library available in SoundPLAN, where an electro-acoustic sound system is selected that approximates the equipment often used at large events on campus. Two loudspeaker towers are created, each with a 2-way loudspeaker and two subwoofers, which are defined as point sound sources. The sound source is placed on campus according to the positioning for events and is operated constantly at maximum power.

Definition of the measurement points

Four measurement points are set after the first simulation has been performed (cf. Fig. 2, yellow circles): one reference emission point at the sound source (x_1), one reference immission point at the noise monitoring system (x_2), one immission point at the roof edge of the same building (x_3) and another at the residential building of the most affected neighbours (x_4).

Silicon Austria Labs (SAL-buildings)

New buildings are currently being constructed at the Campus Inffeldgasse [9], located between the emission point x_1 and the immission point x_4. In order to obtain a prediction of the influence of these buildings, they are also taken into account in the simulation.

Measurement on campus

After the simulation a measurement is carried out at the Campus Inffeldgasse to check the results obtained by SoundPLAN under real conditions. Both the emission and immission points are chosen according to the simulation (cf. Fig. 2) and in order to be able to reproduce the sound propagation as well as possible, the excitation signal is reproduced via an electro-acoustic sound system, as it is also used at events [1]:

- 2x MACKIE SRM 550 1600W High-Definition Powered Loudspeaker
- 4x MACKIE SRM 1850 1600W 18” Powered Subwoofer

The measurement is executed with the help of the ITA Toolbox [10], an open source toolbox for MATLAB, which allows to create the excitation signal based on certain specifications and provides helpful methods to analyse the measurement signal. The excitation signal consists of an exponential sweep in the range of 20 Hz to 20 kHz and is repeated five times per measurement to be measured at the chosen measurement points.

Results and discussion

Simulation

The results of the simulation in SoundPLAN are presented through raster noise maps, sectional noise maps and in tabular form.

The simulated level $L_{rT,1h}$, which is denoted as L_S in this paper, is given in dB(A) and refers to the rating level L_r, averaged over the loudest hour of the day.

For the results of the sectional noise maps, a section from the reference emission point x_1 at the sound source towards the immission point x_4 at the affected residential buildings is set (cf. Fig. 2).

When analysing the raster noise maps shown in Figure 2, it is particularly noticeable that an alley of almost

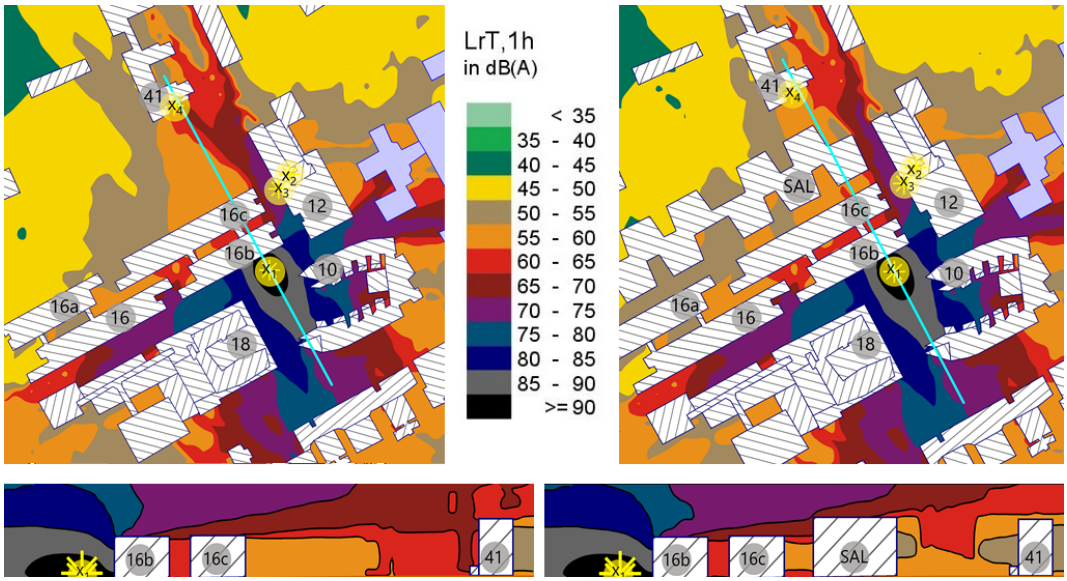

Figure 2: Raster noise maps at 1.5 m height (top) with drawn-in section (turquoise) for sectional noise maps with 25 m height (bottom) showing the sound propagation on campus (left), also including the SAL-buildings (right). The measurement points x_1 to x_4 are marked as yellow circles.

unobstructed sound propagation is formed between the buildings Inffeldgasse 12 and 16b/16c, which means that the residents of the building Sandgasse 41 are most affected by noise pollution.
The placement of the noise monitoring system at the building Inffeldgasse 12 seems reasonable due to this behavior, however a noticeable reduction of the level between the building wall (x_3) and the center of the roof (x_2) is observed (cf. Tab. 2).
In the sectional noise maps in Figure 2 it is shown that the upper floors of Sandgasse 41 are affected the most. If the SAL-buildings are taken into account, a significant improvement of the noise pollution is achieved here.

Table 2: L_S in dB(A) for emission point x_1 and immission points x_2 to x_4 according to the simulation (with SAL-buildings).

	x_1	x_2	x_3	x_4
L_S in dB(A)	96.5	62.3	69.4	61.6 (55.8)

Measurement

For the graphical analysis the measurement results are transformed into the frequency domain. The resulting magnitude spectra are smoothed over octave bands to reduce the ripple, leading to the smoothed magnitude spectra L_p.

Comparison of simulation and measurement

In order to compare the measurement results L_p with the corresponding simulation results L_S, the obtained results are related to the reference emission and immission points x_1 and x_2 by building the difference between the smoothed spectra. The resulting magnitude transfer functions are depicted in Figure 3 as solid lines, in which the magnitude transfer functions are defined as $\Delta_{mn}L$, referring to the difference between the immission point m and the reference emission or immission point n. These magnitude transfer functions are then compared with the corresponding simulation magnitude transfer functions, which are calculated as the difference between the rating levels L_S for each third-octave band (cf. Fig. 3, dashed lines).
The results from simulation and measurement match moderately well. Especially for the very low and high frequency range large deviations can be observed. For low frequencies (< 200 Hz) the differences are constantly underestimated in the simulation for the reference emission point x_1 (wind or traffic noise not taken into account in the simulation). However, high frequencies tend to be overestimated compared to the measurement (dissipation by the environment in reality due to vegetation, building fences, etc.).

Influence of the SAL-buildings

To determine the influence of the SAL-buildings on the sound propagation in the direction of the neighbouring residential area, the results of the simulation in SoundPLAN are used. The sectional noise maps have shown that the SAL-buildings act as a noise barrier towards the buildings in the Sandgasse (cf. Fig. 2, bottom).

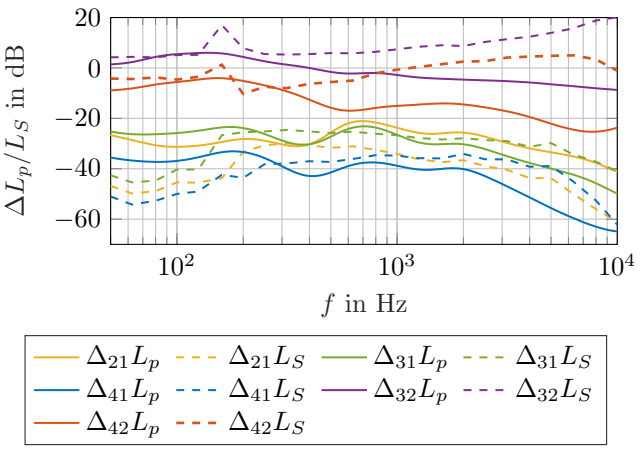

Figure 3: Comparison of the magnitude transfer functions between immission points x_2 to x_4 and reference emission/immission points x_1 and x_2 according to measurement (solid) and simulation (dashed).

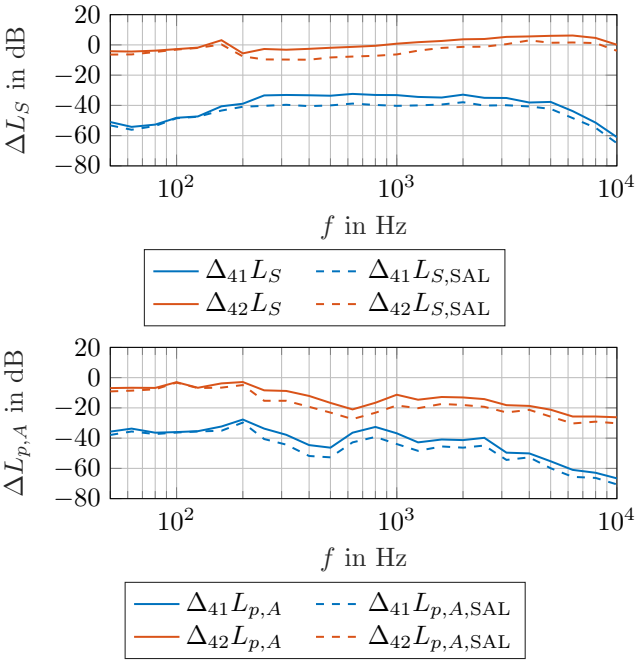

Figure 4: Influence of the SAL-buildings according to the simulation (top) and predicted influence on the magnitude transfer functions obtained by the measurement (bottom) without/with SAL-buildings (solid/dashed).

The results in Figure 4 (top), which show the magnitude transfer function with and without the SAL-buildings, confirm the attenuation of the sound pressure level in the residential area due to the SAL-buildings, especially in the frequency range above 200 Hz.
This observation is used to adapt the magnitude transfer functions obtained by the measurement and to furthermore adjust the limit values for the noise monitoring system. As the corresponding difference

$$\Delta_{\mathrm{SAL}}L_S = \Delta L_S - \Delta L_{S,\mathrm{SAL}} \quad \text{in dB} \qquad (2)$$

between the simulation magnitude transfer function without and with SAL-buildings is given for each third-octave band, the measurement results are considered for each third-octave band as well. The calculation is done

by using Equation (3) to determine the mean A-weighted sound pressure level $L_{p,A}$ per third-octave band.

$$L_{p,A} = 10 \cdot \log\left(\frac{1}{N}\sum_{n}^{N} 10^{\frac{L_{p,A,n}}{10}}\right) \quad \text{in dB} \qquad (3)$$

with:
- $L_{p,A}$ mean sound pressure level per third-octave band (in dB)
- $L_{p,A,n}$ partial level n within the third-octave band (in dB)
- N number of partial levels per third-octave band

The difference $\Delta L_{p,A}$ gives the magnitude transfer function at each third-octave band and is adjusted with the simulation-based influence of the SAL-buildings $\Delta_{\mathrm{SAL}} L_S$ according to Equation (4), which is shown in Figure 4 (bottom).

$$\Delta L_{p,A,\mathrm{SAL}} = \Delta L_{p,A} - \Delta_{\mathrm{SAL}} L_S \quad \text{in dB} \qquad (4)$$

Separate consideration of the bass range

To examine the propagation of low frequencies, reference spectra for popular music genres are assumed at the emission point x_1 and the difference $L_{C,eq} - L_{A,eq}$ is measured at the immission points x_2 to x_4 (cf. Tab. 3). Traffic noise is used as reference spectrum for bass-dominated music genres (techno, dance), while pink noise is used for music genres such as pop and rock [7].

Although the limit value of 10 dB for the difference $L_{C,eq} - L_{A,eq}$ is adhered to at the location of the noise monitoring system (x_2) the limit value is exceeded in the neighbouring residential area (x_4) which is furthermore enhanced due to the newly constructed SAL-buildings (cf. Tab. 3). This shows a reduced attenuation of the low frequencies compared to frequencies above 1000 Hz because of the newly constructed SAL-buildings which reinforces the need to tighten the limit value for $L_{C,eq} - L_{A,eq}$.
Apart from that, the amount of lower frequencies at the immission point x_3 is significantly higher than at x_2, which recommends a repositioning of the noise monitoring system from x_2 to x_3.

Table 3: Difference $L_{C,eq} - L_{A,eq}$ in dB at the immission points x_2 to x_4, assuming the reference spectra traffic noise and pink noise at the emission point x_1 (with SAL-buildings).

	$L_{C,eq} - L_{A,eq}$ in dB			
	x_1	x_2	x_3	x_4
traffic noise	9.4	4.8	9.3	11.4 (13.9)
pink noise	1.4	1.6	3.6	5.6 (8.0)

Conclusion

To investigate the sound propagation at the Campus Inffeldgasse, a simulation in SoundPLAN and a subsequent measurement were carried out. According to the obtained results the limit values for $L_{A,eq}$ and $L_{C,eq} - L_{A,eq}$ are adapted for the noise monitoring system (cf. Tab. 4).

Table 4: Derived limit values at the Campus Inffeldgasse for immission points x_2 and x_3 (D = day, N = night).

	$L_{A,eq}$ in dB								$L_{C,eq} - L_{A,eq}$ in dB	
	$>$ 10 events/year				$\leq$ 10 events/year					
x_2	69	54	75	60	84	64	89	69	5	2
x_3	66	51	71	56	81	61	86	66	7	5
	D	N	D	N	D	N	D	N	D	N
			SAL				SAL			SAL

The alternative position (x_3) of the noise monitoring system as well as the newly constructed SAL-buildings are considered in the adaptation of the limit values. Additionally the analysis of the sound propagation of the low frequency range recommends a repositioning of the noise monitoring system to capture low frequencies more intensely.
As the noise monitoring system uses an external website to monitor the sound pressure level, the development of a university's own SPL monitoring tool is recommended, which considers the measured magnitude transfer functions.

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