Acoustic simulation and auralizations to investigate the impact of textile building façades in urban environments

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Introduction

Cities and their inhabitants often suffer from noise of numerous sound sources and the typical building design in urban areas tends to increase rather than reduce noise levels. While for building façades the sound insulation is often considered as the most critical acoustical parameter, it has been demonstrated that the acoustic characteristics of façades can also have a relevant effect on the noise levels of the urban environment [1]. The application of acoustic simulations and auralizations for urban environments makes it possible to investigate the effect of different building façades in a controlled way [2].

In the presented project, the focus is on textile façades, for which the acoustic properties are investigated by means of measurements and simulations. Additionally, varying absorption characteristics of façades are applied in acoustic simulations of urban scenarios in the city of Aachen. These scenarios are modelled corresponding to real streets and adapted in the simulations for different façade configurations, varying the type of material as well as the amount. In addition to evaluating noise levels, the applied simulation tool enables the generation of auralizations, allowing direct listening and comparison of scenarios and their façade configurations. This paper includes a general project introduction and presents the simulation and auralization results of an example scenario.

Project Overview: STumM

The research project STumM (titled in German "*Schallabsorbierende Textilfassaden im urbanen Raum – Machbarkeitsstudie*") involves an interdisciplinary consortium of researchers from the fields of textile technology, urban design, and acoustics. The project aims to investigate the effect of textile, sound-absorbing building façades on noise levels in urban areas.

Key steps include the selection and conceptual design of façade structures (while also considering non-acoustic aspects such as fire ratings, light transmission, safety, UV protection, weather resistance, and cleaning and maintenance options). In addition to non-standardized in-situ measurements or laboratory measurements of façade elements (cf. Fig. 1.), the project also involves simulations and auralizations of selected urban scenarios in order to evaluate the impact of these façades on noise reduction.

Figure 1: Non-standardized acoustic measurement setup for a façade element with a simple frame / mounting structure in the anechoic chamber, for normal sound incidence.

Acoustic simulation and auralization of urban scenarios

The application of sound propagation models allows the simulation of typical urban situations, considering multiple noise sources and the acoustic properties of the urban environment. As part of the STumM project, a simulation model is applied to three urban scenarios (based on real locations in the city of Aachen, affected by street and/or railway noise). For the first investigations, the simulations were generated using a Geometrical Acoustics simulation model, specifically the RAVEN simulation model [3]. It is based on an image source model for lower-order reflections and a ray tracing algorithm which considers higher order reflections as well as scattered sound energy in general, and allows the generation of binaural impulse responses for defined sound source and receiver positions of the scene. As the propagation model does not consider sound diffraction, which - depending on the sound source's position in the scene - can be relevant in urban propagation situations [4], the simulation model will be either combined or replaced with a model which determines the diffraction paths and generates the corresponding filters [6, 7].

To auralize the simulated simulation, anechoic recordings of typical urban sounds are convolved with the simulated binaural impulse responses. In case of dynamic sound sources (e.g., moving vehicles), the impulse responses are generated stepwise, convolved with the corresponding time frame of the anechoic signal and cross-faded with the previous/following output signal frame.

Example scenario: *Wüllnerstraße*

To investigate the impact of façades with varying acoustical properties, an example scenario was defined. This scenario corresponds to a typical situation at Wüllnerstraße in Aachen, Germany, including a street canyon situation with two static and one dynamic sound source. The simplified 3D model applied for the propagation simulation as well as the positions of sound sources and receiver are shown in Fig. 2. The heights of the buildings are ~20 m on the left-hand side and around ~13 m on the right-hand side of the street. The canyon width ranges from ~25 m in the upper part of the street to ~35 m at the receiver position.

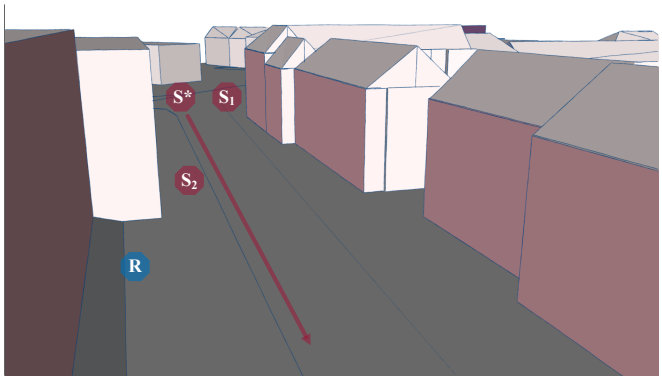

Figure 2: Example scenario *Wüllnerstraße* in Aachen including three sound sources.

The investigated façades on both sides of the street canyon have a total surface of ~3800 m^2. In the first step, to explore potential impact, the façade's absorption is modelled by frequency independent data (yet frequency dependent data for scattering coefficients, medium attenuation and other surfaces in the scenario is considered).

- Absorption scenario A: $\alpha_A = 10\%$
- Absorption scenario B: $\alpha_B = 40\%$
- Absorption scenario C: $\alpha_C = 80\%$

To auralize a typical situation in this environment, a scene of 18 seconds length was defined, including two static sound sources: The traffic noise of a busy intersecting road S_1 (distance to receiver $d_1 \approx 95\,m$) and socializing students combined with ambient nature sounds S_2 ($d_2 \approx 26\,m$). Both sound sources have a mostly stationary noise level with variations of ±2 dB. The third sound source S^* simulates a moving vehicle passing the receiver at a constant speed of $v_{const} \approx 31$ km/h (minimum distance to receiver $d_{3,min} \approx 12\,m$).
The resulting auralization is included in a video file [8].

Simulation results of example scenario

After the binaural output file for the defined scenario was created, the A-weighted sound pressure level (SPL, *slow* evaluation period, $\Delta T = 1$ s) of the second binaural channel (right ear) was evaluated. The results for all three façade variations are presented in Fig. 3. The overall averaged levels for the full length of 18 s do not substantially differ, considering the façade configuration A as the reference, a reduction of 0.5 dB and 1.4 dB is observed for case B and C, respectively.
The temporal variation of the SPL shows that the overall level is determined by the level of the dynamic source S^* and that the difference of the façade configurations increases when the vehicle has passed the receiver and eventually disappears. Thus, in this situation where a

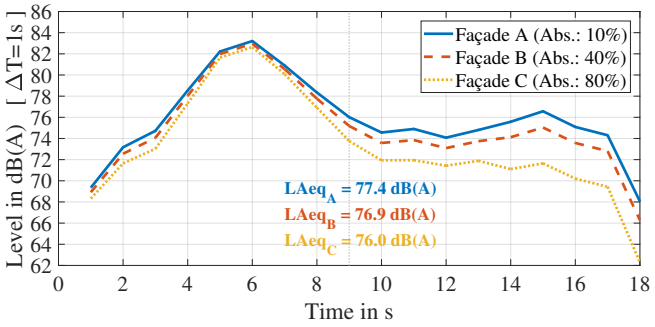

Figure 3: Level over time for the example auralization at *Wüllnerstraße* in Aachen.

sound source with a relevant sound power level is close to the receiver, there is no substantial impact on the overall sound pressure level at the receiver. In situations however, where the sound field arriving at the receiver is dominated by rather long, indirect sound propagation paths, the absorption characteristics of the façades have a larger impact on the noise levels at the receiver position. This is demonstrated in Fig. 4, showing the A-weighted SPL for the second part of simulated scenario $T_2 = [\,9 \ldots 18\,]$ s. The analysis of the evaluated octave frequency bands reveals, that reductions (comparing case A

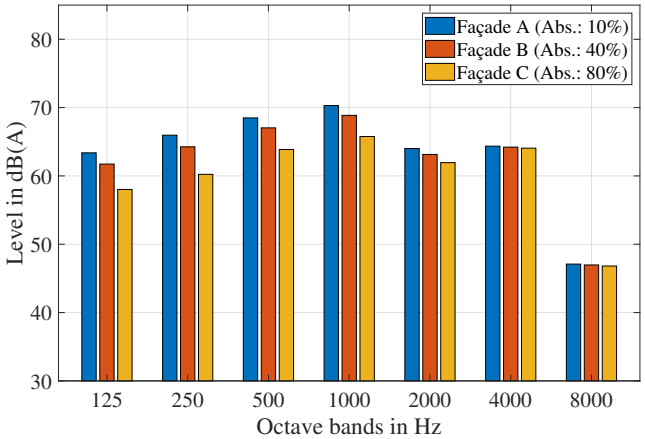

Figure 4: A-weighted sound pressure level for octave bands of second part of simulated scenario $T_2 = [\,9 \ldots 18\,]$ s

to C) up to 5 dB are achieved, especially in the frequency bands 125 Hz – 1 kHz, where air attenuation is less relevant and other surfaces of the environment, on average, do not show pronounced absorptive behaviour. A reduction of the sound pressure levels in the frequency range of 630 Hz – 2.5 kHz is especially important, as this is the spectral range most impacted by tyre or road noise [9] and often dominates the soundscape in urban environments.

Summary, Discussion and Outlook

The presented project investigates the potential of textiles façades in urban environments with the focus on noise reduction. An example scenario was introduced which demonstrates the option to use sound propagation simulation and the tool of auralization to conduct a controlled comparison of noise levels and signals for varying urban environments.

In this first investigation, modelled, frequency-independent absorption data for the façades was defined, which deviates from the real acoustical characteristics of textile façades. While façade A ($\alpha = 10\,\%$) could be regarded as an untreated, regular building façade, case B ($\alpha = 40\,\%$) represents possible, but ambitious acoustic characteristics and façade C ($\alpha = 80\,\%$) features a highly absorbing behaviour, which would be challenging to implement in reality using a typical textile façade design. Noteworthy is also, that the total surface area of the investigated façades, relative to the dimensions of the street canyon, was specified as rather large.

Nevertheless, this initial study revealed that absorbing façades as an alternative to diffusing façades can reduce noise levels, especially when the main noise sources are further away from receiver, e.g., at public locations such as playgrounds or restaurants not directly located next to busy streets. Using simulations of dynamic situations with multiple (moving) sources enables a controlled analysis of the environment's impact on the noise levels. In general, the effectiveness of textile materials for building façades depends on various parameters of the urban noise scenario (e.g., source-receiver distance and presence of direct sound), in addition to the acoustic characteristics of the façades itself (absorption and scattering coefficients), and thus can not be easily evaluated in a general way. These findings are in line with observations of similar studies related to urban environments and façade designs [2, 5].

The next steps of the project involve the simulation and auralization of further urban scenarios in the city of Aachen, as well as the application of measured data of demonstrator façade elements in the simulations. Furthermore, the application of an improved simulation model for urban sound propagation [6, 7] is planned.

Acknowledgements

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