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The increasing migration into cities leads to an increasing number of people stressed by noise. More and more people are moving into urban settings comprised of multiple noise sources and hard reflective glass and steel facades. The omnidirectional arrangement of noise sources like airborne noise or car traffic noise and their reflection on the facades neither composes urban arrangements with silent indoor areas nor comfortable quiet areas outdoor. To come up with requirements for silent areas inside and outside of buildings further design parameters have to be introduced. The facade is not only a shelter for the inside. It can also provide comfort spaces outside the building. As engineers and architects we cannot change the noise source, but we can influence the impact on the surrounding urban space by controlling the reflection of noise emissions on the urban surfaces like facades. In a facade design the capability of reflecting noise can be tuned by modifying the surface. In order to come up with the acoustical needs no radical new way of facade design has to be introduced. Mainly a shift of attention to the acoustic parameters is needed. Based on acoustic measurements of basic geometry principles this research presents known facade designs and their acoustic parameters regarding the reflection capabilities and the functions in a facade.

Keywords: Façade design, parameter, acoustics, urban, noise source, reflection, noise.

1 Introduction

The silhouettes of metropolitan areas are characterized by a high density of skyscraper facades made of glass, metal or stone. On the one hand, this high skyscraper density, which can be seen in Figure 1, stands for economic power, growth and work. On the other hand, these reverberant facade surfaces in urban space are responsible for increasing noise levels in their direct surroundings. In an urban development situation with reverberant facade surfaces, the most common source of noise by road traffic is increasingly perceptible.
The processes in the growing metropolises that confront the architecture with tasks that it cannot solve with the help of its own tools. Since re-densification in metropolises usually relies on areas of former industrial and commercial spaces, these are subject to increased noise emissions. Figure 2 shows a typical situation of a secondary consolidation project, using the example “Bürostadt Niederrad” in Frankfurt.

Around the former commercial area are several traffic routes. The traffic noise sources such as road, rail and aircraft noise affect the area from different directions. Here the situation is further exacerbated by aircraft noise since this type of noise generally acts from above on the urban space. In such characterized areas, the architecture is at its end with its general design tools. So the principle of the arrangement of the bedrooms on the quiet side of a building is only possible if there is still a quiet side. A quiet courtyard is affected by the influence of aircraft noise from above. The only option that is considered here is usually the use of highly sound-insulated facades and window constructions. However, such soundproof constructions generally prevent direct contact with the outside area.

2 Facades as a Noise Modulator in Urban Space

The direct sound and the sound reflecting off the façade surface add up in the urban space. The reflection of a direct signal from a noise source on a reverberant surface increases the measured level at the location of the receiver by up to 3 dB. This level increase is generated by the addition of incoming direct sound and reflected sound. A special arrangement of several reverberant surfaces makes this effect even more powerful. This phenomenon, as shown schematically in Figure 3, is well known.

3 Project Study: Refurbishment of an Office Building

This study of a former office building in the “Bürostadt Niederrad” shows the necessary steps in the facade design process with a focus on special acoustic effects. Figure 4 shows how close the approach route to Frankfurt Airport passes the building. The 100 m long, 8-storey high building is almost perpendicular to this approach route. For the vacant object a conversion was intended into an apartment building. In order to come along with the trend towards acoustic hard surfaces in architecture, only the influence of altered facade geometries was investigated in this study.
3.1. Design Basics

On-site inspections and noise measurements are imperative, as they can provide data on the time response of noise sources and the direction of their impact on the building. Noise mapping data sources can only show tendencies in this context. They hardly provide acoustical information for a detailed facade planning. This is partly due to the coarse resolution of the 10m grid, which makes it very imprecise to detect the direction of noise. On the other hand, reflection parameters used in noise mapping models are strongly location-dependent and lead to strong fluctuations in the resulting noise levels. Furthermore, the places of acoustic interest must be defined for the planned outdoor use. A higher quality of outdoor places can be for e.g. a coffee, playground or rest areas. In this case, such an outdoor place with higher acoustical demands was intended for the east side of the building. In Figure 5 this position is marked at the measuring point “EAST 2”.

3.2. On-Site Measurement

In the on-site measurements, several receiver positions must always be measured simultaneously in order to be able to read the influence of the facade from the comparison of the level-time curves. Figure 5 shows the measurement values for a typical flyby. Significantly the differences in the level-time curves for the different sides of the building can be seen. The measurements show a level difference of about 5 dB between east and west side of the building. The level-time curves with a lower peak measured on the west side indicate that the passing aircraft is audible over a longer period of time.

3.3. Façade Design

In this step, the first façade design variations are developed, which offer different facade geometries and structures from flat, reverberant facades. In the context of this study, a curtain-wall facade with story-high, folded glass surfaces was proposed, which effects by its geometry a different reflection direction. The differently inclined façade surfaces are shown in Figure 6.

3.4. Laboratory Tests for Façade Modifications

Since it is rarely possible to test façade alternatives on site on a scale of 1:1, model studies are necessary for this step. With the scaled acoustic measurement method, models can be acoustically measured in scales from 1:10 to 1:100. In cooperation with the “Federal Highway Research Institute” (BAST) the scaled measurements were carried out in the Laboratory for Acoustic Measurement Technology. For the scaled measurement, the dimensions of the buildings as well as
The level change shown here occurs in the frequency bands from 400 Hz. The level reduction at the measuring point “EAST 2” would ensure that aircraft noise events would not only be perceived as quieter but also as less disturbing.

4 Case Studies - Facade Surfaces

An alternative to changing the reflectivity of reverberant cladding surfaces is the introduction of absorbent material properties or internal geometries.

4.1. Facade absorber

The introduction of absorbent materials is not easy for a variety of reasons. Thus, most known absorbent materials are open-pored. This means that they do not have a closed surface, which meets the architectural desire for a slightly closed, less polluting and sufficiently resistant surface. An exception here is a special form of a green facade. This fully façade integrated revegetation, using substrate mats are from the acoustical point of view highly absorbent surfaces. Among others the effect of vertical greenery for acoustic purposes was investigated in numerical simulations by Smyrnova, Kang, Hornikx, Forssén (2012) or in case studies by Wong et al. (2010).

The full façade integrated revegetation of 90DEEGREEN® meets the requirements of a flat absorber. In order to determine the acoustic potentials of this system, a mock-up was installed in cooperation with the manufacturer on a busy inner-city street in at the Frankfurt University of Applied Sciences. The road traffic noise was measured in front of the green facade at time intervals with approximately constant resulting noise levels. The first measurement was made before the wall was attached. After establishment of the green facade, measurements were carried out without planting and subsequently with fresh planting. With more vegetation, another measurement was taken to get information about the influence of the density of the vegetation.

The difference in the individual frequency bands makes it clear that single values are not sufficient to describe the acoustic effect of a facade. Decisive for a acoustical effect of the facade are level changes in the range of the highly sensitive hearing range of humans between 500 Hz to 4,000 Hz.
Strategies for Design of the frequency to be influenced. Many such structures are currently being installed, but without taking the acoustic effect into account. The surfaces in Figure 12 and Figure 13 show examples from current architectural façade designs.

Fig. 12 Heavily textured surface of a suspended stone element

Fig. 13 Creation of a highly structured surface through vacancies in the closed clinker wall dressing

5 Summary

The listed case studies show opportunities to reduce the noise input into the urban space by the façade. The study presented here of a folded reverberant facade surface clarifies that projects with acoustically effective facades must be designed differently.

• As a basis for this, sites have to be considered acoustically by on-site measurements
• Places with special acoustic qualities and demands must be defined
• It is always necessary to find individual solutions for individual locations.
• The effects achieved must always be considered for individual frequency bands in the highly sensitive human hearing range from 400 Hz to 4,000 Hz

A quieter city is possible!

6 Reference list

Krimm, J. (2018) Acoustically effective facades design, TU Delft
A Redesign Procedure to Manufacture Adaptive Façades with Standard Products

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Although their potential for high environmental performance is largely accepted, adaptive façades have not yet become widespread in practice. Most of the current examples are developed by engineer-to-order design processes, as project-oriented, custom, and complex solutions. More simple and reliable solutions are needed to support the reuse of technical solutions between projects and increase the feasibility of adaptive façades. Therefore, this research aims to develop a procedure to design adaptive façades whose parts are based on engineered standard products with the least number of parts and layers. The research is initiated through the generation of concepts for designing adaptive façades to be manufactured using standard products. From several concepts, ‘redesigning dynamic adaptive façades’ has been selected for further investigation, as it pursues the goals for a solution determined for this research. A preliminary case study is conducted to redesign an adaptive façade to be manufactured with standard products. Its process steps are captured and analysed, and the steps that need improvement are revealed. To systematise and improve the captured redesign process, façade design and product design methodologies are analysed in the context of adaptive façade design. Redesign and reverse engineering processes used in product design are adapted and merged with façade and adaptive façade design processes, and a 5-phase adaptive façade redesign procedure is outlined. Each phase is developed based on mature tools and methods used in product and façade design. An iterative loop of development, application test, and review process is carried out for development of the process steps. Thus, a redesign procedure is generated by the combined application of DFMA and TRIZ in the synthesis of reverse engineering and redesign processes. Consequently, the application of the redesign procedure is demonstrated through a case study. The case study revealed that the procedure has the ability to generate a façade redesign that has a higher constructability index than the reference façade.

Keywords: adaptive façade, constructability, redesign, standard product, reverse engineering, DFMA