Updated urban facade design for quieter outdoor spaces

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Abstract

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

acoustics, soundscape, geometry, facades, design parameter, noise,

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1 INTRODUCTION

Reflections on huge facades made out of glass, steel and other hard reflective materials are increasing the noise levels in public or private spaces of urban agglomerations by redirecting the sound energy to the urban ground. A field measurement of the authors during the dismantling process of a high-rise demonstrated that the reflected sound energy can exceed the theoretical level addition of 3 dB(A) up to 8 dB(A) (Techen, & Krimm, 2014). Thus in the vicinity of new or refurbished buildings equipped with hard reflective facades, the noise levels and the number of noise-affected people will increase. Beside the measureable and perceivable facade effect the on going migration into major cities is leading to a growing number of noise-affected people in the official statistics of the EU guided noise mapping procedure. Based on the noise map regulations defined in the European Noise Directive (END, The European Parliament and The Council of the European Union, 2002) only cities with more than 100.000 inhabitants have to calculate noise maps. In the framework of the END noise map procedure the migration into major cities becomes an equivalent of a migration from non-statistically reported areas to statistically reported ones. In this growing group of the noise-affected people more and more people are harmed by more than one noise source. This increase is also linked to the migration into major cities and its growing demand for new households. In order to provide more households office or industrial buildings were converted into spaces for living. Three exemplarily examples located in the city of Frankfurt/Main are shown in figure 1 and 2. In these examples at one receiver point two or more noise sources can be detected. Receiver points in this context are positions in urban space were people walk or stay. Figure 1 is showing the development area “Lyoner Strasse”. Here abandoned office buildings are going to be converted into apartment buildings. Due to the business optimized urban planning from 1962 the former called “Office Town Niederrad” is in short distance to all important traffic infrastructures like Airport, train station and motorway. The result is a projected conversion area for 3000 apartments surrounded by up to three or more heavy noise sources: The aircrafts approaching Frankfurt Airport, the Motorway A5 and the railroad track.

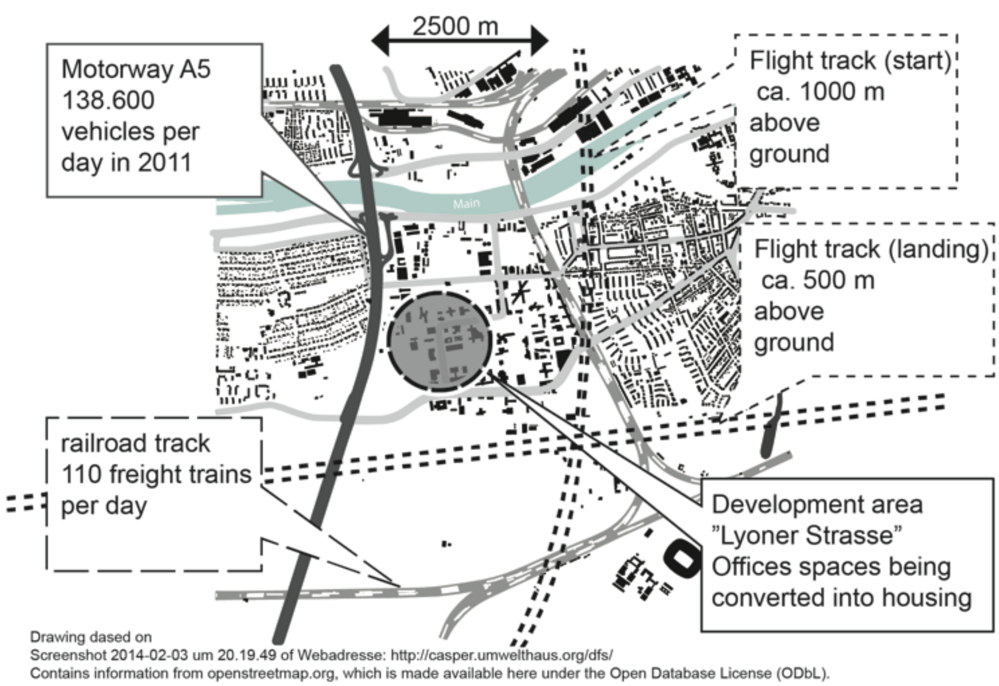

FIG. 1 The situation around the conversion project area of “Lyoner Strasse” in Frankfurt/Main, drawing by the author.

FIG. 2 New housing areas in Frankfurt/Main close to the railroad and flight tracks, drawing by the author.

Another redensification strategy is the replacement of workshops located in the courtyards by apartment buildings. Figure 2 shows two conversion areas of former industrial or workshop usage. The new housing areas in Frankfurt/Main Sachsenhausen are located very close to the main railroad tracks to Frankfurt main station. The nearby flight track with aircrafts flying in 600 m above ground is contributing even more high noise levels to the urban acoustic space there. This noise source - noise receiver setting results in perceivable noise levels outdoors or indoors far above the minimum comfort levels of 55 dB.

The data of the The Federal Environment Agency of Germany (UBA) are confirming this trend of migration into noisy areas. In 2014 68 % of the people captured by the noise mapping of 2012 are affected by one or more noise sources (Myck, 2014). More than half of the 68% group of these inhabitants is affected by two or up to five noise sources. See figure 3.

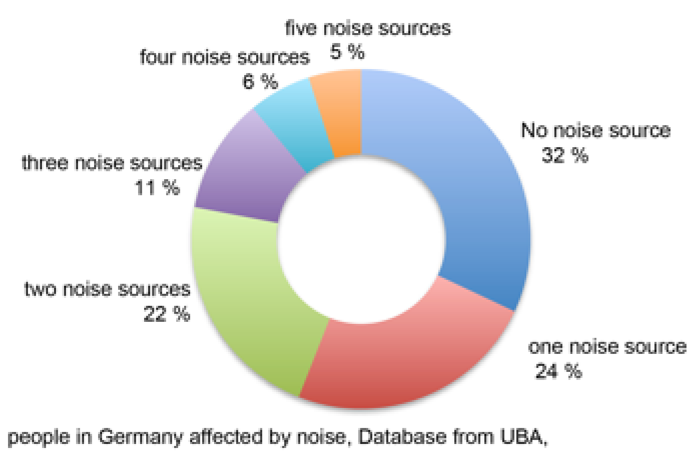

FIG. 3 People in Germany affected by noise, drawing by the Author, based on Myck, 2014 .

Furthermore these facts have out-dated the classic architectural tooling like the orientation of rooms to the silent face of the building. Whenever an urban space is surrounded by noise sources on street level and in the air, the concept of orientating functions like a sleeping room to the silent face of a building is not longer possible. Some efforts were made to come up with solutions for buildings in relation to one noise source. Among others the research conducted by L. Nijs and F. Kranendonk "Akoestisch optimaleoriëntering van bouwmassa's nabij verkeerswegen" (Nijs & Kranendonk, 1979) and "Reclaiming land from urban traffic noise impact zones" from Arc de Ruiter can be named (de Ruiter, 2005). The research of Martijn Lugten "re-sil(i)ence, design patterns for an aircraft noise abating spatial environment" from 2014 was focussing on aircraft noise (Lugten, 2014). The ongoing broad research on soundscapes presented in the book Soundscape and the Built Environment edited by Jian Kang and Brigitte Schulte-Fortkamp is not directly linked to the architectural solution of a facade design (Kang & Schulte-Fortkamp, 2015). A lot of research was conducted throughout the years in order to investigate and determine the influence of a facade on an urban acoustic space. But all these investigations have the limitation that they are dealing with one specific facade in a specific arrangement. A few examples should explain the problem of applying these results to the architectural needs of a metropolitan area. In the early investigations of urban spaces the focus was on the range of acoustic signals in street canyons and on the speech intelligibility over distance. Among others Wiener Malme and Gogos can be named (Wiener Malme and Gogos, 1965). Lyon investigated the influence of multiple reflections and their influence on the sound propagation in an urban space. He recommended the scaled model measuring technique as a promising tool for a precise sound propagation in three dimensions (Lyon, 1973). Bullen and Fricke introduced the scattering on facades to their sound propagation model (Bullen&Fricke, 1976). Picaut and Simon were proofing in 2001 that a given structured facade with its reflection abilities could be replaced by pure geometry (Picaut&Simon, 2001). Van Renterghem and Botteldooren are treating the green facade or green roofs in a suburban housing setup with different simulation and measurement methods (Van Renterghem and Botteldooren, 2008, 2009, 2011). In the research of Schiff, Hornikx and Forssén, the concept of the noise transmission between shielded canyons was simulated with numerical and measurement methods (Schiff, Hornikx and Forssén, 2008, 2010). These research projects were investigating the acoustic and its methods and not the architectural aspect of it. The scale of the used urban situations is more linked to smaller cities as to major cities and their high-rises. Furthermore all researched simulation methods except the scaled model measurement are remaining in two dimensions. From all this research a lot of proposals for investigating an urban space with several simulation or measurements methods can be drawn out but only a few recommendations for a facade design can be found. So up to now the impact of the urbanisation and the influence of the facade on the urban soundscape were neither considered seriously as architectural design parameters nor translated into an architectural language for the design of facades.

2 CASE STUDIES

In the following two case studies the attempt was made to investigate the influence of modified facade geometries to the noise impact on the surrounding urban space. The scale measurement method based on the method of dimensional analysis by Lord Rayleigh was used in this geometry study (Rayleigh, 1915). With this method it became possible to scale measuring setups down to a smaller size applying the same dimension factor for scaling the setup and the signal to be measured. The first scale model investigations in engineering were used in the middle of the 18th century for the analysis of rivers and bridges. Later on the method of scale modelling became common for the development of aeroplanes, cars, ships, bridges, and concert halls. Scale measurements are widely used in industry and research because they facilitate testing the impact of changed shapes or changes in size of downscaled elements, thus saving time and resources. In a 1:1 scaling it is virtually impossible to change for example the whole construction of a bridge over a valley in order to select the construction which is delivering a better performance due to airflow in this valley. The method of scale model engineering used for the acoustical investigations was developed with recommendations and formulas of D.J. Schuring (Schuring, 1977). When setting acoustical measurements of an existing urban situation, the building layout has to be scaled by the same factor as the wavelengths of the audio signal emitted from the source. If the building layout is scaled down by factor 10 the frequency has to be scaled up by factor 10 to achieve a wavelength scale down of 1:10. Limiting factors to scaling in acoustical measurements are laboratory space and threshold frequencies of the equipment. In order to focus on pure geometry all scale model surfaces were made out of hard reflective materials. All scaled measurements done in the framework of this research were focused on pure geometry because one important limitation of the scaled model measurement method is difficulty of downscaling material properties. Nevertheless the measurements and their results stay reliable because whenever a hard reflective geometry is reducing noise levels an introduction of absorbing material is always improving the acoustical performance. Both cases were measured in a scaled measurement set-up and in a field measurement. As the case studies should represent the daily practice in engineering or architectural offices the approach to an acoustic facade intervention in both case studies was different. In the case study Lyoner Strasse 54 mainly design decisions led to a facade design. The possible acoustical qualities were considered in a second step. Opposite to this the facade modifications of the Henninger Turm study were developed for identifying the acoustical effect of adding horizontal or vertical structures to the south facade.

2.1 CASE STUDY LYONER STRASSE 54

FIG. 4 The abandoned office building in the Lyoner Strasse 54, picture by the author.

In this study, the urban acoustic space around an eight-storey office building was investigated. The building is located on the South part of the Lyoner Strasse in Frankfurt/Main, See figure 4. The 100 m long building is orientated nearly perpendicular to the arrival flight track of Frankfurt Airport. Refer to figure 5.

In the measurement set-up in the facilities of the German Federal Research Institute for roads and traffic (BAST) a 1:100 downscaling of the existing situation was built. The model of the building with the facade modification is shown in figure 6. In this case the facade modification changes the plain hard reflective surface of the model into a triangulated form of facade geometry. The surface quality of the facade modification regarding the acoustics remains hard reflective.

The positions of the six measurement points were defined in order to detect the edge effect at the corners of the building in difference to the measureable effect in middle of the 100 m facade of the building. With having on both sides three measurement points it will be possible to determine the emerging effect according to the building face. Refer to figure 7.

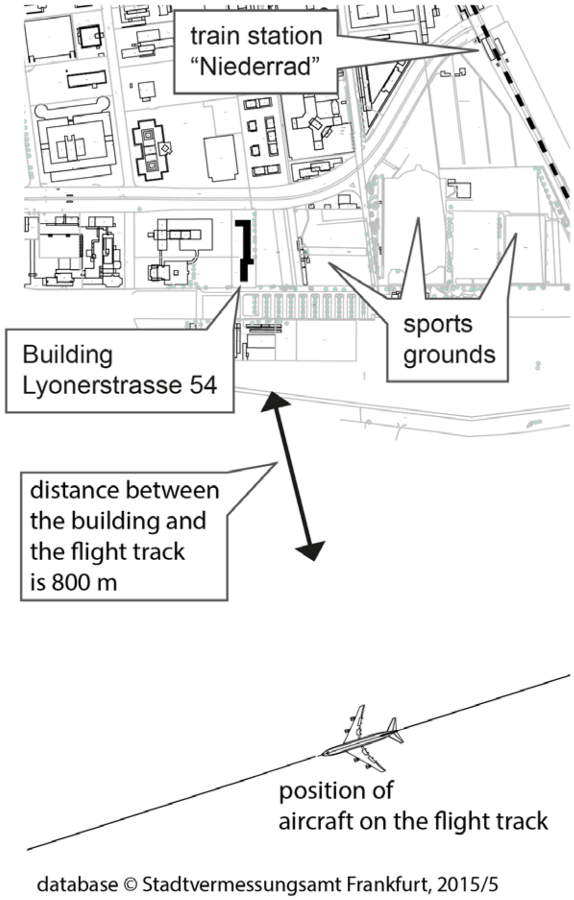

FIG. 5 Drawing of the urban space and its noise sources around Lyoner Strasse 54, drawing by the author.

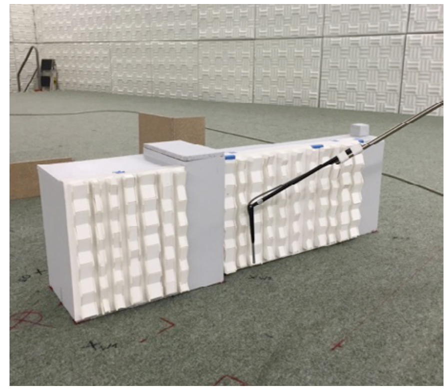

FIG. 6 Measurement model in grey colour with attached facade modification in white, picture by the author.

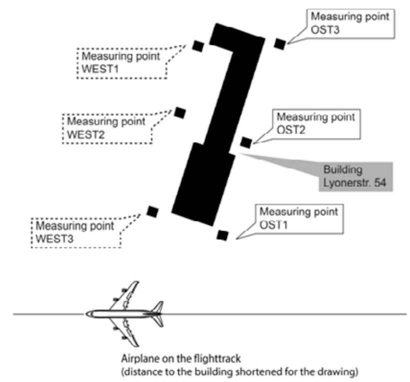

FIG. 7 Position of the measurement points around the building Lyoner Straße 54, drawing by the author.

The moving aircraft in reality was replaced by an air pressure noise source in the scaled measurement. Because of spatial limitations of the measurement room the original distance of the airplanes to the building has to be shortened. The air pressure noise source was mounted on a moving track system in a height of 150 cm above ground and in a distance of 261 cm to the building in order to meet the geometrical conditions of the existing situation. With this equipment it was possible to measure appearing noise levels at the predefined points around the building. The moving track of the noise source in conjunction with the measurement system delivered a set of frequency-distributed levels in the range between 100 Hz and 2000 Hz at every 1 cm. The single dB values for every point on the moving track were then calculated out of the frequency-distributed levels. The measurements were proceeded with the facade modification and repeated without. Subtracting the measured levels without facade modification from the captured data with the facade modification delivers the resulting level change. The result for the facade modification at measurement point West2 and OST2 is shown exemplarily in the graphs in figure 8.

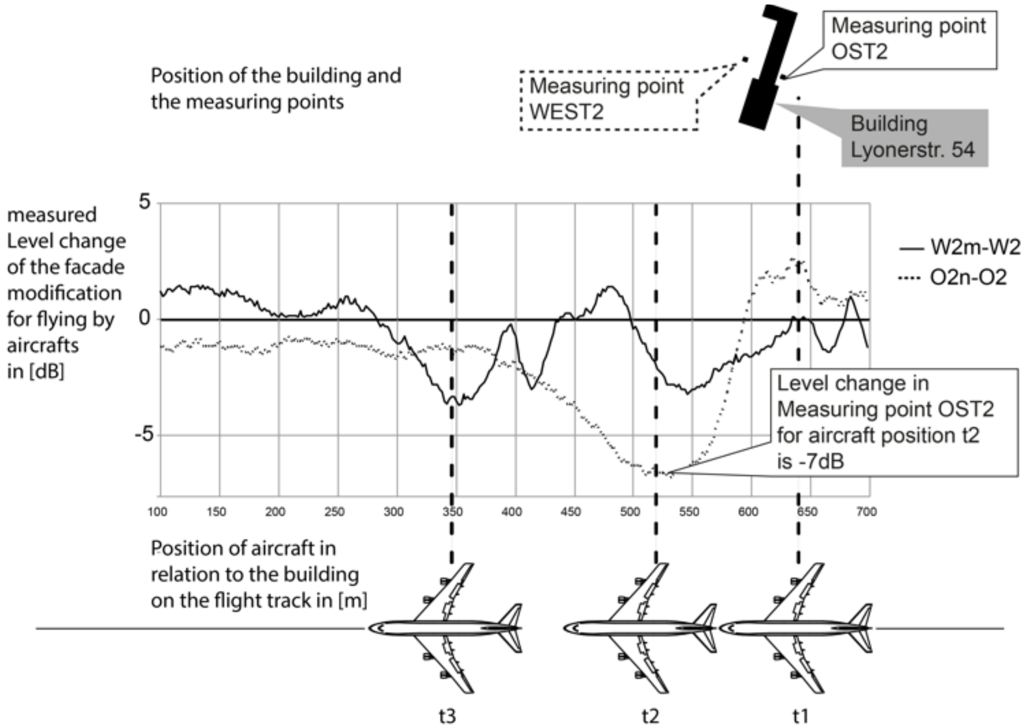

FIG. 8 Measurement results for Lyoner Strasse 54 linked to the airplane position, measurements of the author at the facilities of the BAST.

The graph in figure 8 is impressively depicting that around a solitaire building an effect of a facade modification is delivering level changes more than the theoretical 3 dB. For the point t2 the level change at the measuring position OST2 is -7 dB. The measurement data give evidence for the possibility of reducing noise levels during an aircraft noise event around a freestanding building.

2.2 CASE STUDY HENNINGER TURM

The urban plot around the Henninger Turm in Frankfurt/Main was taken as a basic layout for an investigation of facade modifications and their impact on the urban acoustics in the vicinity of a building. Measurement and noise source positions are defined by the field measurement positions from 2013 (Techen, & Krimm, 2014). As there was no moving noise source in the measurement facilities available for the simulation of a flying airplane, the measurements were done using a ring radiator as a point source in two positions. The two positions of the point noise source were representing two points in time of the moving airplane on the flight track. The noise source position "on axis" was perpendicular to the south facade of the tower. The "off axis" noise source position was angled 19 degree away from the normal of the south facade. For an overview of the measurement points and the layout of the set-up refer to figure 9.

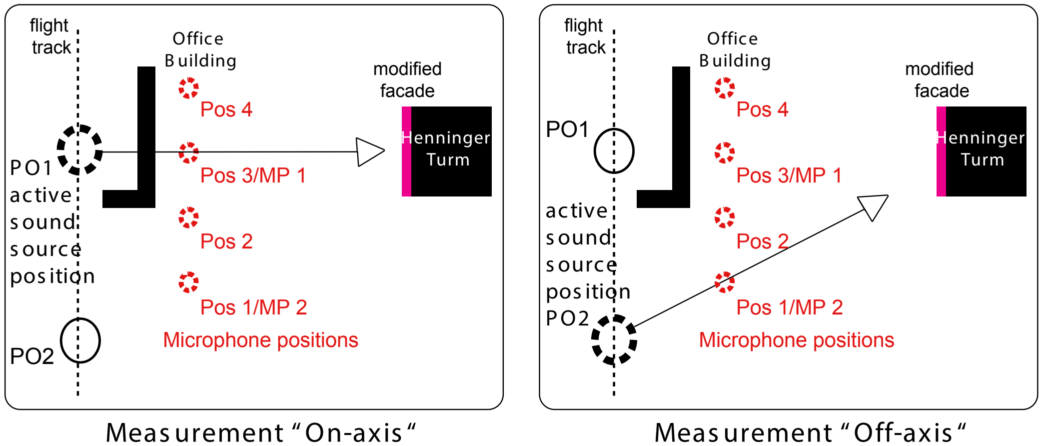

FIG. 9 Measurement positions (measurement points) in the scaled measurement setup, drawing by the author.

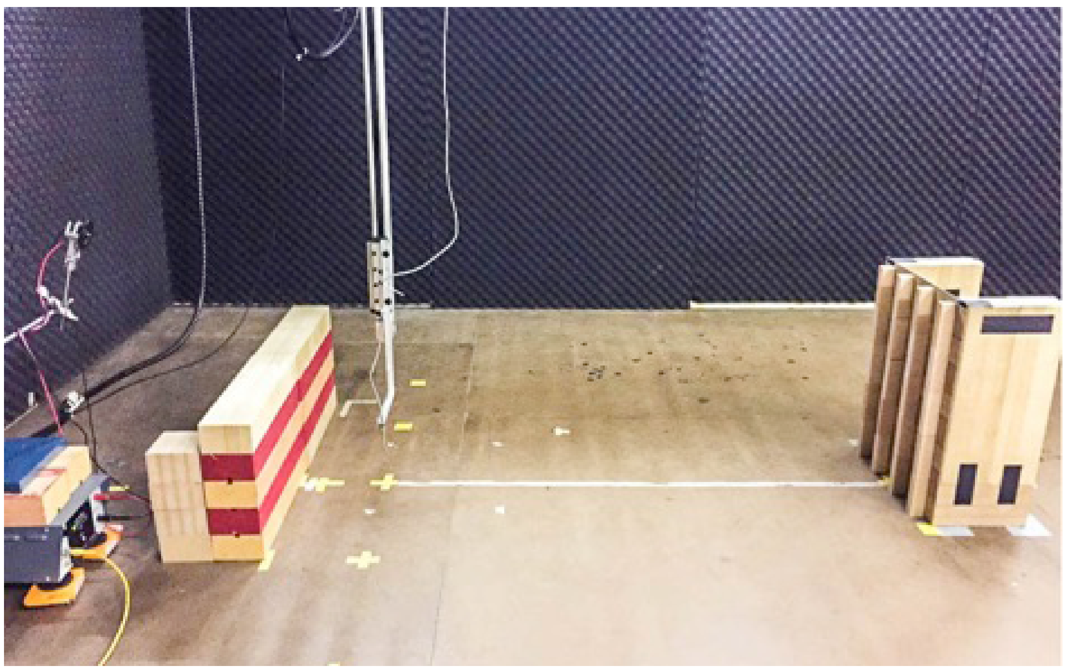

FIG. 10 Measurement set-up in a 1:50 down scaling at the measurement facilities at TU Delft, picture by the author.

The measurements were taken in the facilities of the Laboratory of Acoustical Wavefield Imaging, Department of Imaging Physics at the Delft University of Technology by the author. The measurement model in the scale of 1:50 consists out of planed beech wood blocks representing the building on-site of the field measurement around the Henninger Turm. In figure 10 the set-up in the anechoic chamber at TU Delft is shown.

On the plain facade of the tower model smaller beech wood blocks could be added in different configurations. For this row of measurement sequences the facade modifications were classified in horizontal oriented modifications and vertical oriented modifications. In these two classes, the implemented variation of density in the arrangement of blocks results in varying sizes of the front face area. Additional to that, blocks with one tilted face were used in the class of the horizontal arrangement gaining for an insight on the effect of downward or upward reflection. The Sizes of the beech wood blocks were representing facade modifications in the dimension of 0.5 m x 1.5 m x 3.0 m or 1.0 m x 1.5 m x 3.0 m. Figure 11 shows the measured facade variations and their abbreviations.

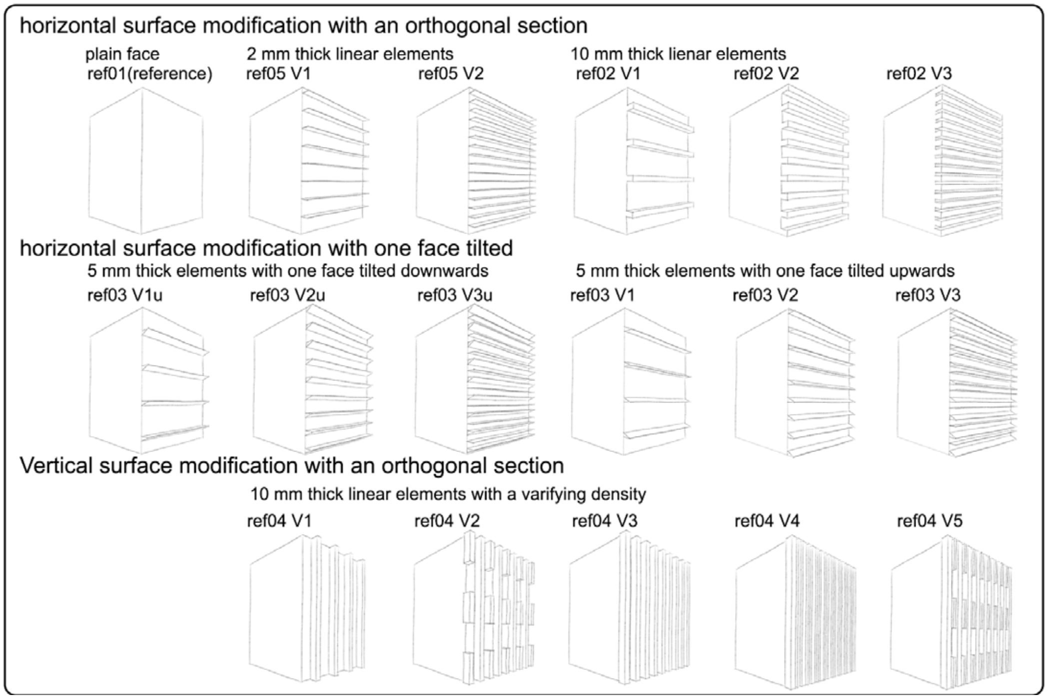

FIG. 11 List of the measured surface modifications, drawing by the author.

Aiming for a more detailed view on the frequency distributed noise levels and the noise coverage of the urban space four measurement points in front of the facade modification were introduced in this setup. With these four points the measurement data was evaluated due to the frequency-distributed level in each measuring point. As the frequency-distributed levels are not so clear readable in terms of the acoustical impact of a facade modification the method of calculating single values out of frequency-distributed levels was used. The average frequency distributed noise level of each of the four measuring points was calculated out of the frequency distributed noise level values of the single measurement points. In order to obtain insight on the effect of a facade modification the change of noise levels was calculated by subtracting the measured level values of the modification from the level values of the reference model ref01 measured in the sequence. The change of noise levels in relation to the reference model was calculated for average noise level for the validated frequency range of 25 Hz to 630 Hz in one microphone position and in all four microphone positions. The results for the measurement sequence of the facade modifications "ref02 v1 - v3" are shown exemplarily in the following. The graphs are showing results from two defined arrangements of noise source and measurement position. If the noise source is on axis with the active measurement point the measurement is defined as a "on axis" measurement. Whenever the measurement position is not in the axis of the noise source to the measured object, the measurement is defined as "off axis". Calculating the average out of the frequency distributed level data set for each measuring point delivers a single value on the broadband weighting of one surface modification regarding one measuring point. The results are showing for the "on axis" measurement a level reduction from 0,25 dB up to 0,5 dB. The values from the "off axis" measurement are detecting a maximum level change to the reference model from 0,15 dB, refer to figure 12.

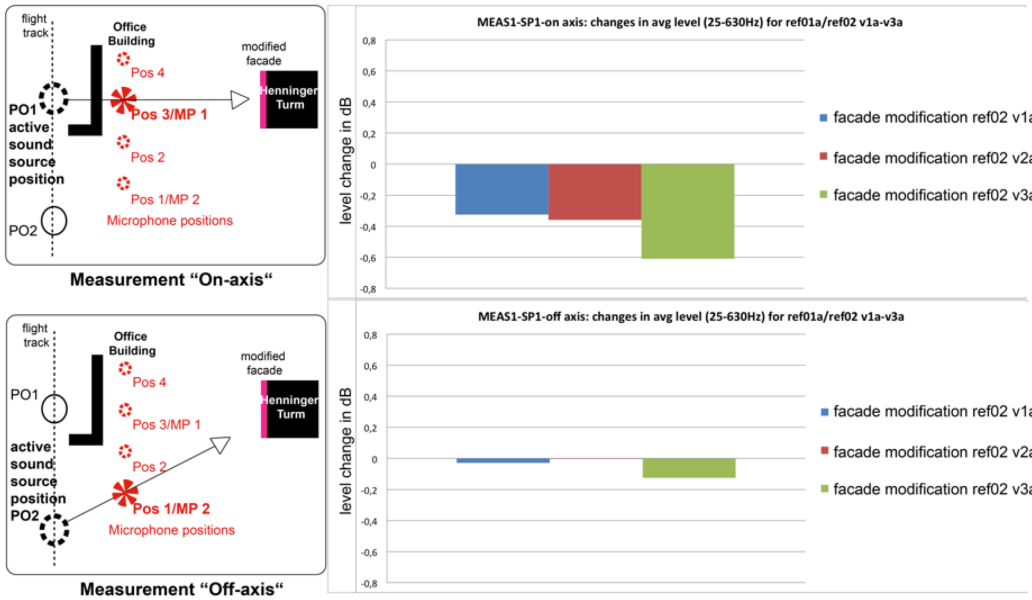

FIG. 12 Level changes for the facade modifications ref02 v1, refo2 v2 and ref02 v3. Measurements on-axis and off-axis conducted by the author.

The measurement with the noise source positioned on axis indicates level changes for the averaged noise level of the validated frequency range up to -0,6 dB. The values derived from the measurement with the noise source located off axis results in an average noise level change in the range of -0.1 dB for the three surface modifications. Data of all four positions were used to obtain information on the noise coverage of the area in front of the south facade. Therefore the four averaged frequency-distributed levels of each microphone position were averaged resulting in one level value for each surface modification within the validated level range of 25 Hz to 630 Hz. The result draws an oppositional picture to the averaged value for one microphone position. Each surface modification is increasing the level when taking all four points into account, refer to figure 13.

The data of this geometry design study represented in the graphs is indicating that the effects of surface modifications on a facade are located in spots. At the locations of the spots a level change of 3 dB can be measured. Putting this into the perspective of inspecting all four measurement points simultaneously the effect switches from a level increase of 0,6 dB to a level decrease of 0,2 dB. Remarkable is here not the small level change below 1 dB but the switching from a level decrease to an increase when the whole area of the four measurement points was taken into account. Only with an evaluation of all measurement data in a table a "best modification" can be detected. See table 1.

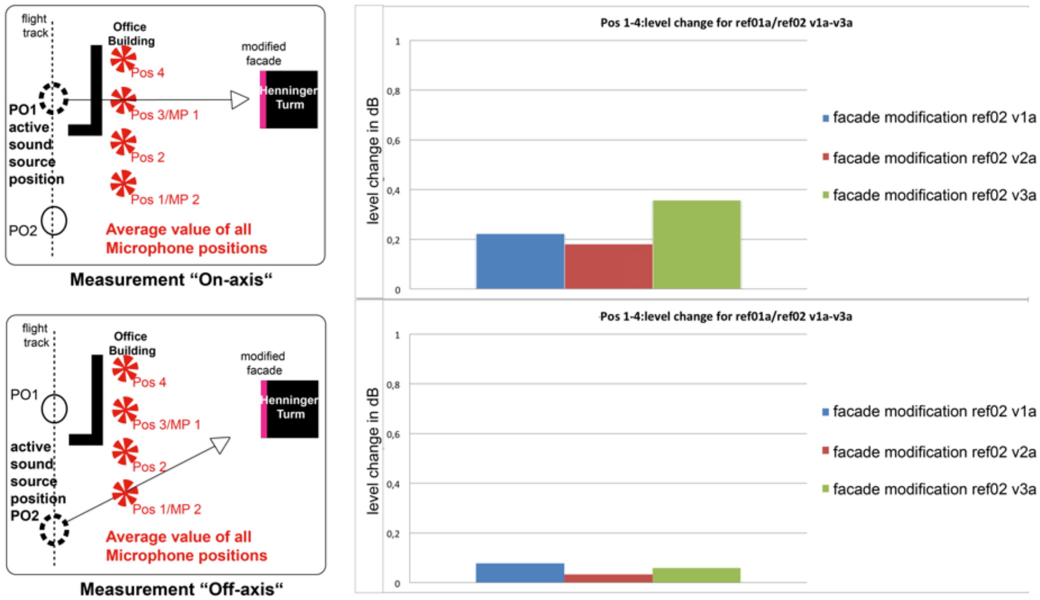

FIG. 13 Averaged noise level values for positions 1-4, measured on-axis and off-axis.

FACADE MODIFICATION	ORIENTATION	DENSITY	MAXIMUM LEVEL CHANGE	FREQUENCY OF MAXIMUM LEVEL CHANGE	AVG. LEVEL CHANGE ON AXIS FOR 25 - 630 HZ	AVG. LEVEL CHANGE OFF AXIS FOR 25 - 630 HZ	AVG. LEVEL CHANGE IN FOUR POINTS ON-AXIS FOR 25 - 630 HZ	AVG. LEVEL CHANGE IN FOUR POINTS OFF-AXIS FOR 25 - 630 HZ
			dB	Hz	Sp1/MP 1	Sp1/MP 2	SP 1/MP1	SP2/MP2
Ref02 V1	hor.	1	-1.9 dB	160 hz	-0.3 dB	0.0 dB	+0.2 dB	+0.1 dB
Ref02 V2	hor.	2	-2.6 db	400 Hz	-0.4 db	0.0 dB	+0.2 dB	0.0 dB
Ref02 V3	hor.	3	- 3.0 dB	400 Hz	-0.6 dB	-0.1 dB	+0.4 dB	+ 0.1 dB
Ref03 V1	hor.	1	-1.9 dB	200 Hz	-0.4 dB	0.0 dB	+0.3 dB	+0.1 dB
Ref03 V1u	hor.	1	-3.2 dB	250 Hz	-0.2 dB	0.0 dB	+0.3 dB	+0.1 dB
Ref03 V2	hor.	2	-3.5 dB	250 Hz	-0.4 dB	0.0 dB	+0.3 dB	+0.1 dB
Ref03 V2u	hor.	2	-4.5 dB	250 Hz	-0.9 dB	0.0 dB	+0.5 dB	+0.1 dB
Ref03 V3	hor.	3	-3.2 dB	250 Hz	-0.4 dB	0.0 dB	+0.4 dB	+0.1 dB
Ref03 V3u	hor.	3	-4.9 dB	250 Hz	-0.9 dB	0.0 dB	+0.5 dB	+0.1 dB
Ref04 V1	vert.	1	-1.9 dB	200 Hz	-0.2 dB	+0.6 dB	-0.2 dB	-0.3 dB
Ref04 V2	vert.	2	-2.4 dB	160 Hz	-0.2 dB	+0.5 dB	-0.2 dB	n.a.
Ref04 V3	vert.	3	-2.7 dB	160 Hz	-0.4 dB	+0.5 dB	-0.2 dB	-0.4 dB
Ref04 V4	vert.	4	-4.4 dB	400 Hz	-0.5 dB	+0.5 dB	0.0 dB	-0.3 dB
Ref04 V5	vert.	5	-3.5 dB	400 Hz	-0.4 dB	+0.5 dB	-0.1 dB	-0.4 dB
Ref05 V1	hor.	1	-1.8 dB	400 Hz	-0.2 dB	0.0 dB	+0.1 dB	0.0 dB
Ref05 V2	hor.	2	-3.3 dB	400 Hz	-0.6 dB	0.0 dB	+0.2 dB	0.1 dB

TABLE 1 The calculated results of the measured sequences

3 CONCLUSION

Both case studies are pointing out that acoustical design of facades has to be individually measured and evaluated. The use of the scale measurement method gives the possibility to engineers and architects to introduce geometric surface modifications to a building design process whenever an acoustical approach is needed. The measurements can be introduced according to the design stage of a project. With the scaled measurement method it is possible to investigate geometric details of an acoustic design in a 1:10 downscaling as it is possible test a building geometry with 1:100 models. The effects on the urban space in relation to the facade can be predicted and tuned to a complete coverage without an overall decreased noise level. If we want to come up with the challenge of creating a lively and comfort environment in the process of an increasing urbanisation the tool of scaled measuring has to be introduced to architectural design processes in order to define the geometrical basis for acoustically comfortable spaces. The even more remarkable outcome of the case studies is that all observed level changes were caused only by a change of geometry. No material properties were yet involved in the studies. All achieved level changes in both case studies could be optimised in further developments. The results of acoustical effective facades could be tuned by introducing specially shaped perforations of the facade surface or by adding materials with acoustical properties to the building envelope.

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