

Highlights of Room Acoustics and Sound Isolation Design

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Designing the Room Acoustics of “Grosser Saal”

Entering the Elbphilharmonie “Grosser Saal” from the dynamically flowing and smooth lines of the lobby’s interior surfaces, what first impresses the eye is the sudden change to a room of intentionally uneven, textured wall and ceiling surfaces. The surface micro-shaping of the walls and ceiling create a visual design with a seashell motif and serve the role of promoting acoustical diffusion for the hall’s acoustics. From the surfaces of the walls and ceiling we can expect the soft reflections and, in addition, these surfaces dissipate and eliminate any undesirable localized echoes that might otherwise occur.



Figure 1: Acoustic test with 1/10 scale model

The audience seating blocks and ceiling height, as well as the placement of a hall’s walls determine how reflections reach different locations within a hall. To study these basic shapes in the “Grosser Saal”, we began by using computer simulation based on the geometrical acoustics to study how the reflections would distribute in the “Grosser Saal”. With these studies we had intensively discussed about the basic room shape with the architect.

In the next phase of our room acoustics design after fixing the basic room shape, we built a 1/10 scale model of the hall interior and conducted acoustical experiments in the scale model to study more details about how sound would behave in the space. Our first step in scale model testing was to check for detrimental echoes and, if an echo was found, to solve how to eliminate it. In halls such as Elbphilharmonie’s “Grosser Saal” that have the vineyard (also called “arena”) shape, sound can easily return back into the room as a long path echo (a strong reflection with a long time delay). Our tests in the 1/10 scale model of the “Grosser Saal” found long path echoes at the stage and nearby seating. In the case of a long path echo, the options to eliminate it are: changing the angles of some reflective surfaces; adding sound absorbing measures; or adding diffusing elements. The architect favored diffusion to eliminate the long path echo as one of diffusing surface patterns which were usually expected to create soft reflections.

To test and confirm the efficacy of the seashell motif surface, we made a 1/10 scale version of the seashell motif surface and affixed it to the portions of the wall in the model that had caused the echoes. We also used scale model testing to determine the depth of indentations necessary to achieve our desired results.



Figure 2: Micro-shaping on the ceiling for sound scatter



Figure 3: Acoustically transparent wall in front of the pipe organ

In the project's "Grosser Saal", the diffusion wall material was fabricated from gypsum board that is fiber reinforced to have relative density of 1.5. The fabrication process involved bonding together multiple layers of gypsum board panels and then sculpting out the surface in the seashell motif pattern. In the locations where we expected the surface producing soft reflections, the depth of indentations for diffusion measures 10 to 30 mm. (0.4 to 1.2 in.). Where we aimed to eliminate echoes, the depth of indentations for diffusion measures 50 to 90 mm. (2 to 3.5 in.). Also, because we needed these panels to have sufficient weight to effectively reflect sound even at low frequencies, the panels were fabricated so that they have a post-sculpting average density of 125 kg/sq. m. (25.5 lbs/sq. ft).

The seashell motif material is used entirely on the walls and ceiling of the "Grosser Saal". The 3D modeling was used to determine where to place joints in the panels of this material and then the panels were fabricated at an off-site factory. In addition, the flat panels of the same gypsum board material for the "Grosser Saal"'s flooring substrate over which the wood flooring was installed.

Audience Seating of "Grosser Saal"

Our primary requirement for the audience seating in the "Grosser Saal" specified that all surfaces be acoustically reflective except those that would be covered when a person is in the seat. This meant cushioning and upholstering only the front of the seat back and the horizontal seat, and using wood paneling for the rear side of the seat back. The unique design of the seating creates a visually smooth transition line between the seat and seat back when the seat is in the raised position. The seat's upholstered fabric is attached directly to the rigid panel of the seat's rear side.



Figure 4: Audience seating

In particular, because the seat cushions of the audience seating are thick, when we tested the seating in a reverberation room, we learned that its equivalent sound absorption area is a rather large value of slightly greater than 0.3 (at mid-range frequencies and with the seat vacant). However, when the seat is occupied, the equivalent sound absorption area is less than 0.4, which means that the difference between a vacant and occupied seating is quite small.

Interior Finishes of “Kleiner Saal”

Our acoustics design of the “Kleiner Saal” both prioritized the hall’s use for recitals and, at the same time, gave strong attention to its use as a multipurpose hall. The room’s tiered floor can be stored behind the hall’s rear wall using a pneumatically powered mechanism, making it easy to convert the room to a flat-floored space for events and receptions. Also, the walls of the “Kleiner Saal” have absorbing banners that can be moved up and down like roller shades to vary the room acoustics for the needs of a different kinds of events.

For recital and chamber music use, we gave the walls of the “Kleiner Saal” an intentionally uneven surface treatment that promotes diffusion, as we did for the “Grosser Saal”, but we used different materials to achieve this. In the “Kleiner Saal”, we fabricated the walls of laminated wood with cut-out patterns that achieve the desired uneven surface treatment.

For sound isolation reasons, which I explain in a below paragraph, the hall’s structure has a box-in-box concrete design. We kept the concrete ceiling of the “inner” box as an exposed concrete ceiling (with a black paint finish) in order to effectively utilize the hall’s limited ceiling height.

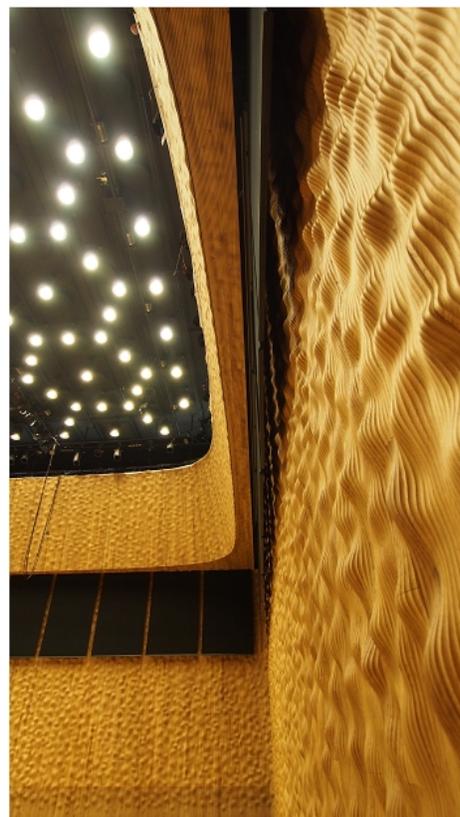


Figure 5: Micro-shaping on the wall at “Kleiner Saal” for sound scatter

Sound Isolation to Address Ship Whistles

For Elbphilharmonie’s architectural design, the architects kept the old brick warehouse facade that stands directly at the waters’ edge of the Elbe River and constructed the new halls on top of the old facade. The Elbe River functions as an active seaport for large, ocean-going vessels and ship terminals line the waterway on the east side of the Elbphilharmonie building. The berths accommodate large ships such as the Queen Mary 2 (weighing 76,000 tons) and other cruise liners.

When a cruise liner leaves its berth for a voyage, it blows its ship whistle. The sound of the whistle can be heard even several kilometers away in downtown Hamburg hotel rooms. Ship regulations require that the larger the ship, the lower the frequency of the ship’s whistle. In the case of the ship whistle of the Queen Mary 2, we needed to achieve sound isolation of ISO R’w (weighted sound reduction index) rating of 90, and 75 dB isolation at 125 Hz octave band. To achieve this



Figure 6: Large ship passing by “Grosser Saal”

high level of sound isolation, we adopted a building anti-vibration system using metal springs that can be set to a lower natural frequency than is possible using anti-vibration rubber material. Our goal with this design was to achieve more effective sound isolation at lower frequencies than can be achieved with rubber sound-isolating materials. Specifically, the both Halls structure has a 200 mm.-thick (8 in.-thick) concrete outer box (made of half-precast concrete) and, inside of this box, an inner concrete box, also 200 mm.-thick (a shotcrete deck structure) supported on the metal springs. The both Halls’ interior was constructed inside this inner box concrete structure.

The natural frequency of our design is 3.5 Hz. The springs used in this design can be compared to the rubber bearings used in a seismic isolation structural design. However, because rubber bearings are designed to dampen the effects of horizontal shaking, they are comparatively stiff in the vertical direction, while the building anti-vibration springs in Elbphilharmonie are flexible in both the vertical and horizontal directions.



Figure 7: Ceiling structure and spring at “Grosser Saal”



Figure 8: Inner box (shotcrete) for sound isolation at “Kleiner Saal”

In July, 2016, we visited Elbphilharmonie before construction completed and tested our sound isolation solution by measuring and listening to a large ship’s whistle. We confirmed that we could hear the whistle when we stood sandwiched between the “Grosser Saal”’s outer concrete box and the inner box. When we stood next to the small window facing to the river in the hall, we could not hear the whistle’s sound. We breathed a sigh of relief to have confirmed the success of our sound isolation design.

Acoustic Parameters According to ISO 3382-1

The following values were measured using the methods of ISO 3382-1: 2009 Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces.

Elbphilharmonie: <https://www.elbphilharmonie.de/en/>

Acoustic quantity	Grosser Saal	Kleiner Saal (Concert Config.)
Reverberation Time, T30, in seconds		
Unoccupied	2.4	1.7
Occupied	2.3	1.4
Sound strength, G, in decibels	5.4	11.0
Early decay time(EDT), in seconds	2.3	2.0
Clarity, C80, in decibels	0.3	-0.8
Centre time, TS, in milliseconds	135	143

Note) Frequency averaging 500 Hz to 1000 Hz, measured in unoccupied

Figure 9