1 INTERNATIONAL CONGRESS CENTRE IN KATOWICE, POLAND: ACOUSTIC DESIGN AND PERFORMANCE

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2 INTRODUCTION

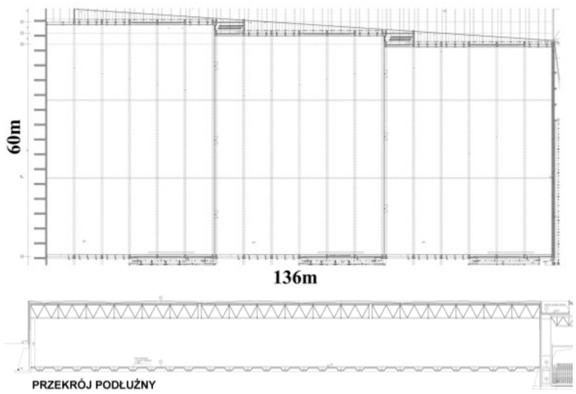
This paper discusses the design, realization and acoustical performance of the newly opened (march 2015) International Congress Centre (MCK), located in Katowice, Poland (Figure 1). Three types of rooms are discussed: 100,000 m^3 multi-functional room, a 600 seats speech auditorium and the small meeting rooms. Design process decisions and consequences for acoustics are briefly described.

Figure 1. International Congress Centre in Katowice. Design JEMS Architekci. Shown in colour next to circular in shape “Spodek” (The Saucer) 10,000 seats sport’s hall constructed in 1971 on the left and NOSPR Concert Hall opened in 2014 in lower right corner.

3 MUTLI-FUNCTIONAL ROOM

The multi-functional room (Figure 2) is intended for fairs, congresses, concerts and meetings with the sole use of sound amplification. It’s huge volume (approx. 100,000 m^3 below ceiling level) and large linear dimensions (136x60x12,5m; 8000 m^2 of floor area) could result in a long reverberation time, low intelligibly of PA system and high amplification of noise generated by it’s users or equipment. To overcome those risks, the acoustical design was aimed at reducing reverberation time to a level of maximum 1,5 second, preferably without the typical increase at low frequencies. Limiting reverberation time at low frequencies is required when sound is amplified by loudspeakers, because even directional loudspeakers become omnidirectional at low frequencies[1]. The architect, Warsaw based office JEMS Architekci, is known for minimalistic approach to theirs designs[2]. That's why in the architectural concept, the surfaces surrounding multi-functional room were designed in glazed concrete. Roof was designed in corrugated steel supported on large (4m high) structural steel beams. Dense HVAC installation suspended beneath the roof was left visible. Even taking into the account sound absorption and diffusion of all HVAC installations and ceiling supporting structure, the expected reverberation time as verified in simple Odeon model, was calculated at approx. 6 seconds (average 500-1000Hz). To achieve planned reverberation time of 1,5 sec., walls have to be covered with highly efficient absorbing material. The need to cover walls with sound absorbing material resulted in architect decision to finish the room interior in pure black matt colour, for both walls and ceiling, and to hide HVAC installations behind suspended ceiling. The room was suppose to look like a perfect cuboid or a black-box theatre, where walls are just a background for whatever is planned inside the room. This decision eliminated any possibility to introduce diffusion on the walls in the form of absorbing baffles or a mixture of reflecting and absorbing materials. Diffusion could be used in rectangular room to make the sound field more diffuse, and to reduce the risk that individual reflections will become audible as echo.

Together with an architect, a wood-wool finishing panels (Heradesign) were selected as the main sound absorbing material to cover walls and ceiling. This product, selected mainly from aesthetics reasons, when combined with a mineral wool hidden behind, can achieve quite high sound absorption coefficients (see Table 1, lit.1-2). Wood wool is also easy to renovate by painting it's surface. Subsequent painting is decreasing sound absorption only to small extent, as the wood-wool fibres form a very open and rough surface (see Table 1, lit.3-5).



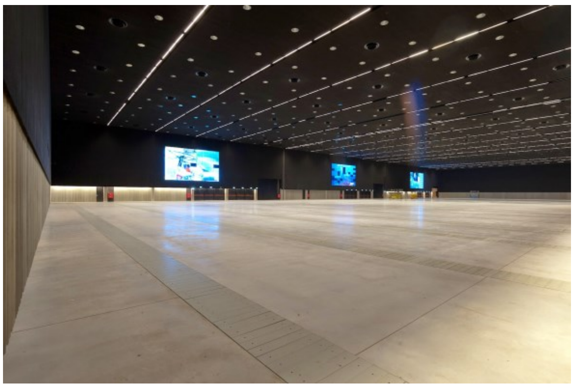


Figure 2. Multi-functional room, ICC Katowice. Plan and section (left). Finished room (right).

Table 1. Sound absorption of wood-wool panels (laboratory measurements)

Lit.	Product name	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
1.	Wood-wool panel Heradesign Superfine, black, 25mm with 50mm stone-wool "DP-5", 50kg/m^3, mounting E300, tested at ITB, Warsaw, June 2010	0,50	1,00	0,95	0,90	0,80	0,90
2.	as above, with 50mm Isorock ISOVENT-L stone-wool, 50kg/m^3	0,65	1,00	0,95	0,85	0,75	0,85
3.	Wood-wool panel Heraklith, black, 25mm, over 80mm empty void (mounting E105), tested in Wien, 1998, 1 layer of paint (400g/m^2)	0,25	0,50	0,70	0,50	0,55	0,70
4.	as above, 2 layers of paint (800g/m^2)	0,25	0,50	0,70	0,50	0,55	0,75
5.	as above, 3 layers of paint (1200g/m^2)	0,25	0,50	0,60	0,45	0,50	0,70

To maximize sound absorption at low frequencies, 25mm wood-wool panels on walls (Heradesign Superfine) were installed in front of 50mm of mineral wool and with 60cm void behind panel, except for one of the shorter walls where the void was reduced to 20cm due to architectural restrains (Figure 3). Suspended ceiling was constructed in the same way as walls (25mm wood-wool panel + 50mm mineral wool), but with a void of approx. 400cm. In authors experience, such a large void could reduce the sound absorption of suspended ceiling at mid and high frequencies. Also, the volume above suspended ceiling is approx 32,000 m^3, almost 1/3 of a volume below ceiling. To prevent excessive reverberation in the ceiling void, approx. 3000 m^2 of sound absorbing material was proportionally distributed throughout the void in both directions, mostly in the form of sound absorbing ceiling baffles, 1,2x0,6x0,05m each (Figure 3).

Figure 3. Multi-functional room, ICC Katowice. Wood-wool panels over 5cm mineral wool and 60cm void behind the panel (left). 3000 m2 of sound absorption distributed in the ceiling void to prevent from excessive reverberation in the void.

Covering almost all surfaces with absorption is not without the risks - any surface left without absorption, even a small one, can reflect audible echo. In ICC multi-functional room, the lower part of the hall, up to 2,5m above the floor, had to be made in pure concrete to prevent possible damage. This left two possible choices to prevent echo from appearing in the lower part of the room - either redirect sound upwards or downwards (by sloping bottom 2,5m of wall) or use diffusion. Unfortunately, the architect did not accepted any non-vertical visual element in this room, neither deep diffusion on the walls. Several variants of diffusing elements were discussed (Figure 4). Finally, a vertical “zig-zag” shaped diffuser was accepted, but with limited depth of just 9,5cm. This depth should at least diffuse frequencies from approx. 800Hz up. Unfortunately later (in the construction process) the depth of “zig-zag” shape diffuser was further reduced by half, basically converting this diffuser into an almost flat wall - one could say very expensive and very heavy flat wall (!). Measurements showed (Figure 6), that such a low profile shape is able to diffuse only frequencies from 2kHz and up. Fortunately, this room will rarely be used without anything located on the floor (like exhibition stands, chairs, etc). Those elements should block sound from specullar reflections in 2D plane at the ear height. Just in case, to prevent such a situation, fixing points for banners/curtains were planned along the perimeter of the hall. Measurements made during construction and in finished hall showed gradual reduction of reverberation time from 4,0 seconds in untreated room to as low as 1,0 second in room during opening show (Figure 5). From results presented on Figure 5 we can conclude, that each additionally introduced absorption was almost equally efficient in both low and mid/high frequency range. However measurement conducted in fully finished, but totally empty room (like on Figure 2, right picture), resulted in very strong and prolonged echoes and increase in reverberation up to almost 4,5 seconds at mid-freq. Example of energy time curves for several frequencies measured in such an empty hall are shown on Figure 6.

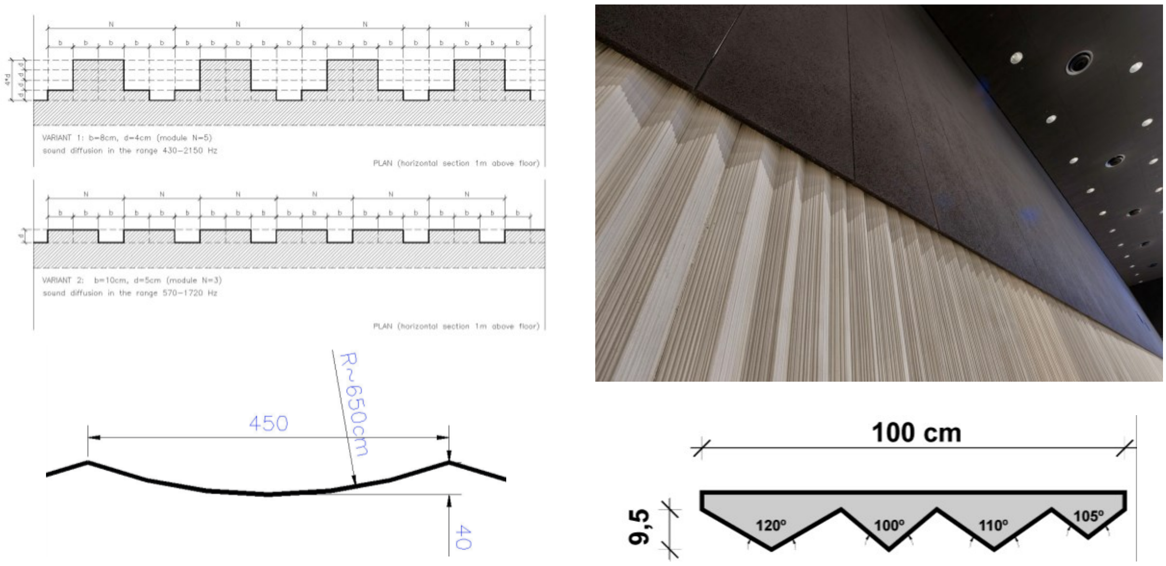


Figure 4. Multi-functional room, ICC Katowice. Three conceptual designs of sound diffusion elements covering lower 2,5m of exposed concrete walls - in the form of QRD diffusers or simple curving elemenst (left). Finally, the concept shown at the right (zig-zag shape) was constructed in the hall, but all dimensions were scaled down by the factor of 2 (one diffusing module was only 4,75 deep and 50cm wide). Concrete diffusers as constructed in the hall (upper right)

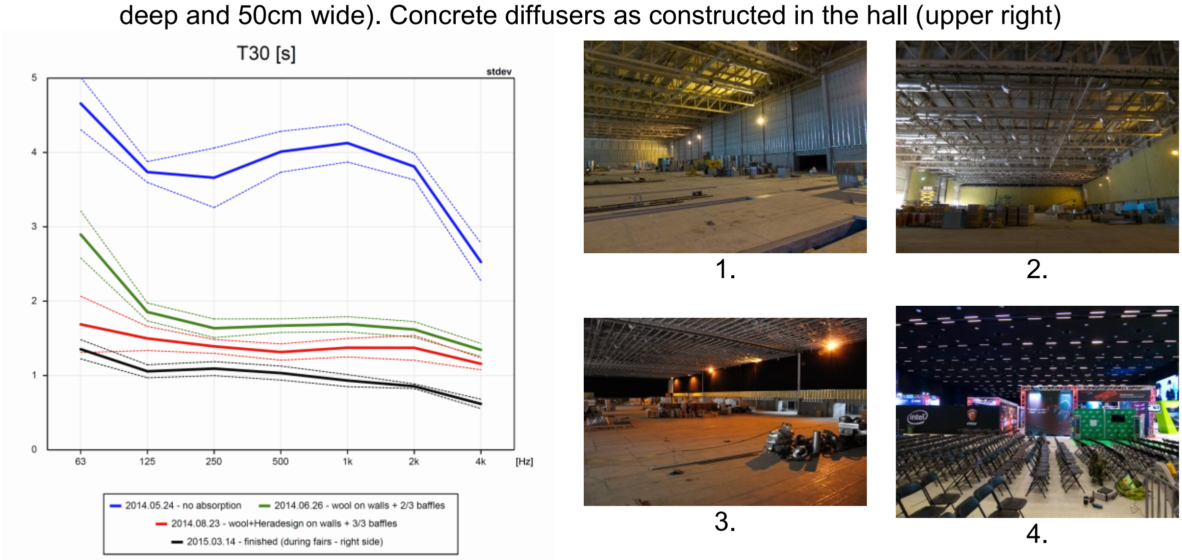


Figure 5. Multi-functional room, ICC Katowice. Measured reverberation time (T_{30}) at several stages of construction (from the top curve): no absorption, metal grid on all walls (1) / 50mm mineral wool on all wals + 2/3 of all baffles in the void (2) / wood-wool on all walls + all baffles in the void (3) / finished room, measurement during Intel Extreme Masters fairs (4)

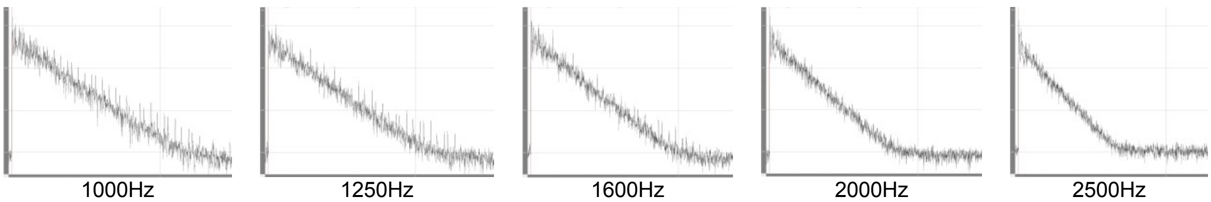


Figure 6. Multi-functional room, ICC Katowice. Measured energy time curve for 1000-2500Hz in totally empty room (as on Figure 2, right picture). Individual isolated peaks (echoes) are visible until 1600Hz. From 2kHz curve is smooth, but reverberation is still in a range of above 3 seconds.

Fortunately installation of just hard chairs on the floor is introducing enough diffusion to bring back reverberation to a level of 1,0~1,5 second and eliminate audible echoes. One of the possible explanations of extended reverberation time measured in empty multi-functional room is, that at lower part of the room, in the horizontal plane, an almost 2 dimensional reverberation is generated. “Zig-Zag” diffusers have ribs only along vertical edge, so they are diffusing sound mostly in horizontal plane, which keeps sound “locked” in bottom 2,5 meter of the room, not allowing it to get absorbed in the upper part of the room. This could explain curves on Figure 6, where individual peaks (echoes) disappear from 2000Hz and up (from where diffusers seems to become efficient), but reverberation time is still long. When some furniture’s or other installations are places on the floor, sound is reflected in diffuse way from them, and gets absorbed in upper part of the walls or the ceiling. Such diffusing elements in the form of pallets or exposition stands were present in the room during all measurement sessions shown on Figure 5, and prevented detection of that phenomenon until room was totally cleaned.

Multi-functional room can be divided into three smaller rooms using two 12,5m high sliding partitions (Figure 7). In acoustical design both partitions were covered with a mixture of mid/high frequency (mineral wool) and low/mid frequency (perforated board) absorbers with approximate thickness of 40mm on each side. Due to architectural (parking space) and structural (maximum load on roof structure) constrains, both weight and partition thickness was limited. In that situation achieving as high sound absorption of movable wall as planned, was not possible. Maximum acceptable thickness of movable partition was set to 136mm. Authors, together with the manufacturer of the movable wall (Polish company Modul, using HUFCOR elements) had to design a partition within given constrains, with at least R_W=40dB of sound insulation and maximum possible sound absorption. Final design consisted of 92mm thick core with 16mm wood fibre boards on steel profiles as structural elements and 50mm mineral wool filling. This core was covered on both sides with sound absorbing element consisting of 12mm thick mineral wool (made from Rockfon Pacific 12mm boards) covered with black fleece and with 10mm MDF panel. MDF panel is perforated with circular holes measuring 8mm in diameter. Perforated part has a 19,6% perforation ratio. MDF panel has a black coloured core, so the side of the perforation is also black. This ratio of perforation was a maximum possible for 10mm MDF board, so the board would still offer some impact resistant. Sound absorption data for the wall installed in multi-functional room is shown in Table 2, together with earlier design of that wall and data for other type of movable walls (with linear perforation) installed in conference rooms, and discussed further.

Table 2. Sound absorption of movable walls designed for ICC Katowice (laboratory measurements)

Lit.	Product name	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
1.	Movable Wall for Multi-functional room - final design: 136mm thick, circular holes Ø8mm at 16x16 centres, 19.6% perforation ratio, 10mm front MDF board /black core/, with 12mm mineral wool behind (Rockfon Pacific board)	0,25	0,25	0,50	0,75	0,70	0,70
2.	Movable Wall for Multi-functional room - preliminary design: 147mm thick, circular holes Ø8mm at 20x20 centres, 12.6% perforation ratio, 6mm front MDF board, with 12mm mineral wool behind (Rockfon Pacific board)	0,15	0,25	0,50	0,65	0,50	0,40
3.	Movable Wall for conference rooms - 129mm thick, mixed perforation - front: slits 4mm every 8mm; back: circular holes Ø8mm at 16x16 centres, 16mm front MDF board, with 12mm mineral wool behind (Rockfon Pacific board)	0,30	0,35	0,60	0,85	0,85	0,95

The sound insulation of movable partition was evaluated at the laboratory prior to installation, and also later with on-site testing. To reduce the flanking transmission, the void above suspended ceiling along partition length is separated with plasterboard wall (Figure 7, right scheme). Sound insulation of 136mm thick partition measured in laboratory was $R_W(C,C_{tr})$=43(-1,-6). Sound insulation measured on-site in the multi-functional room was $R'_W(C,C_{tr})$=49(0,-1) for one of the walls, and $R'_W(C,C_{tr})$=46(0,-1) for the second one. To allow organizing two simultaneous loud performances at the same time in the multi-functional room, it was planned that performances can take place in two edge rooms, leaving central room as the buffer zone. Sound insulation measured on-site for such a scenario was $R'_W(C,C_{tr})=64(-1,-1)$. Higher values were not possible to be measured, due to lack of power from omnidirectional source in such a large room.

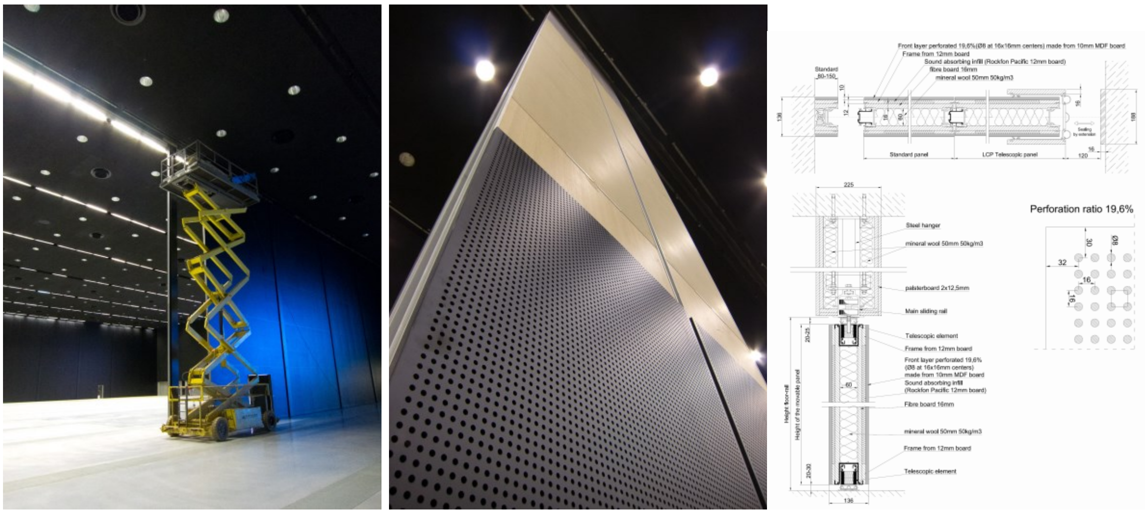


Figure 7. Multi-functional room, ICC Katowice. Movable partitions (12m high), hanging from roof structural beams. Each partition is only 136mm thick.

Background noise level measured in fully functional room with HVAC system at maximum was 30-35dB(A) depending on location in the room. Speech Intelligibility of a PA system measured at ear height is above STI=0,63. In emergency situation with noise level at approx 67dB(A) STI from the sound warning system was calculated to be above required 0,50.

4 SPEECH AUDITORIUM

The 600 seats speech auditorium (Figure 8) is intended for conferences and visual presentations with the sole use of sound amplification. It's floor area is approx 600 m^2, and internal volume is approx. 5,000 m^3. Room height is approx. 10m. However, above suspended ceiling, there is a void of approx. another 10m, creating an additional volume of 5,000 m^3. Both volumes are linked through sound absorbing ceiling. Void was partially filled with HVAC installations, but similarly to multi-functional room, to damp the void, it was decided to use there approx. 600 m^2 of additional absorption in the form of acoustical baffles (Figure 9).

In the architectural concept of ICC Katowice one of the main material to be used almost everywhere was black expanded metal mesh made from lightweight aluminium. This material was also used inside auditorium, as it allowed to freely design complicated 3d geometry of the room. From acoustical point of view expanded metal mesh needed to be converted into sound absorbing material which was accomplished by installing 50mm of mineral wool behind the mesh (Figure 10). Sound absorption data for such a sandwich construction is shown in Table 3. During construction, it became clear, that due to lightweight nature of the mesh and it's almost 20mm wide slat, and additionally the way mesh was connected to supporting frame (mesh was point welded to a front of a C channel), mesh is prone to audible vibrations. Mineral wool behind mesh was installed into the C channel, and was stiff enough not to touch mesh surface, as the mesh was a little bended down (sagging) when installed on ceilings (!). To suppress mesh vibrations, mineral wool was supported from the behind with the help of metal bars (or C channels) to push the wool towards the mesh (Figure 10). This in most cases eliminated vibrations, but in authors opinion this type of mesh (lightweight mesh with wide slat) is not well suitable as interior finishing material due to a risk of uncontrolled vibrations. Much safer acoustically (but not so "strong" visually") is the mesh with smaller openings and narrower slat width (see Figure 10, right picture).

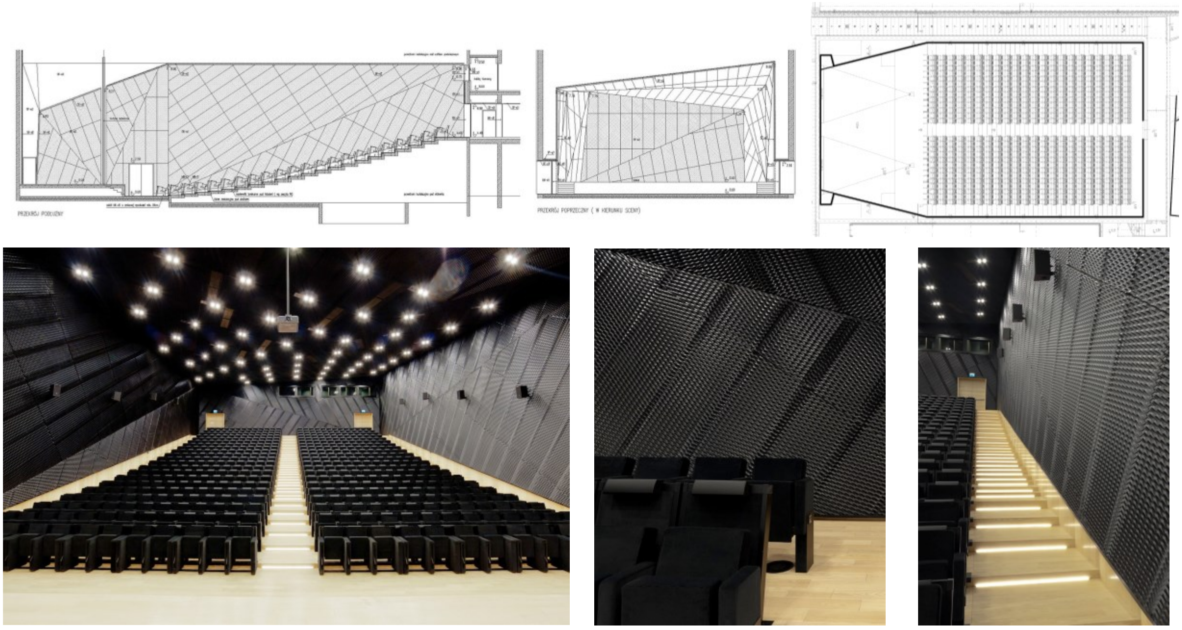


Figure 8. Speech auditorium, ICC Katowice. Plan and section (upper). Finished room (lower).

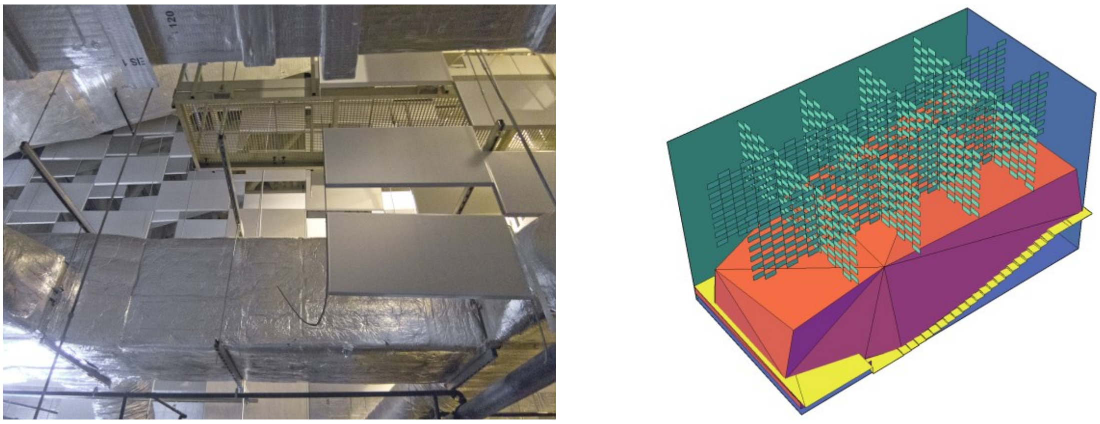


Figure 9. Speech auditorium, ICC Katowice. Acoustic baffles (Rockfon Baffle) in the void over auditorium (left). Odeon model geometry used to estimate the effect of baffles absorption (right).

During design, it was planned to install reflecting surfaces (plasterboards painted black) under some areas on the side walls and central part of ceiling, to make the room addressable with natural voice. With those elements in place, Odeon simulations showed that predicted reverberation time will be approx 0,8 seconds, with an increase in low frequencies up to 1,1 sec. During construction, it became clear, that installation of the reflecting surfaces behind the mesh is not possible. First, the mesh is then prone to vibrations. Second, it is not possible to get identical shade of black (and tint) of the black fleece on the wool and painted plasterboard. It was then decided to use mineral wool behind all mesh elements, which resulted in very much reduced reverberation time in finished room compared to predictions. Measured reverberation time in auditorium is shown on Figure 11. Even with such a low RT, room acoustics is pleasant without the feeling of “anechoic” conditions. Intelligibility of PA system is high (as expected with such a short RT), and thanks to low background noise level of just 30dB(A) and short reverberation, room is also addressable with natural (unamplified) speech. Speaker voice is intelligible even at last row of audience with both normal and raised voice.

Table 3. Sound absorption of expanded metal mesh designed for ICC Katowice (laboratory measurements). All values are almost identical to those measured for just a wool without the mesh.

Lit.	Product name	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
1.	Expanded metal mesh with 50mm mineral wool behind (Rockfon ICP Black), 250mm void (E300)	0,75	1,0	1,0	1,0	1,0	0,95

Figure 10. Expanded metal mesh during sound absorption test (Laboratory of ITB, Warsaw) Mesh type RO 170, IMAR s.a. (Spain), 170x63mm, slat width 20mm. Please note the difference in visual mesh opening depending on angle of view (left & centre left). Ceiling expanded metal mesh element with mineral wool and supporting bars to push wool towards mesh, suppressing it’s vibrations (centre right). Different type of mesh used in corridors, with much smaller opening and bended edge connected to supporting C channel along the whole edge. This mesh is much stiffer and not prone to vibrations. Mineral wool is loosely placed on top of it (right).

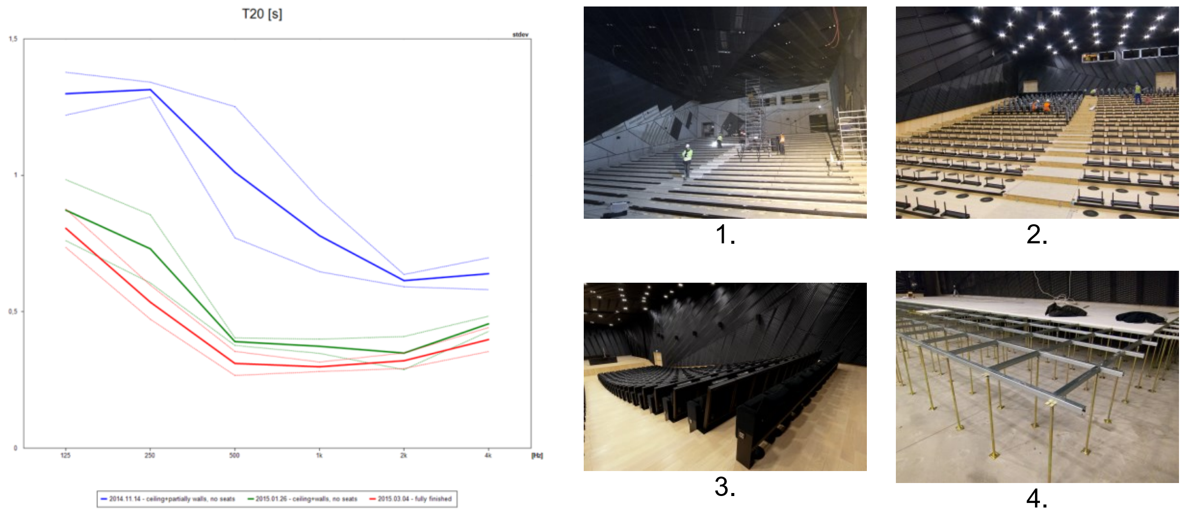


Figure 11. Speech auditorium, ICC Katowice. Measured reverberation time (T_{20}) at several stages of construction (from the top curve): ceiling and partially covered walls (1) / fully finished without seats (2) / fully finished with seats (3). Detail of stage with 90cm void beneath. Approx. 30% of floor area under the stage was covered with 50mm mineral wool blankets to dump the sound. (4)

5 MEETING ROOMS

There are about 20 meeting rooms in ICC Katowice (Figure 12). Some of them can be further divided into smaller rooms with the use of movable partitions, like the one described in Table 2, line

3). In almost every room, two parallel walls are finished with glazed reinforced concrete. Those walls (marked with solid black colour on Figure 12) are mostly structural walls, and could not be altered in any way. This was also one of the main aesthetical aspects of the meeting rooms interior design. A contrast between pure reinforced concrete walls going in one direction, and a pleasant wooden surfaces going in perpendicular direction. All wooden panels are perforated (in similar way as described in Table 2 line 3, but with 50mm mineral wool). External walls (marked with blue dots on Figure 12) are fully glazed, so corner room has three flat, reflecting surfaces. In all meeting rooms, floor is covered with sound absorbing carpet, and ceiling is covered with the same type of expanded metal mesh (with mineral wool behind) as was described in previous chapter (Auditorium; see Table 3). In all meeting rooms the negative effect of parallel smooth concrete walls is causing the audible flutter. This flutter is however coloured with a metallic sound, what is especially annoying. The source of that metallic colouration is not clear. One of the possible explanation is, that some expanded metal mesh panels are vibrating along loose (not welded) edges, when exposed to louder sounds, and that vibrations are prolonged by flutter. Flutter is also reduced, when some ceiling panels are demounted, creating openings in the ceiling. Of course, when rooms are furnished, and people are inside, this effect almost disappear, so there are no complains about the acoustics from the users of meeting rooms.

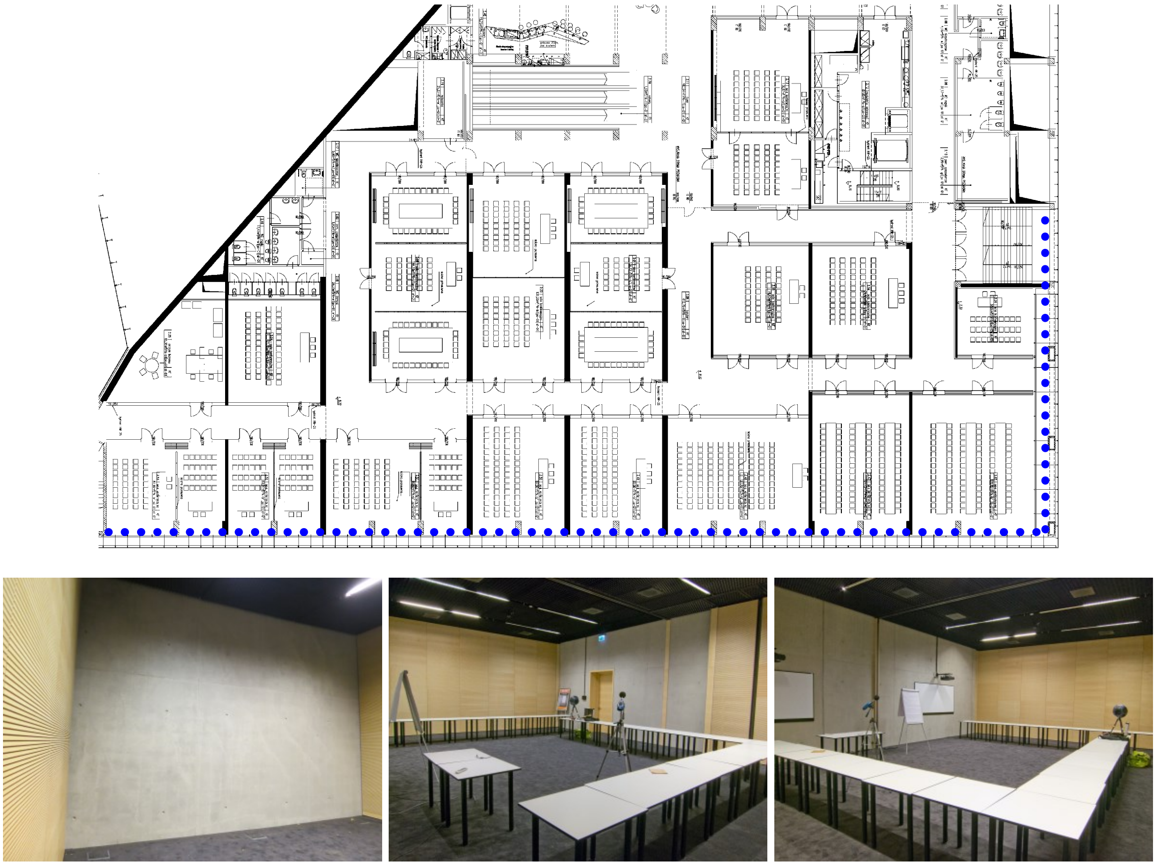


Figure 12. Meeting rooms, ICC Katowice.

To further investigate possible remedy for flutter echo problem, in one of the rooms (Figure 13) several layouts of sound absorbing material (120x85cm mineral wool panels, 50mm thick) was applied on one of the parallel concrete walls. Then, measurements and subjective evaluations were done. Room dimensions were 8,09 x 5,9 x 3,9m. Concrete walls were two shorter wall (5,9x3,9m). One of the longer walls was a movable wall (with linear perforation as described earlier). The other wall was a brick wall covered with wooden panels with linear perforation and 50mm of mineral wool. All tests were done in empty rooms (no furniture’s) with just 2 person conducting tests.

Subjective evaluation showed, that only layout 3 and 4 fully eliminate flutter. In all other layouts flutter is detectable when clapping hands and exploding balloons.

Further experiments involved just speech signals. One person was speaking and other was subjectively evaluating if flutter is influencing the speech. For speech comfort, acceptable layouts were 3,4,5 and 10. For remaining layouts (1,2,6,7,8 and 9), the amount of absorption was too small or it's distribution was not optimal, to totally eliminate flutter in speech. This mean, that from speech comfort point of view, at least 40% of concrete wall (like on layout 10) has to be covered with absorption, so flutter is minimized to such extent, that it does not disturb while speaking. Absorption has to be equally distributed on the wall surface.

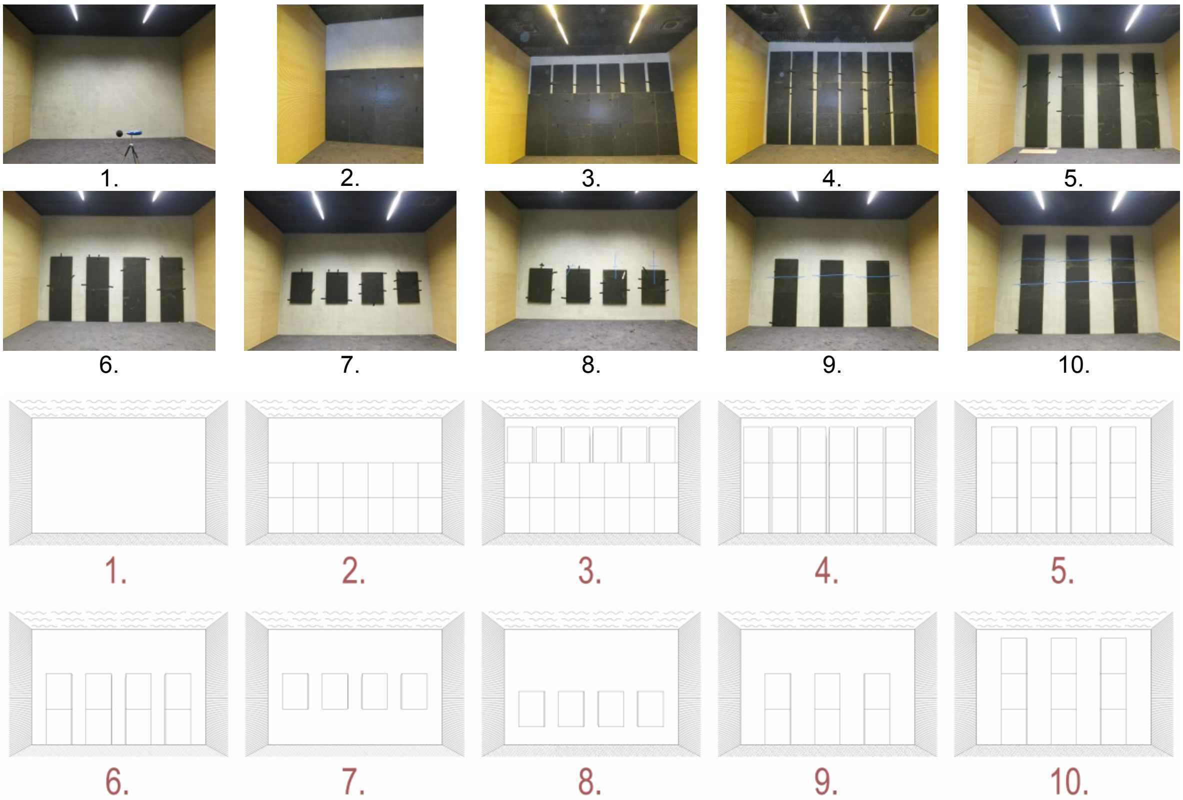


Figure 13. Flutter echo reduction experiments. Meeting rooms, ICC Katowice. Concrete wall dimensions are 5,90 x 3,90m. Each mineral wool panel is 1,20x0,85m (5cm thick).

6 SUMMARY

Both the architect and the user are happy with the acoustics of the ICC Katowice. Besides this positive feedback, the authors experienced the following: 1) in highly damped room, small reflecting surfaces can create strong echoes; 2) lightweight expanded metal mesh should rather be avoided inside rooms, as it is prone to audible vibrations, and 3) in highly damped rooms, flutter echo between two parallel flat concrete walls is very hard to suppress with the use of absorption.

7 REFERENCES

1. T.Rossing (editor). Springer Handbook of Acoustics. Chapter 9 (2007).
2. JEMS Architekci, www.jems.pl