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Comment on article "Nico F. Declercq *et al.*: An acoustic diffraction study of a specifically designed auditorium having a corrugated ceiling: Alvar Aalto's lecture room"

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The conclusion to the article "An acoustic diffraction study of a specifically designed auditorium having a corrugated ceiling: Alvar Aalto's lecture room" by Nico F. Declercq *et al.*, Acta Acustica united with Acustica **97** (2011) 599–606, states: "... *the improvement with respect to a smooth ceiling is significant enough to give Aalto the credit he disserves for designing a corrugated ceiling not just for esthetics but also for acoustics.*" But the analysis presented below shows that the corrugated ceiling is not better than a flat surface. Also, the analysis will improve on the original article by: (i) covering a wider frequency range and (ii) using a more exact representation of the geometry.

Boundary Element Modelling (BEM) has been shown to accurately predict the scattering from diffusing surfaces [1]. BEM allows the upper frequency of the analysis to be extended beyond 800 Hz (as was used in the original article) and so consider a wider and more suitable bandwidth for speech. Furthermore, a BEM allows the exact shape of the ceiling to be modelled rather than approximating it as a simple sinusoid.

The 2D BEM model uses the geometry shown in Aalto's sketch, reproduced in Figure 1b of the article. The sketch shows ray paths considered by Aalto to be important in the design. As these include paths reflecting from the end walls, these are included in the BEM predictions. The floor is not included so the effect of the ceiling can be seen in isolation. All surfaces are modelled as hard and non-absorbing. The omni-directional source is placed at the head of the talker, and the receivers follow a line passing through the heads of the seated listeners. The pressure reflected from the surfaces are predicted for 11 frequencies for each 1/3 octave band from 125 Hz to 2.5 kHz. These are then combined to give an estimate of the 1/3 octave reflected pressure level. Figure 1 displays the reflected pressure level for two contrasting frequencies.

At low frequency the corrugated ceiling produces a set of minima and maxima due to interference effects; these are caused by periodicity and reflections from the end walls. At high frequency, these ripples are less significant when summed over a 1/3 octave band.

Also shown in Figure 1 are predictions for a flat ceiling (including front and back walls). This flat ceiling produces a higher scattered pressure level than the corrugated ceiling. The level difference varies with frequency but across all 1/3 octave bands tested and across all receivers, the flat ceiling produces a reflected level on average 3.9 ± 0.2 dB greater than the corrugated ceiling.

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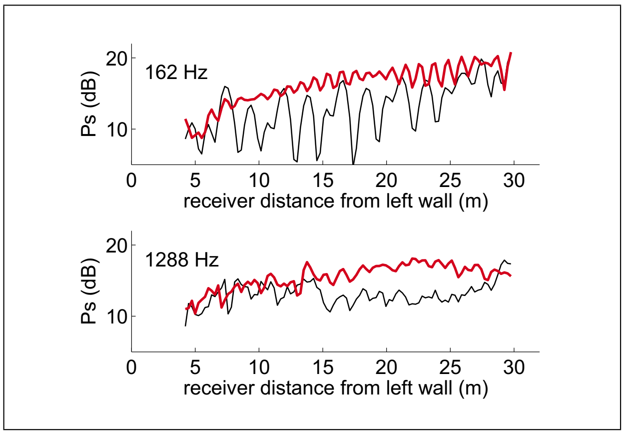

Figure 1. Reflected pressure level (arbitrary reference) for two example one-third octave frequencies as a function of receiver distance. ——— Corrugated ceiling; ——— Flat ceiling.

This occurs because the talker and listeners are in the near field; this level difference varies with source and receiver position.

The corrugated ceiling produces less reflected energy for the source and receiver positions in Aalto's sketch. This would normally be associated with poorer reinforcement of speech given the delay time of the ceiling reflection. It is therefore wrong to conclude that the corrugated ceiling is an improvement compared to a flat ceiling.

References

[1] T. J. Cox, P. D'Antonio, "Acoustic Absorbers and Diffusers", Taylor Francis, 2009, 252-268.

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Continuation of the research on the architectural endeavors of Alvar Aalto is highly appreciated. It is clear that Trevor Cox applies a powerful and correct numerical technique that is capable of dealing with the exact geometry and with frequencies beyond the frequency range our simulations are capable of. Three issues appear to us. First of all Trevor Cox has based his conclusions on results for an omni-directional sound source whereas a human speaker is not omni-directional but directed towards one end of the discussion room as in our Figure 8. This is very important because backscattering by a corrugated structure is a dominant effect only when it is not covered by direct acoustic waves originating from the sound source. An omni-directional sound source has no ’front’ or ’back’ whereas the conclusions in our paper which are very much based on Figure 8, signify the fact that speech can be well heard behind the speaker and not only in front of the speaker even when the speaker is far away from the end walls or even when such end walls are ’removed’ by making them perfectly absorbing. This brings us to the third issue, namely the fact that the quality of the room cannot be estimated only for a speaker near the end wall as in Figure 1b in our paper or as in the numerical results reported by Trevor Cox, but also at larger distances such as in our Figure 8. In addition an outline would be very interesting of the frequency dependence of the results produced by Trevor Cox. It would be interesting to get to know if the applied method, which does not pre-assume the likeliness of diffraction by a periodic structure such as with our plane wave expansion method, does indeed indicate a diffraction phenomenon resulting in structures as in our Figure 6. This could be subject to further studies.