

## Acoustic modelling of indoor and outdoor spaces

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## EDITORIAL

### Acoustic modelling for indoor and outdoor spaces

Predicting the sound field in spaces in the built environment, both indoors and outdoors, is of high importance in the field of acoustics, both in research and industry environments. In the industry, prediction methods are indispensable, for example in the development of acoustic-related products. Also, predicting the acoustic performance of spaces by utilizing simulation tools is a widely used approach being favoured over time-costly scale model studies. In research environments, predicting methods are used to develop new concepts of buildings, or building elements, to create acoustics protecting humans against adverse health effects and promoting well-being, performance (e.g. in working environments) as well as the acoustic quality of performance spaces like concert halls.

Nowadays, a major challenge for the development of acoustic prediction methods is generating a realistic and real-time auralization<sup>1</sup> of spaces. The acoustic performance of spaces has, for a long time, been evaluated by metrics related to amongst others the equivalent sound pressure level, and the decay of the sound level in a space over time. The perceptual appreciation of a sound environment cannot be captured by such metrics only. Time-dependent effects, such as the effect of moving source and/or receiver, and arising associations related to the nature of the source of the sound field determine how subjects perceive it. To support the research of perceptual evaluation of sound fields, prediction methods computing realistically the time-dependent sound field are therefore highly important. A research thread receiving much attention in this respect is soundscaping. In noise control, soundscaping implies that a positive sound field is strived for, whereby the sound field is composed of both natural and human-made sounds. Besides being supportive for perceptual research, auralization methods are also useful as a design tool for buildings, and in the communication of noise control measures to the public in an environmental setting (how does it sound in your back garden when a noise screen will be erected?).

A second challenge worth to be addressed is the field of low-frequency acoustics. Low-frequency noise could arise from sources outdoors, such as airplanes and heavy vehicles, and indoors by noise produced by neighbours. Lightweight materials in buildings are being applied in family houses and offices, which are advantageous regarding flexibility. The consequence of lightweight materials is that noise problems might occur in the low-frequency

range, as they are difficult to abate by lightweight materials. Prediction methods need to be able to predict the performance of buildings in this frequency range. A diffuse field assumption is the common practice in building acoustics, however typically not valid for the low-frequency range where modes dominate the acoustic performance of spaces and building elements. Also, a question in building acoustics still not answered is: what is the definition of sound insulation of a building element in the low-frequency range?

Three categories of acoustic prediction methods can be distinguished, which can be used to evaluate the acoustic performance of spaces: wave-based methods, geometrical acoustics methods and diffuse field methods. Whereas the latter two methods offer fast solutions, they are amongst other conditions only valid for the higher frequency range. Still, these methods are under development to push their capabilities beyond its conventional limits. For example, geometrical acoustics methods are under development by improving the predicted effect of diffraction (Svensson and Calamia 2006). However, to predict the acoustics for the full frequency range of interest, wave-based methods are needed for the low-frequency range and for frequencies with related wavelengths larger than present surfaces or objects. Clearly, wave-based methods are needed to answer the current research challenges as pointed out above. Besides, wave-based methods are also needed to solve sound propagation in inhomogeneous media in complex environments, as in outdoor acoustics. Partly driven by the advances in computer power, development of wave-based methods for acoustic propagation problems in the built environment has attracted increased attention in recent years. Some important developments of time-domain numerical methods (as they are favoured for auralization purposes over frequency-domain methods) are efficient finite-difference time-domain schemes (Kowalczyk and van Walstijn 2011), the application of the fast multipole boundary element method to room acoustics (Atak et al., 2010), the Fourier pseudospectral time-domain method (Hornikx 2009; Mehra et al., 2012) and the discontinuous Galerkin time-domain method (Atkins and Shu 1998). Current state of the art in time-domain modelling is the availability of open-source codes (Krijnen and Hornikx 2014; Saarelma and Savioja 2014; Sheaffer and Fazenda 2014) and accelerations on the graphic processing unit (GPU) (Tsingos, Jian, and Williams

2011). Besides these ongoing developments of numerical solution methods, other challenges include identifying the frequency range for which wave-based methods are preferable over geometrical acoustics methods (Vorländer 2013). This relates both to the lowest frequencies for which geometrical acoustics methods are still valid and to the frequency from which irregularities in a space (in terms of arbitrary objects and boundary shapes) make deterministic wave-based methods irrelevant. As a natural step, hybrid modelling approaches (both in space and time) are being developed. Also, the importance of correctly modelled boundary conditions has been pointed out to be of high importance.

This ‘virtual’ special issue of the *Journal of Building Performance Simulation* contains four papers that contribute to the field of acoustic modelling.

- (1) Navarro and Escolano present an overview of the contributions of using the diffusion equation to simulate sound fields inside buildings. The diffusion equation is an efficient method to compute sound fields in rooms with low absorption, and it predicts the later part of the reverberation, that is, the method does not capture the direct sound from source to receiver and the first reflections from room boundaries. The diffusion equation is explained and its range of applications is highlighted.
- (2) The paper by Vorländer et al. presents the state of art in virtual reality for architectural acoustics. The paper thereby addresses one of the current challenges in acoustic modelling as addressed earlier. It describes the needs for generating a virtual reality of the acoustics of an indoor or outdoor space, and how the currently developed methods fit into this framework. The authors clarify the status of current research in this field and address open questions that yet remain to be answered.
- (3) Hornikx et al. present a contribution to evaluation of various types of prediction methods for acoustic simulation of spaces, in this case two sports halls. The models are of different nature: a diffuse field approach, a geometrical acoustics method and a wave-based method. The authors have mimicked the design stage of a building in their work, that is, the stage at which exact material properties in the room are not yet at hand. The results of the paper indicate the applicability of the different methods to predict the sound field of sports halls.

I should also mention another paper in the field of acoustic modelling, published recently in *Journal of Building Performance Simulation* Volume 7, Number 6. This paper by Guillaume and Fortin doi:10.1080/19401493.2013.864335 is an example of a paper in which a numerical solution of the wave equation, in this case the transmission line matrix model, is accelerated to make its solution more feasible

with respect to the computation time. The authors decompose their geometry into subdomains, including a layer of ghost cells in each subdomain. This approach allows to efficiently utilize the GPU for carrying out computational operations, which clearly accelerates the computations. As meteorological conditions can be included in the method, it also applies to outdoor scenarios.

I would like to conclude this editorial by thanking the journal editors Jan Hensen and Ian Beausoleil-Morrison for promoting the field of acoustics by giving it a forum by means of this special issue.

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### Note

1. *Auralization* is the process of rendering audible, by physical or mathematical modelling, the sound field of a source in a space.<sup>32</sup>

### References

- Atak, O., K. Huijssen, M. Rychtarikova, B. Pluymers, and W. Desmet. 2010. “Application of the Wave Based Method for Mid-frequency Analysis on a Room Acoustics Case.” Proceedings of ISMA2010, Leuven, Belgium, 1969–1983.
- Atkins, H. L., and C.-W. Shu. 1998. “Quadrature-free Implementation of the Discontinuous Galerkin Method for Hyperbolic Equations.” *AIAA Journal* 36: 775–782.
- Hornikx, M. 2009. “Numerical Modelling of Sound Propagation to Closed Urban Courtyards.” PhD thesis, Chalmers University of Technology, Gothenburg, Sweden.
- Kowalczyk, K., and M. van Walstijn. 2011. “Room Acoustics Simulation Using 3-D Compact Explicit FDTD Schemes.” *IEEE Transactions on Audio, Speech and Language Processing* 19 (1): 34–46.
- Krijnen, T., and M. Hornikx. 2014. “openPSTD: The Open Source Implementation of the Pseudo Spectral Time-domain Method.” Proceedings of forum acusticum, September 7–12, 2014, Krakow, Poland.
- Mehra, R., N. Raghuvanshi, L. Savioja, M. C. Lin, and D. Manocha. 2012. “An Efficient GPU-based Time Domain Solver for the Acoustic Wave Equation.” *Applied Acoustics* 73 (2): 83–94.
- Saarelma, J., and L. Savioja. 2014. “An Open Source Finite-difference Time-domain Solver for Room Acoustics Using Graphics Processing Units.” Proceedings of forum acusticum, September 7–12, 2014, Krakow, Poland.
- Sheaffer, J., and B. M. Fazenda. 2014. “WaveCloud: An Open Source Room Acoustics Simulator Using the Finite Difference Time Domain Method.” Proceedings of forum acusticum, September 7–12, 2014, Krakow, Poland.
- Svensson, U. P., and P. T. Calamia. 2006. “Edge-diffraction Impulse Responses Near Specular-zone and Shadow-zone Boundaries.” *Acta Acustica United with Acoustica* 92: 501–512.
- Tsingos, M., W. Jian, and I. Williams. 2011. “Using Programmable Graphics Hardware for Acoustics and Audio Rendering.” *Journal of the Audio Engineering Society* 59: 628–646.
- Vorländer, M. 2013. “Computer Simulations in Room Acoustics: Concepts and Uncertainties.” *The Journal of the Acoustical Society of America* 133: 1203–1213.