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WAVE-BASED ROOM ACOUSTICS MODELLING: RECENT PROGRESS AND FUTURE OUTLOOKS

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EXTENDED ABSTRACT

The goal of room acoustics simulation is to faithfully reproduce the acoustics of a space, in order to analyse objective acoustic parameters and/or to conduct subjective analyses of resulting auralisations[1]. It is generally accepted that sound is carried by waves and that a wave description of sound is the most solid foundation for any physical description of room acoustics[2], and thus one could reasonably argue that waves serve as the most natural foundation for any type of room acoustics simulation. However, it is more common to see ray-based (or image-source–based) descriptions of sound propagation – i.e. models based on the principles of geometrical acoustics[3] (which precludes diffraction and is thus, essentially, a high-frequency approximation) – used as foundations for room acoustics simulations (see, e.g., Ref. 4).

That ray-based simulations are more popular than wave-based ones is primarily due to the fact that ray-based simulations tend to be computationally cheaper than wave-based simulations, especially when coupled with diffuse-field assumptions (meaning that far fewer rays than strictly necessary by geometric considerations can be used to generate the late part of an impulse response). Unfortunately, the speed of conventional ray/diffuse-field–based simulations comes at the cost of generality; it is well-known that such approaches largely fail to reproduce modal behaviour and non-diffuse fields, and the incorporation of diffraction into such approaches remains a formidable challenge. Furthermore, such tools tend to have different, sometimes *ad hoc*, approaches to simulating diffraction (which includes scattering) and late parts of impulse responses. As a result, different tools tend to produce different results for a fixed set of input data (e.g., room geometry and boundary conditions), whereas one would expect the myriad such tools to converge to one “ground-truth” solution.

Wave-based simulations, on the other hand, have no limit (in theory) to their generality, as they are simply discrete analogues of the partial differential equations (or general solutions thereto) describing acoustics. Wave-based methods come in various flavours (e.g., finite/boundary element and finite difference/volume; see, e.g., Ref. 5) and they can be expressed in the time-domain (solving, e.g., the 3-D wave equation) or the frequency-domain (solving, e.g., the Helmholtz equation in 3-D); but, ultimately, they are all designed to converge to the same solution for a fixed set of initial and boundary conditions (i.e., input data). Most importantly, wave-based approaches are theoretically valid across the entire frequency range, reproduce all forms of diffraction and are applicable to both diffuse and non-diffuse fields (and anything in between). See Figures 1 and 2.

The generality of wave-based methods does not come without associated costs. Firstly, the computational costs of wave-based methods may be prohibitively expensive – e.g., generally, memory scales with room volume and the cube of the frequency of interest. Additionally, the numerical design of such methods – such that one has consistency and stability (two properties needed for convergence to an underlying solution) – can be rather challenging, especially when incorporating the features required for detailed modelling of room acoustics (such as, e.g., frequency-dependent impedance boundary conditions and non-trivial room geometries).

The purpose of this talk is to provide an overview of recent progress in addressing these challenges with one family of wave-based methods: finite-difference time-domain (FDTD) methods, and to provide outlooks on (future) challenges which remain to be addressed. In particular, this talk will review recent work from the present authors dealing with, but not limited to: modelling complex geometries, frequency-dependent boundaries, and viscothermal losses in air[6,7]; directional source modelling[8]; the acceleration of FDTD methods across multiple graphics processing unit (GPU) devices[9], and novel wave-based/ray-based hybrid approaches. Sound examples, consisting of high-fidelity auralisations of large spaces (such as concert halls), will be presented.

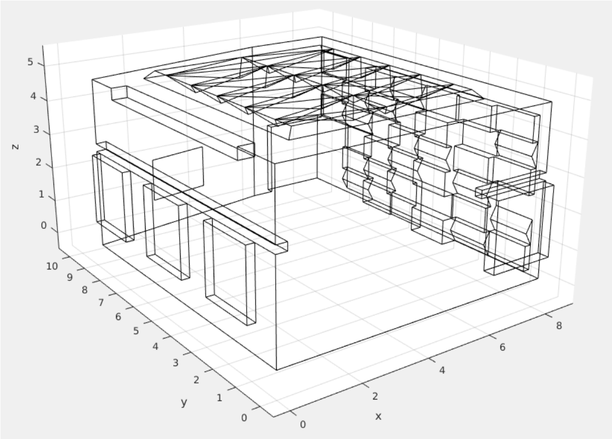

Figure 1: 3D model of PTB studio, with axis units in metres.

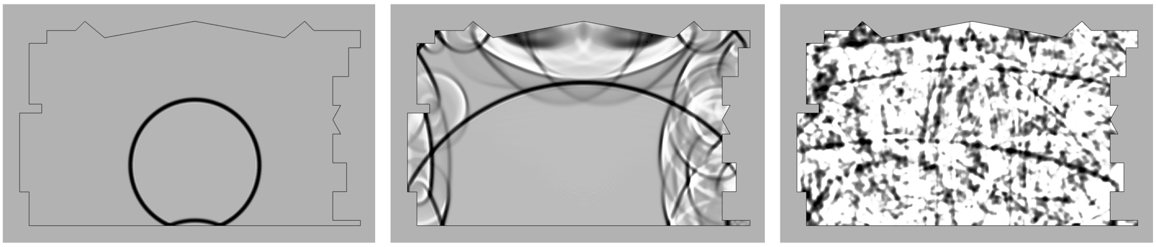

Figure 2: Snapshots from a 3D wave-based simulation within PTB studio as two-dimensional x-z slices (at y=4.3m) at times: 5ms, 15ms, and 50ms (left-to-right).

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