Hybrid Room Impulse Response Synthesis in Digital Waveguide Mesh Based Room Acoustics Simulation

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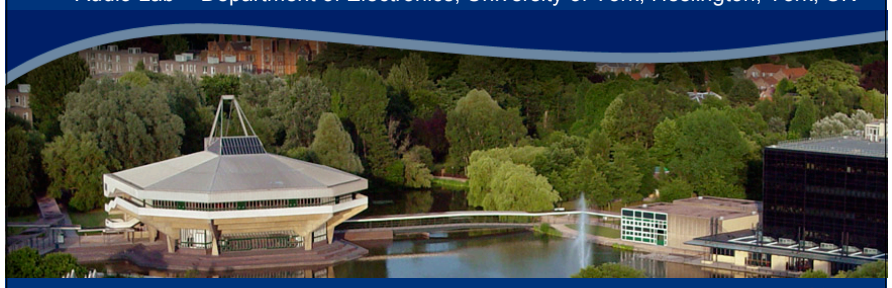
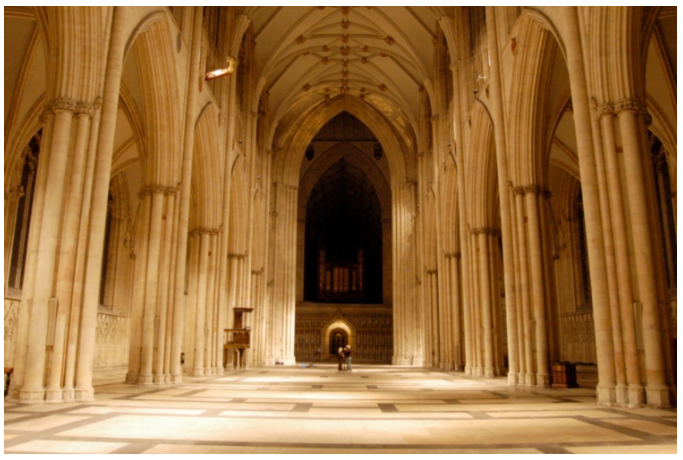


Motivation: Virtual Environment Modelling



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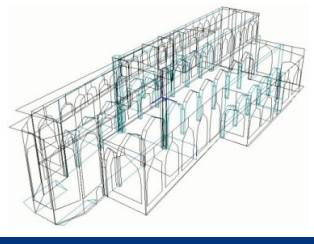
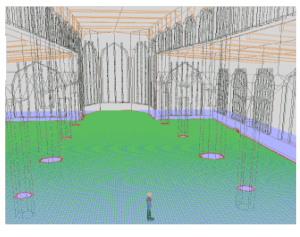
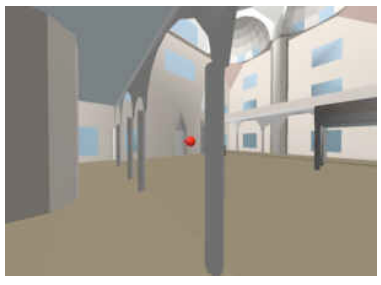




Existing Solutions: Geometric Acoustics



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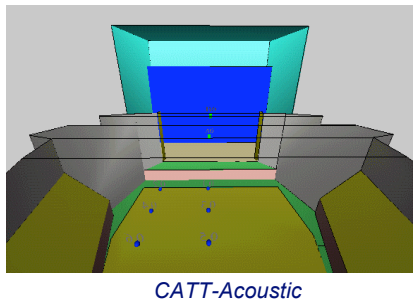

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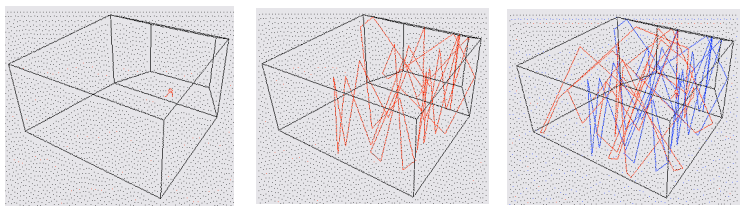
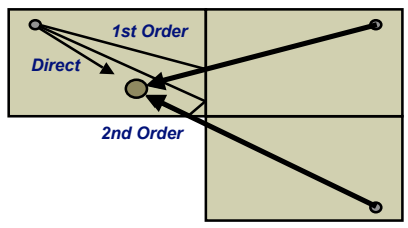
Existing Solutions: Geometric Acoustics





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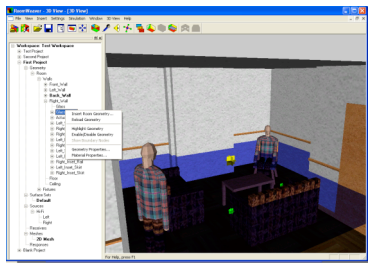
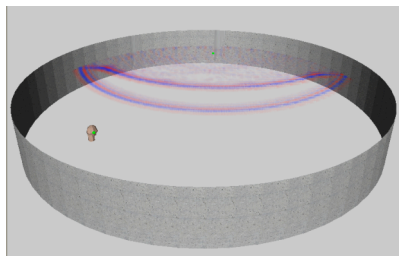
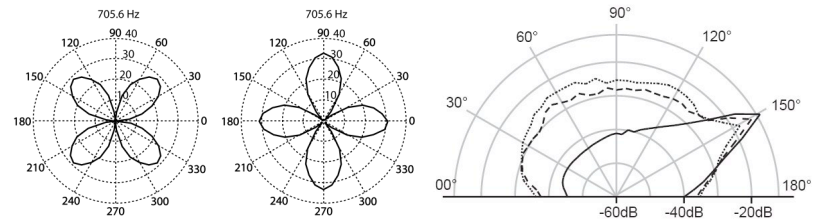
From RoomWeaver to RenderAIR







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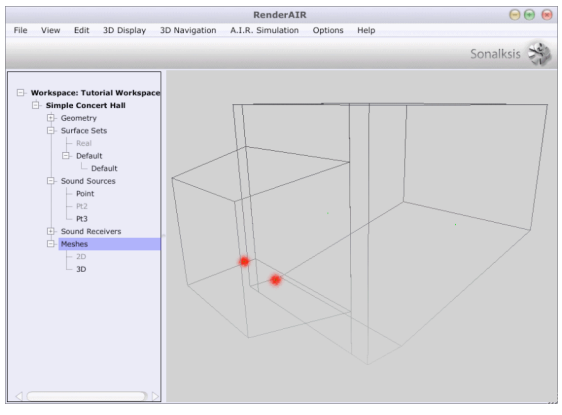
RenderAIR



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Overview

- The Digital Waveguide Mesh (Summary).
- The *RenderAIR* Hybrid DWM System.
- The Hybrid IR Synthesis.
- Case Study and Performance Benchmarking:
  - Reverberation Time
  - Modal Accuracy
  - Computational Resources
- Summary and Future Work.

The Digital Waveguide Mesh

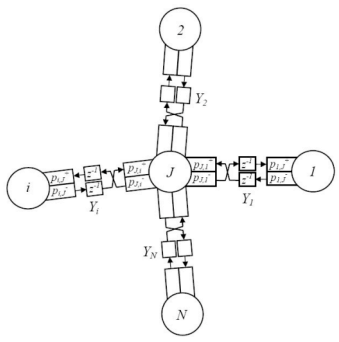
- Acoustic Physical model and an extension of the 1-D Digital Waveguide.
- Equivalent with FDTD methods.
- Time domain system excited by an impulse.
- Diffraction and sound occlusion are inherent.
- Computationally expensive.
- Reliable frequency dependent boundaries and diffusion models are still being developed.

The Digital Waveguide Mesh

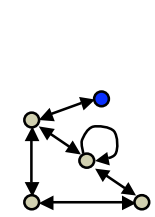
- **Scattering junctions** allow individual digital waveguide elements to be connected together at a sampling point.
- They can accommodate any number of connected waveguides, but for a lossless system, two conditions must hold at the junction:
  - Sound pressure (forces) are equal
  - $\text{Velocities}_{IN} = \text{Velocites}_{OUT}$ (flow = 0)
- Such that:

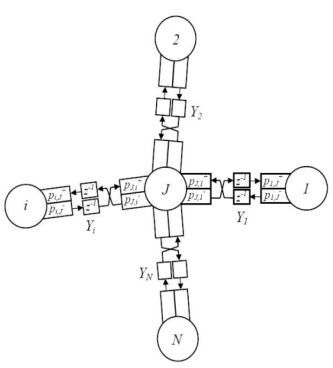
$$p_J(n) = \frac{2}{N}\sum_i^N \left[p_i^+(n-1)\right]$$

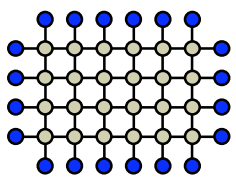
$$p_J(n) = \frac{2}{N}\sum_i^N \left[p_i(n-1)\right] - p_J(n-2)$$



Networks and Meshes



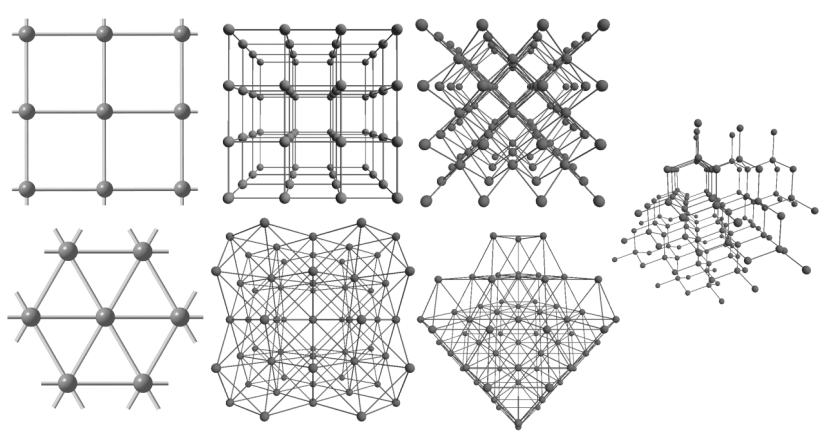




Network: *An abstract representation of a system as a series of interconnected delay lines.*

Mesh: *A physical representation of a system as a regular grid of sampling points.*

Mesh Topologies (Schemes)



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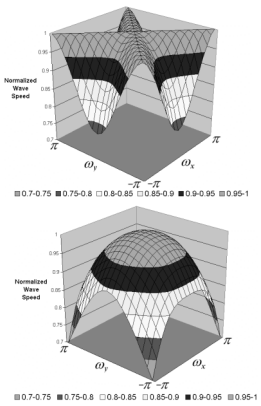
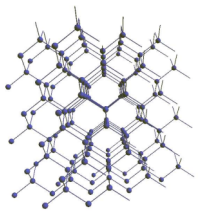
Limitations





$$f_{update} = \frac{c\sqrt{N}}{d}$$

$$p_J(n) = \frac{2}{N}\sum_i^N [p_i^{+}(n-1)]$$

$$p_i^{-}(n) = p_J(n) - p_i^{+}(n)$$

$$p_{i,J}^{+}(n+1) = p_{J,i}^{-}(n)$$

$$p_J(n) = \frac{2}{N}\sum_i^N [p_i(n-1)] - p_J(n-2)$$

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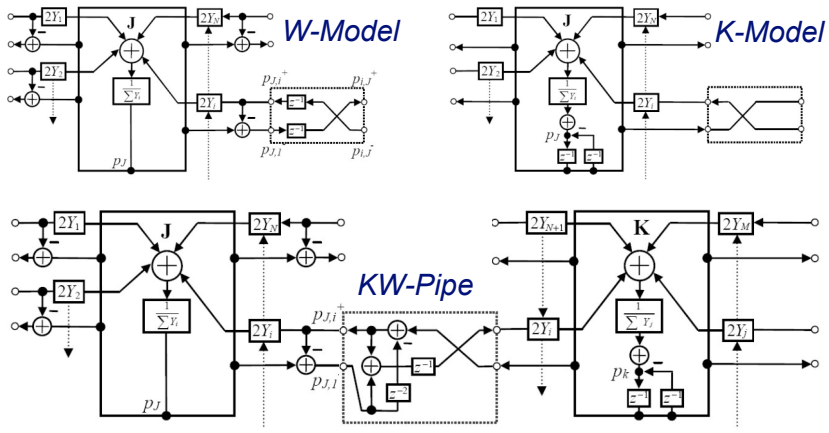
Hybrid DWMs



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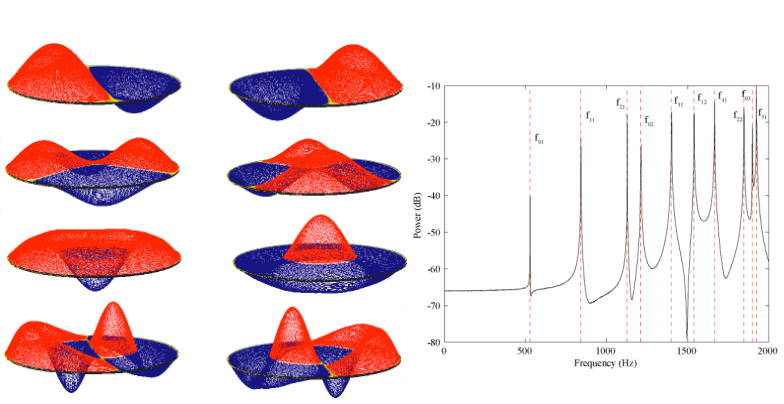
Advantages



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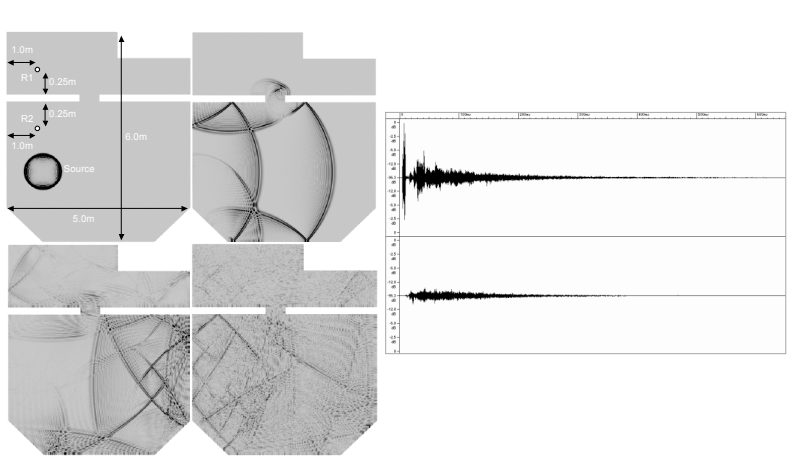
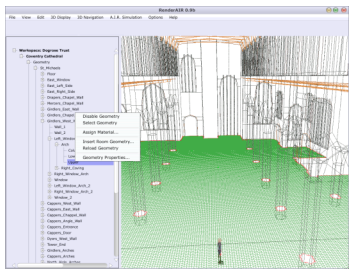
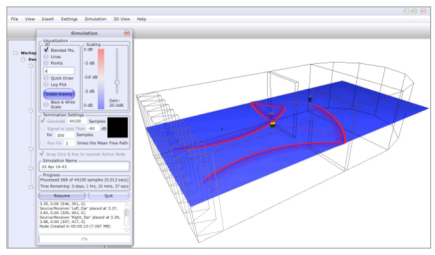
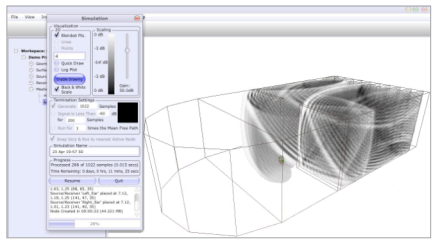
Advantages



The RenderAIR System



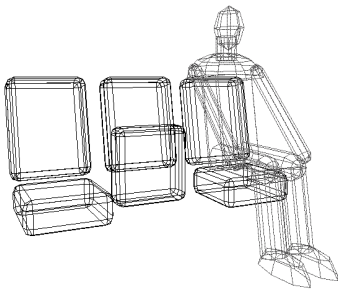




- Inspired by current architectural acoustics/CAD applications.
- Mesh Topology plug-ins.
- “Efficient” hybrid mesh models.

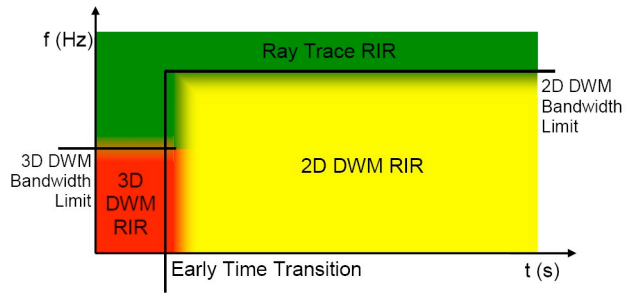
The RenderAIR System

- Simple scripting and GUI specify all parameters of interest.
- Scripts make use of hierarchical object models that can also take control variables
  - E.g. Chair: Open; Closed; Occupied.
- Can import *Collada* format geometry files:
  - 3rd party formats including *Google Sketchup* export.
  - E.g. can use *Google Earth* buildings.
- “Grows” a mesh to fit the user defined geometry.
- Surfaces defined using octave band absorption coefficients and diffusion coefficient.
- Surface sets can be changed individually or globally.



Hybrid IR Synthesis

- 3-D FDTD modelling at audio bandwidth is still very expensive and real-time is beyond even next generation CPUs.
- Other approaches must be found if this method is to be made useful for today’s users.



Hybrid IR Synthesis: Post-processing

- IR source deconvolution.
- Air Absorption – Time varying octave band filter.
- 2-D decay curve compensation.
- Multiple IR B-format encoding:
  - Southern and Murphy, “A second order differential microphone technique for spatially encoding virtual room acoustics”, AES 124th Convention, 2008, Paper No. 7332.
- Hybridisation of the IR:
  - 3D rectilinear DWM (low sample rate, early part truncation).
  - 2D triangular DWM (high sample rate).
  - Ray tracing (high-frequency/late part).

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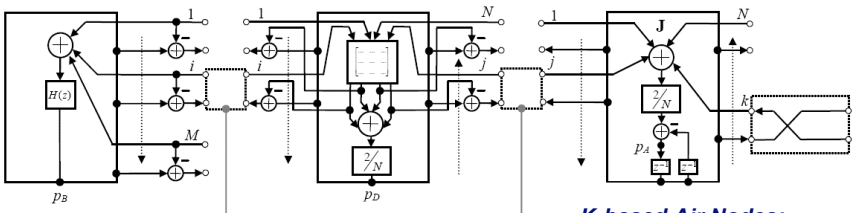
RenderAIR DWM Block Diagram



W-based Boundary Nodes: *Flexible; Stable*

W-based Diffusing Layer: *Input/Output variables; lossless; stable*

K-based Air Nodes: *Efficient*

Waveguide Element Communication in K-domain via ***KW-pipes***

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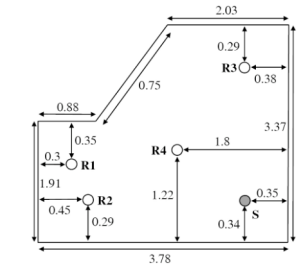
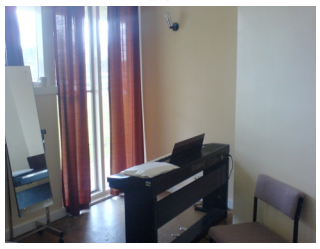
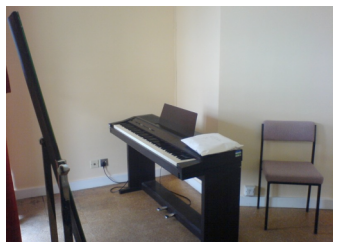
Case Study: Real vs Geometric vs DWM







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Case Study: Real vs Geometric vs DWM

- **Case 1: Actual Test Room**
  - W-channel of Soundfield Microphone; 15s 22Hz-22kHz log sweep.
- **Case 2: Geometric Acoustic Simulation**
  - W-channel B-format response.
  - 20,000 rays used.
- **Case 3: 3-D DWM Simulation**
  - 3-D subgrided rectilinear DWM valid to 10kHz.
  - W-channel B-format response.
- **Case 4: 2-D DWM Simulation**
  - 2-D triangular DWM valid to 22050 Hz.
  - W-channel B-format; 3-D RT60 correction applied.
- **Case 5: 3-D/2-D Hybrid Simulation**
  - 3-D DWM valid to 10kHz used up to 38ms.
  - 2-D DWM corrected to 3-D used for late part response.

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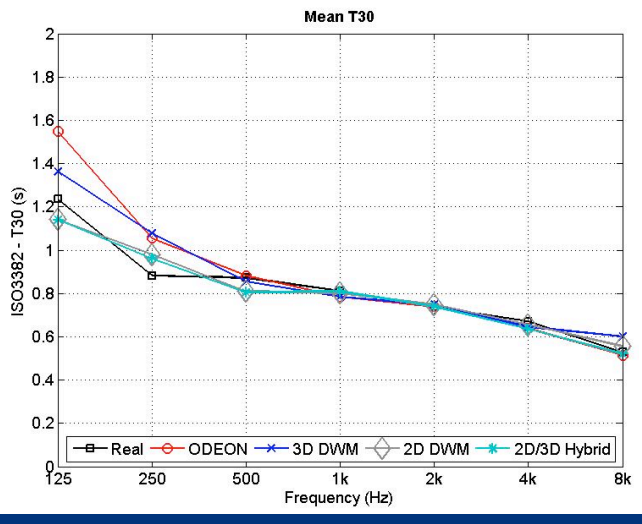
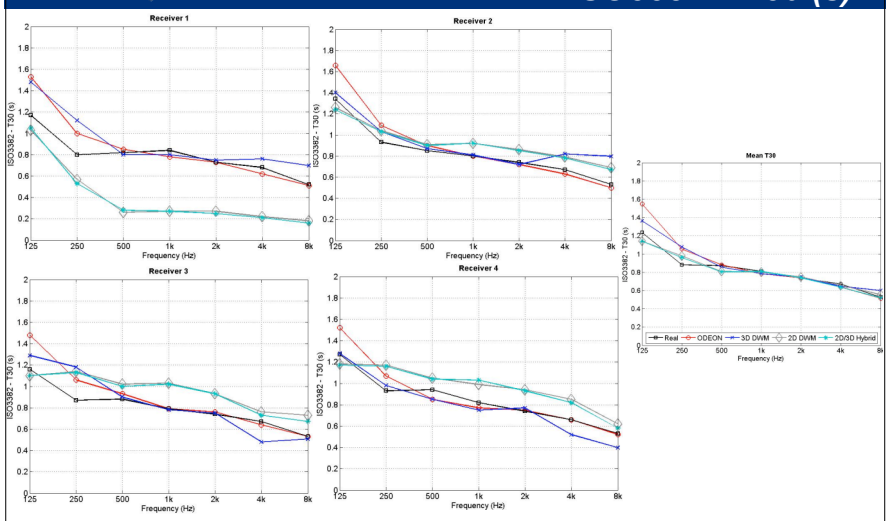
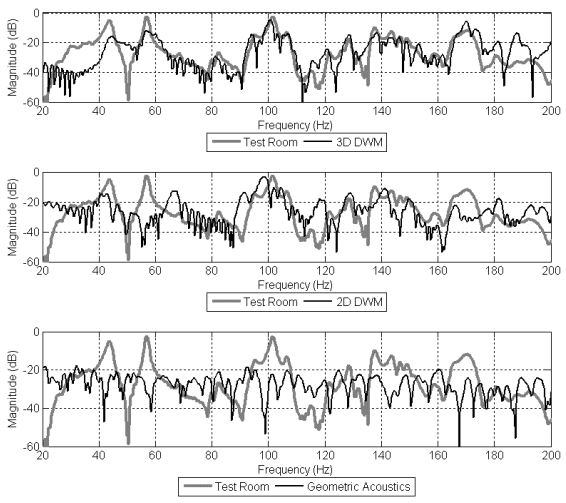
Case Study: ISO3382 – T30 (s)



Case Study: ISO3382 – T30 (s)



Case Study: Modal Response



Case Study: Computational Resources

0.8s RIR	Case 2 (G-A)	Case 3 (3-D DWM)	Case 4 (2-D DWM)	Case 5 (Hybrid)
Time (Hrs:Mins)	00:54	14:18	00:37	01:38
Memory Used (Mb)	--	72	4	76

- Receiver 1 – Real:
- Receiver 1 – 2-D:
- Receiver 1 – Hybrid:

Summary and Future Work

- RenderAIR provides a platform for FDTD based room acoustics research and development.
- Hybrid DWMs provide flexible implementation options.
- Hybrid IRs offer an interim solution to the computational resources problem.
- First results show promise but there is still some way to go!

- Boundaries – new formulation is being implemented:
  - Kowalczyk and van Walstijn, *JAES* Vol. 56, No. 7/8, 2008.
- Much work to be done on IR hybridisation.
- Scalable parallelisation strategies (inc. grid) for large spaces.
- Testing against Round Robin room acoustics data.
- Perceptual tests – how accurate do we need to get?

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Thank You For Your Attention…

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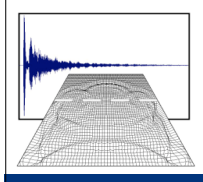

Alex Southern: Spatial Encoding

http://www-users.york.ac.uk/~aps502/

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