MODELLING ROOM ACOUSTICS

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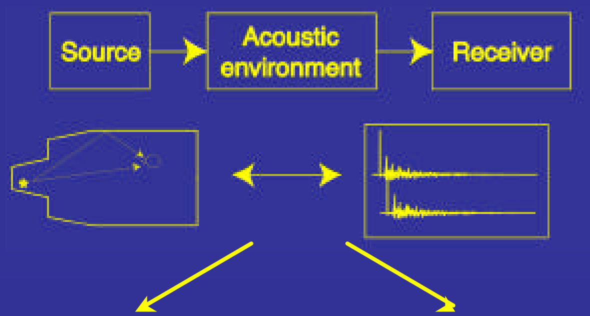
COMPUTER MODELLING IN ROOM ACOUSTICS

- Principles
- Techniques: wave equation solving or sound field decomposition (e.g., geometrical acoustics)
- Short history
- What is the state of the art?
- How accurate is computer modeling?

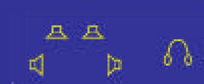
COMPUTER MODELLING IN ROOM ACOUSTICS - PRINCIPLE

Impulse response (IR) prediction

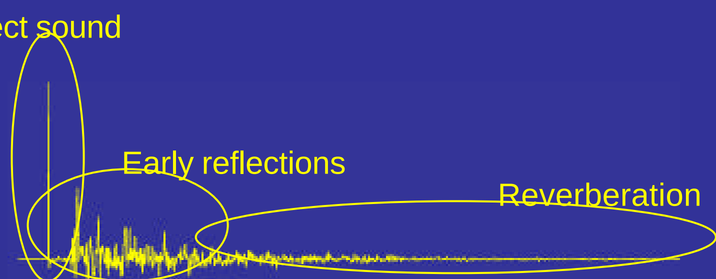


Numbers:
Parameter values

Auralization:
Listen to the result



THE IMPULSE RESPONSE



The IR prediction/calculation methods come in two classes:

1. Solving the wave equation numerically, i.e., iteratingly one time step after another ⇒ comp. load grows linearly with time
2. Sound field decomposition, i.e., find and add elementary waves ⇒ comp.load grows (much) faster with time!

SOUND FIELD DECOMPOSITION, 1

Image Source Method,

Ray/Cone Tracing,

Edge diffraction

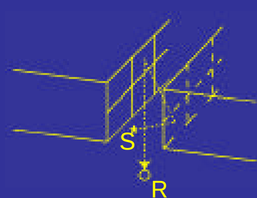
The real boundary is replaced by:

IS = Image sources. Represent <u>specular reflections.</u>
ES = Edge sources. Represent <u>edge diffraction.</u>
SS = Surface sources. Represent <u>diffuse reflection/</u>surface scattering.

- The number of IS/ES/SS grows very fast with time!
- Boundary impedances possible - but only with plane wave reflection coefficient.

SOUND FIELD DECOMPOSITION, 2

Radiosity

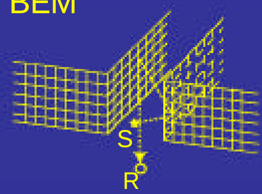


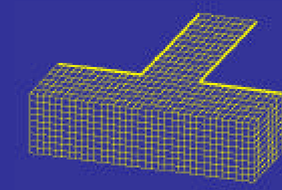
The boundary is pre-divided into surface patches that do not need to be smaller than the wavelength.

- Easy to implement only-diffuse reflection (typically Lambert)

- Tricky, but possible, to implement specular reflection

WAVE EQUATION SOLVING





The surface or the volume is divided into elements.

- The elements must be much smaller than λ
  $\Rightarrow$ Computational load for FDTD/FEM $\propto$ f^3 / f^4!
- All details must be modeled
- Source directivity is tricky with FEM/FDTD

COMPUTER MODELLING IN ROOM ACOUSTICS - SOME MILESTONES

1970 1980 1990

Beam Tracing - Walsh et al
(specular + diffraction)

Image Source Method -
Juricic & Santon
(only specular)

FDTD/DWG -
Botteldooren
Savioja

Radiosity - Kuttruff
(only diffuse)

Time BEM -
Dohner et al

Ray tracing - Krokstad et al
(specular & diffuse)

Hybrid method -
van Maercke

COMPUTER MODELLING IN ROOM ACOUSTICS - SOME MILESTONES

1980 1990 2000

Software: CATT-Acoustic, Odeon, EASE Ramsete

Other:
Bose Modeler
Raynoise
Epidaure
Ulysses
...

Systematic evaluation: Round-Robin 1 - Vorländer Round-Robin 2&3 - Bork

RELATED FIELDS

Outdoor sound propagation

Music processing

Virtual reality

Small rooms (e.g., car cabins)

Accurate room modeling

Industrial buildings (e.g., factories)

Building acoustics (sound insulation)

Loudspeaker system modeling

M E T H O D S , 1

	Room acoustics, factories, loudsp. systems	Noise control (small rooms)
ISM + Ray/cone tracing	√	
FEM		√
BEM		√

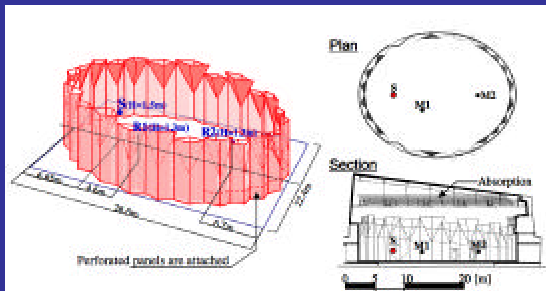
Sofar, mainly in research:
Beam tracing, Radiosity, ISM + Edge diffraction, FDTD

M E T H O D S , 2

FEM, BEM, FDTD	Comp. load grows very fast with frequency (f^3 / f^4). All details must be modeled!
FEM, FDTD	Source directivity tricky.
ISM + Ray/cone tracing	Does not (yet) handle diffraction
Beam tracing	Does not (yet) handle scattering.
Radiosity	Does not (yet) handle diffraction.

Do not handle spherical reflection from absorbers (or seat-dip effect)

STATE-OF-THE-ART FDTD,1



(From Sakamoto et al, ICA 2004)

At ICA 2004, Sakamoto (Tokyo University) demonstrated an FDTD calculation of a small concert hall (~ 5000 m3) up to 1.4 kHz. The model had >100 million elements, ran on 8 PCs with 11 GB for 34 hours.

STATE-OF-THE-ART FDTD,2

	1 kHz	2 kHz	4 kHz	8 kHz
5000 m^3	10 GB 1 day			
40000 m^3				
160000 m^3				

STATE-OF-THE-ART FDTD,2

	1 kHz	2 kHz	4 kHz	8 kHz
5000 m^3	10 GB 1 day	80 GB 16 days		
40000 m^3	80 GB 2 days			
160000 m^3				

STATE-OF-THE-ART FDTD,2

	1 kHz	2 kHz	4 kHz	8 kHz
5000 m^3	10 GB 1 day	80 GB 16 days	640 GB 256 days	
40000 m^3	80 GB 2 days	640 GB 32 days		
160000 m^3	640 GB 4 days			

STATE-OF-THE-ART FDTD,2

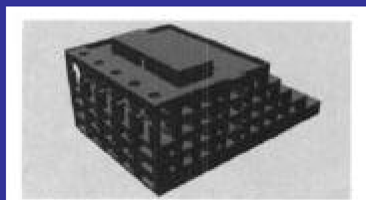
	1 kHz	2 kHz	4 kHz	8 kHz
5000 m^3	10 GB 1 day	80 GB 16 days	640 GB 256 days	4.8 TB 11 yrs
40000 m^3	80 GB 2 days	640 GB 32 days	4.8 TB 512 days	
160000 m^3	640 GB 4 days	4.8 TB 64 days		300 TB 44 yrs

STATE-OF-THE-ART FDTD,2

	1 kHz	2 kHz	4 kHz	8 kHz
5000 m^3	10 GB 1 day	80 GB 16 days	640 GB 256 days	4.8 TB 11 yrs
40000 m^3	80 GB 2 days	640 GB 32 days	4.8 TB 512 days	
160000 m^3	640 GB 4 days	4.8 TB 64 days		300 TB 44 yrs

But, next time BNAM is in Finland, computers are maybe 100 times faster, so 0.4 years instead of 44 years!

STATE-OF-THE-ART BEAM TRACING


(f) Building: ~250 rooms of Soda Hall. (10,057 polygons)

(From Funkhouser et al, JASA 2004)

Beam tracing implements eighth order specular reflection in a 10 000 plane model: 190 seconds preprocessing + 49 seconds, using 19 MB of memory on a PC.

Note! Only specular reflections - no scattering, no edge diffraction (but edge diffraction has been demonstrated).

EXAMPLE, EDGE DIFFRACTION

Streetcorner, omni-directional sound source

Only specular reflections

Specular reflections and edge diffraction

Specular reflections give truncated wavefronts, which is clearly wrong. The inclusion of edge diffraction can be more or less important in rooms.

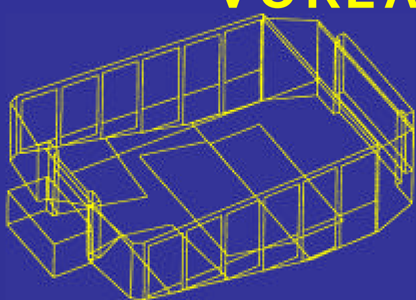
THE INPUT DATA PROBLEM

Absorption	Now: 125 Hz - 4 kHz
Scattering	ISO scattering coefficient is coming
Scattering	Scattering function
Source directivity	

We need shared and standardized data sets!

Advanced methods can never give better output data than the quality of the input data!!

ROUND ROBIN I, VORLÄNDER 1995



Auditorium at PTB

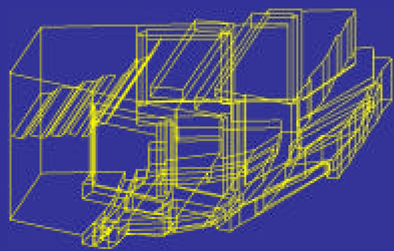
Only 1kHz band

14 different softwares

Findings:

- Specular + diffuse reflections needed for rev. tail
- 3 softwares were judged very reliable - within 1-2 JND for most parameters
- Importance of right input data

ROUND ROBIN II, BORK 2000



Concert hall, Elmia

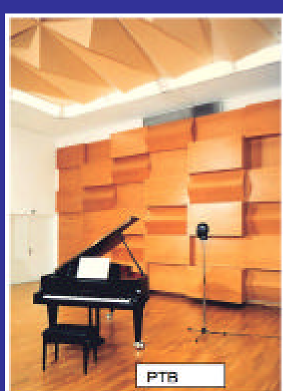
125 Hz - 4 kHz bands

16 participants

Findings:

- Most parameters and softwares had similar accuracy
- Problems in 125 Hz band - diffraction or seat-dip effect not modeled by any software

ROUND ROBIN III, BORK 2002



(From Bork 2002)

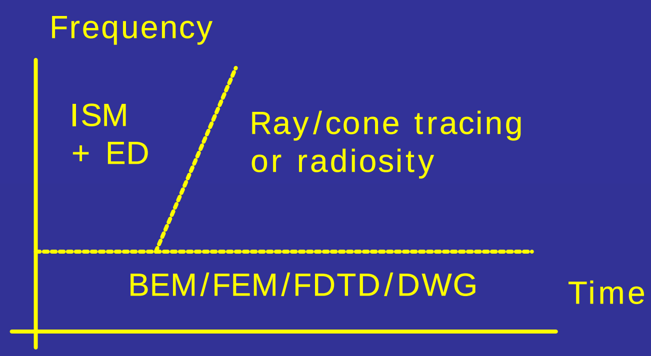
Studio at PTB

125 Hz - 4 kHz bands

Findings:

- Uncertainties in measurement of lateral parameter - microphone problems
- Large deviations between measurements and simulations for 125 Hz.

THE ULTIMATE METHOD?



We would have liked a single method
- but it does not seem feasible!

CONCLUSIONS

Computer modeling of rooms clearly mature, with ISM+Ray/cone tracing, but still some phenomena to take care of:

- Seat-dip effect
- Diffraction
- Scattering data/functions
- Source directivity (multi-channel recordings?)
- Source or receiver near absorbing surfaces.

Input data, and standardized format needed: scattering data, source directivity.

Benchmarking/Round Robins very important. Need to continue - even for auralization. Very important to control “nuisance factors” in comparisons.

Advanced methods need good input data!!!

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