Validation of Geometrical Room Acoustics Algorithms by Comparing Predicted and Measured Responses

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Introduction

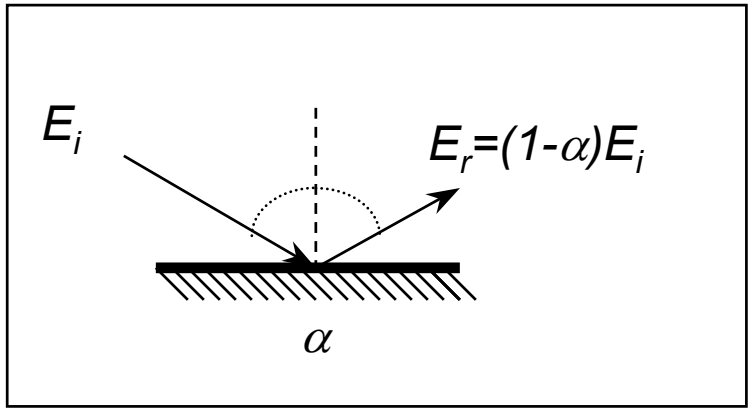
- Problem:
  - prediction of the objective/subjective quality of a sound field
- Solutions:
  - manual calculations
  - scale modeling
  - computer aided modeling

    numerical methods: FEM, BEM, FDM, TIBEM, etc.
    - \+ precise, extensive
    - − complicated, computationally expensive

    geometrical methods: MISM, RTM, CTM, TBM, etc.
    - \+ easy to use and implement
    - \+ fast algorithms
    - \+ acoustical quality (medium and high frequencies)
    - − limited precision (low frequencies)

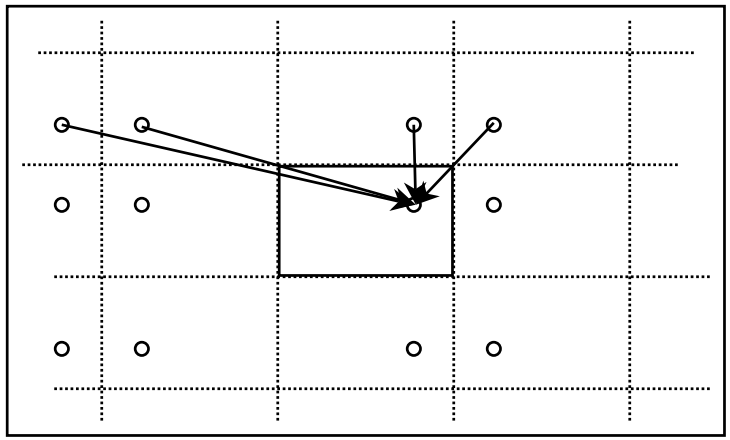
Geometrical Room Acoustics - Basic Assumptions

- Sound energy travels in straight lines
- Wave phenomena are absent
- Sound is treated as energy function, not pressure
  - energies may be summed directly
  - phase effects are absent
- Sound energy reflects specularly from surfaces
- Reflecting surfaces absorb energy independently from angle of incidence

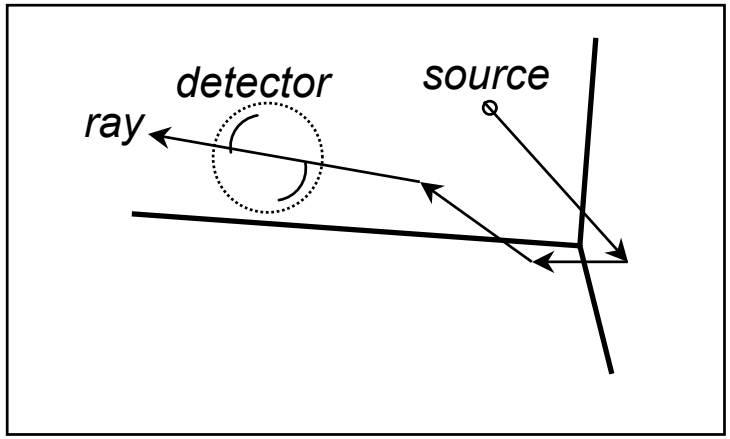


Geometrical Room Acoustics - Modeling (1)

- Mirror Image Source Method (MISM)

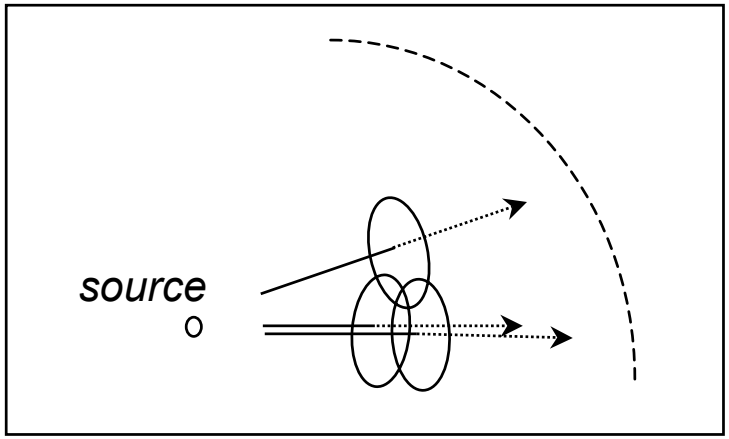


- Ray-Tracing Method (RTM)

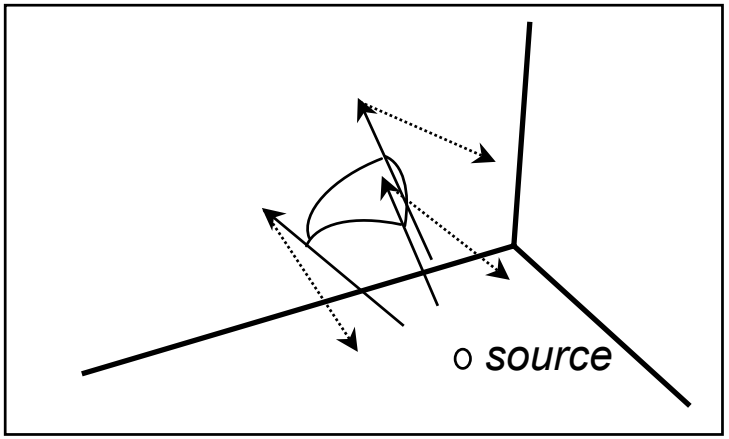


Geometrical Room Acoustics - Modeling (2)

- Cone-Tracing Method (CTM)

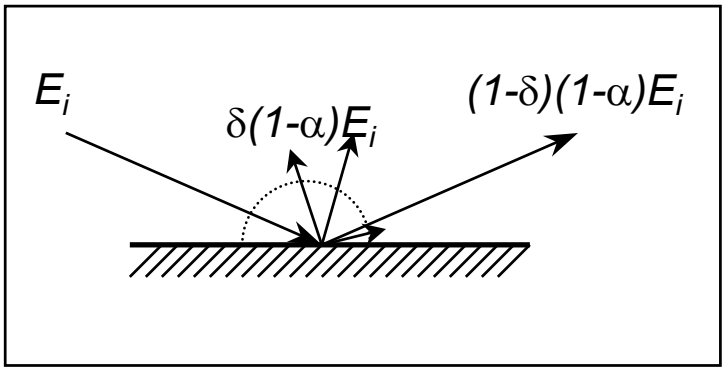


- Triangular Beam-Tracing Method (BTM)



Geometrical Room Acoustics - Extensions

- Diffuse reflections
  - diffusion factor δ
  - random reflections
  - reflection combinations (S-S, S-D, D-S, D-D)



- Diffraction
  - Kurze-Anderson formula
  - "Edge diffusion"
- Refraction
  - Sampled beam/cone/ray-tracing
- Phase
  - Coherent sources
  - Causal linear system: amplitude response ➡ phase response

Validation Process - Overview

Goal

- What are the practical limits of geometrical modeling?
- Developing a reliable, yet simple modeling method

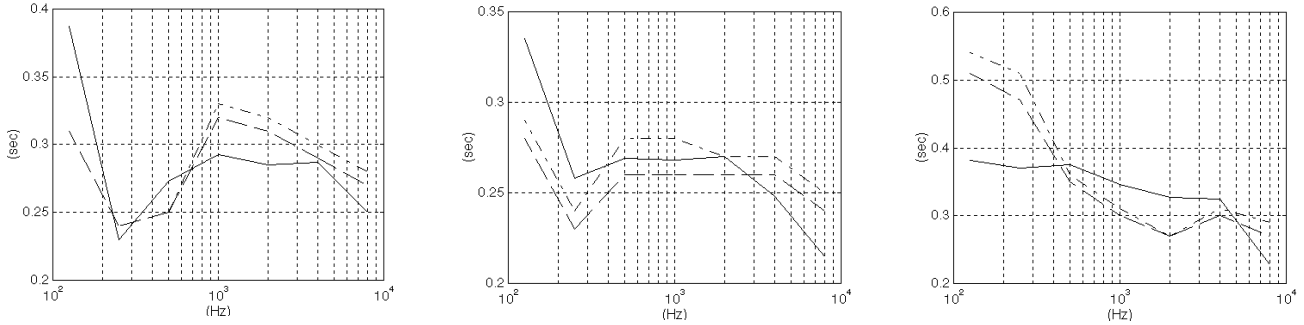
Validation process

- Measurement in acoustically treated small rooms (MLSSA)
  (control rooms, reference listening rooms)
- Subjective test in measured rooms
- Comparing subjective and objective results
  (important acoustical qualities)
- Modeling the measured rooms with different methods (RAYMOISE)
- Comparing predicted and measured results

Validation Process - Results (1)

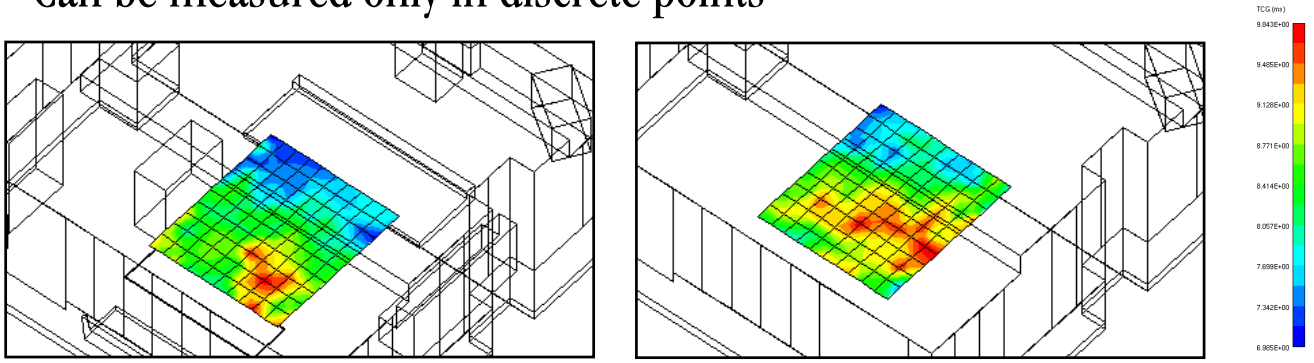
Statistical results (reverberation times)

- Good matching with measured reverberation times
- Doesn't change if furniture is considered...



Acoustical quantities

- Largely depend on furniture
- Largely depend on position
- Can be measured only in discrete points



Validation Process - Results (2)

Error sources

- Parameters
  - absorption coefficients
  - diffusion coefficients
  - directivitiy off source/receiver
  - etc.
- Geometry errors - positions, sizes, etc.
- Limitations of the modeling algorithm...

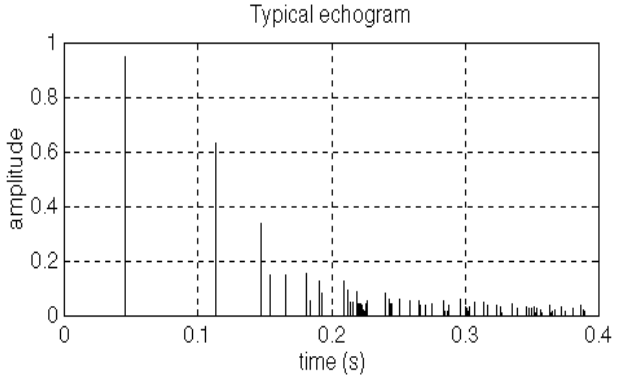
Improving precision

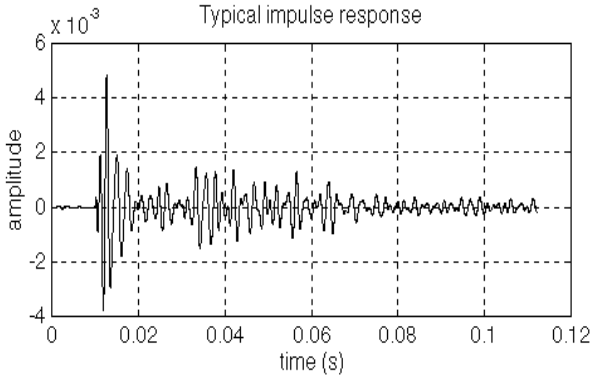
- Parameters
  - thorough and consistent material library
  - detailed data about sources and receivers
- Improving modeling algorithm?

Calculating Parameters from Measured Data

Results of geometrical modeling algorithms

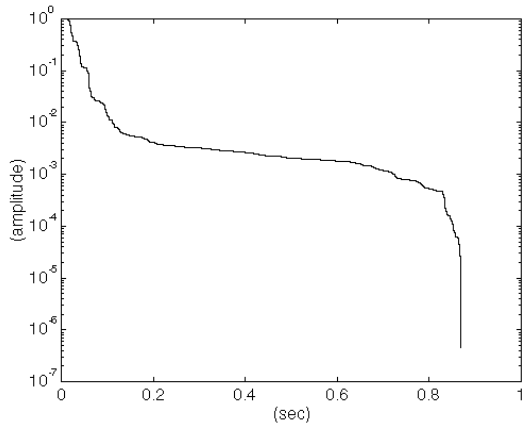
- Echograms and impulse responses...





- Energy-decay curves

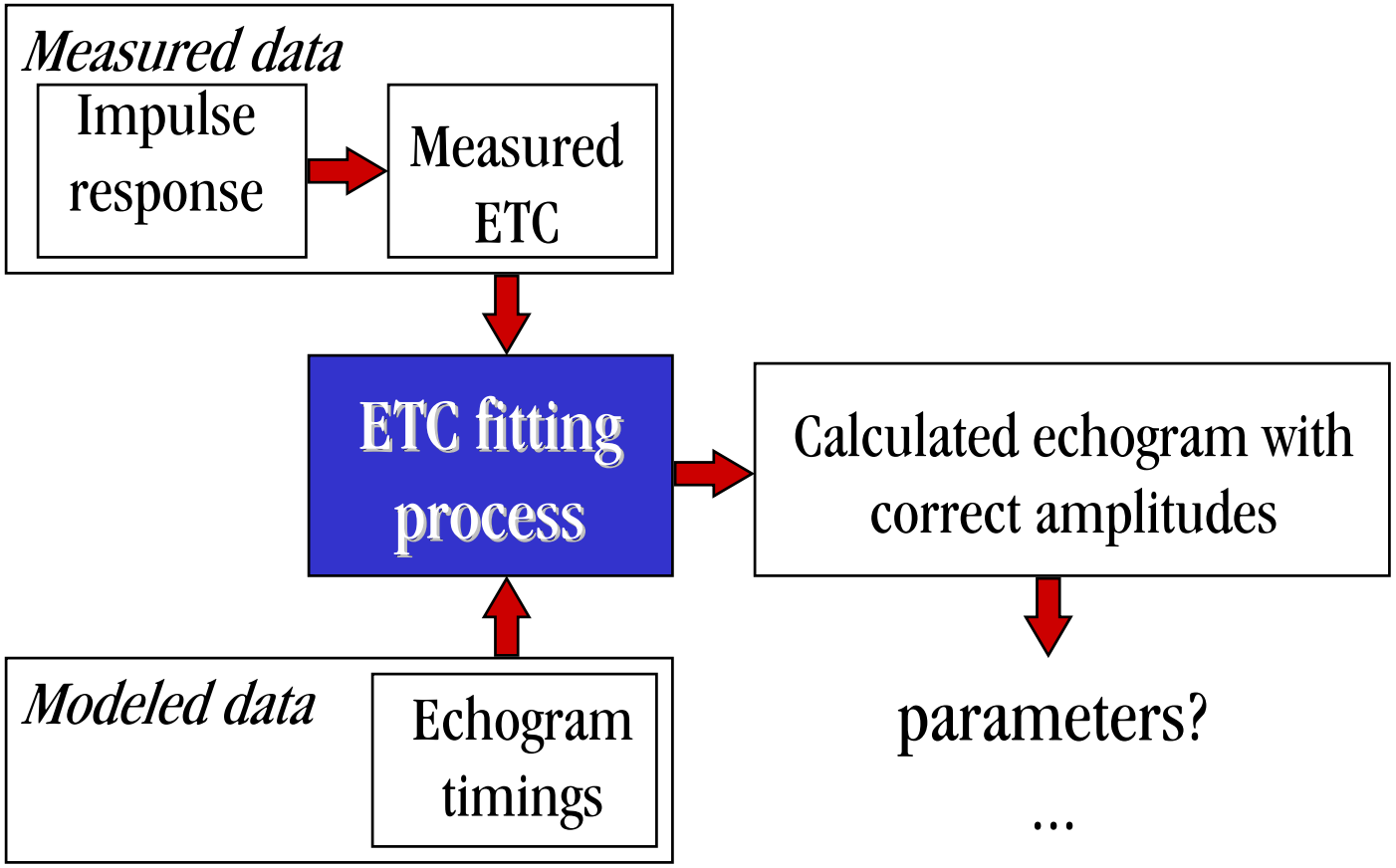
$$\mathrm{ETC}(t) = 1 - \frac{\int_0^t p^2(t)\,dt}{\int_0^\infty p^2(t)\,dt}$$



almost every acoustical quantity is calculated from ETC (Definition, Clarity, Reverberation, etc.)

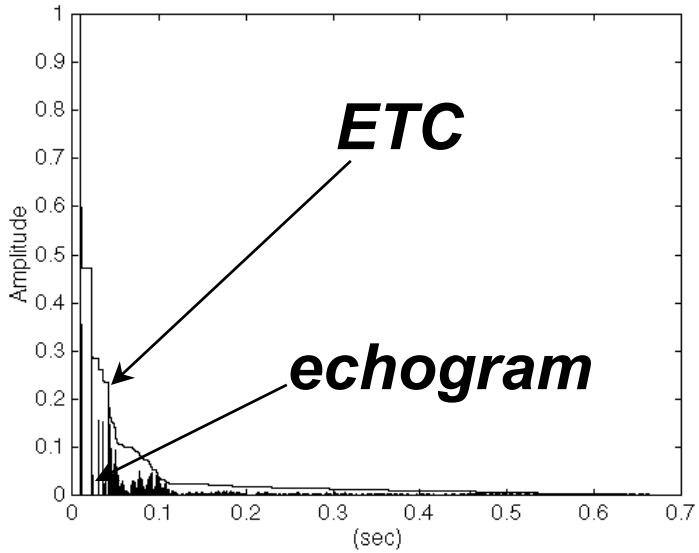
Calculating Parameters from Measured Data (2)

- Calculation



Calculating Parameters from Measured Data (3)

- ETC fitting



- Correcting the calculated echogram
  - air absorption, etc.

Calculating Parameters from Measured Data (4)

- The equation system for calculating the α-s

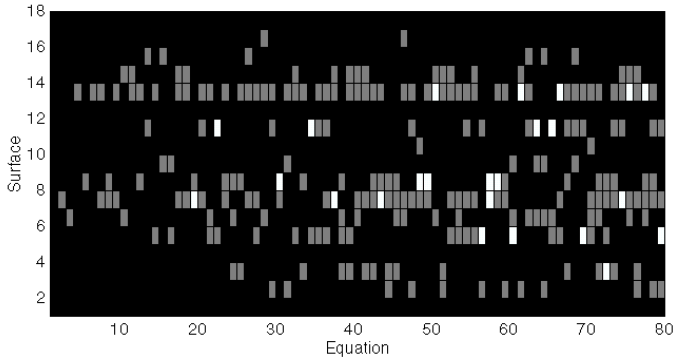
$$\left(1-\alpha_1\right)^{M_{1,1}} \cdot \left(1-\alpha_2\right)^{M_{1,2}} \ldots \cdot \left(1-\alpha_N\right)^{M_{1,N}} = A_1$$

$$\vdots$$

$$\left(1-\alpha_1\right)^{M_{K,1}} \cdot \left(1-\alpha_2\right)^{M_{K,2}} \ldots \cdot \left(1-\alpha_N\right)^{M_{K,N}} = A_K$$

corrected amplitude of k-th reflection

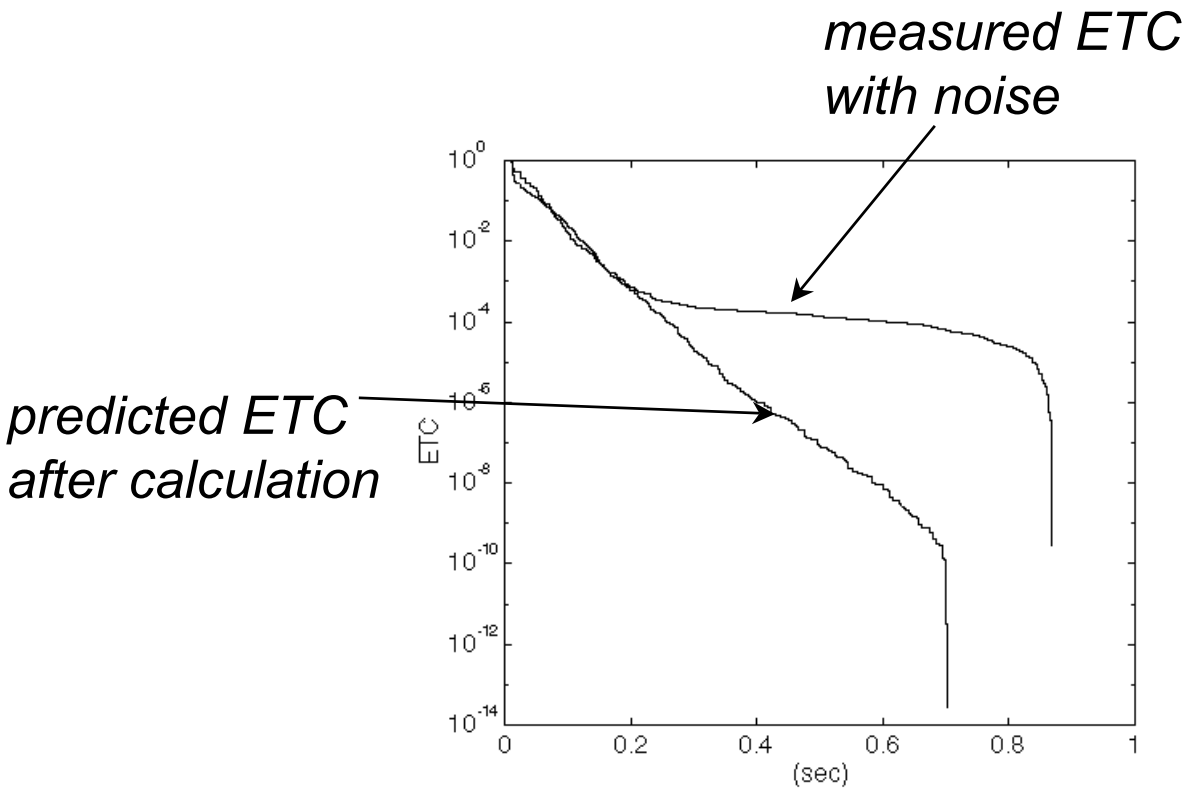
absorption coeff. of n-th surface



- Solving the equation - considerations
  - first reflections should be precise
  - decay slope of ETC is important

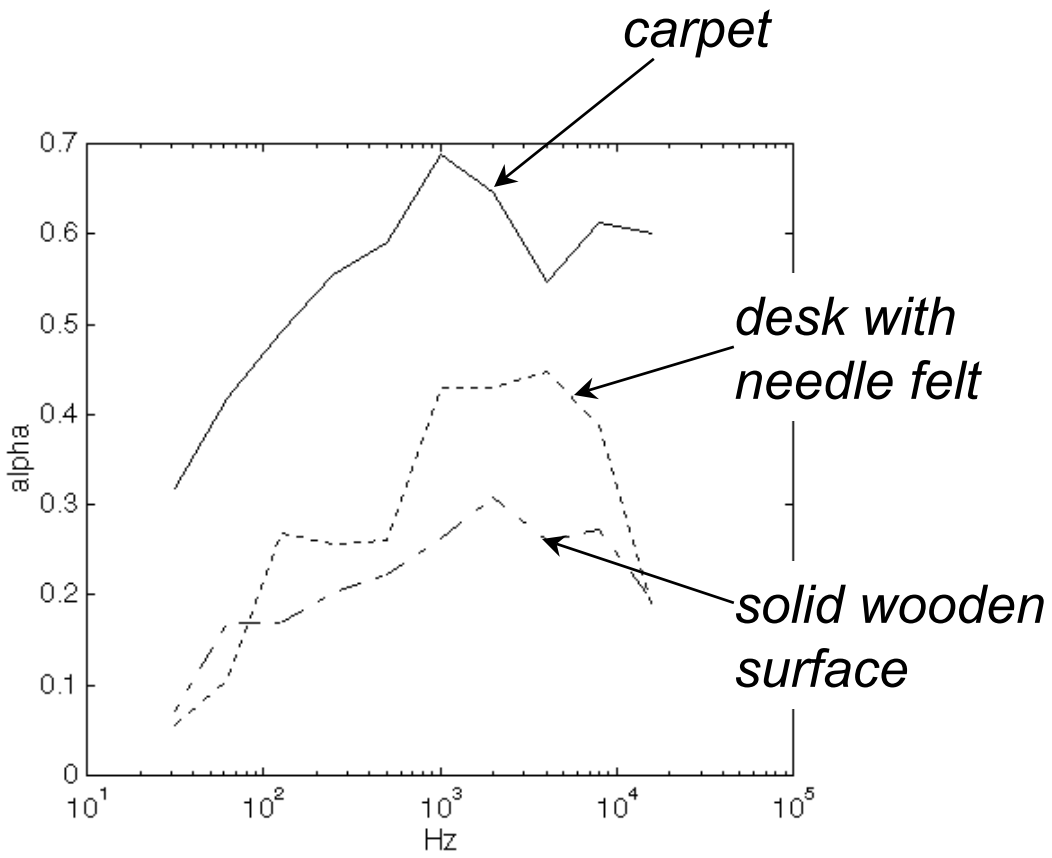
Results - ETC

- Comparing ETCs



Results - absorption coefficients

- Calculated absorption coefficients



Conclusions

- Validity of geometrical room acoustics modeling
- Calculation of absorption coefficients from measured responses
- Further work...