Assessing the quality of a workplace environment by means of analyzing speech intelligibility

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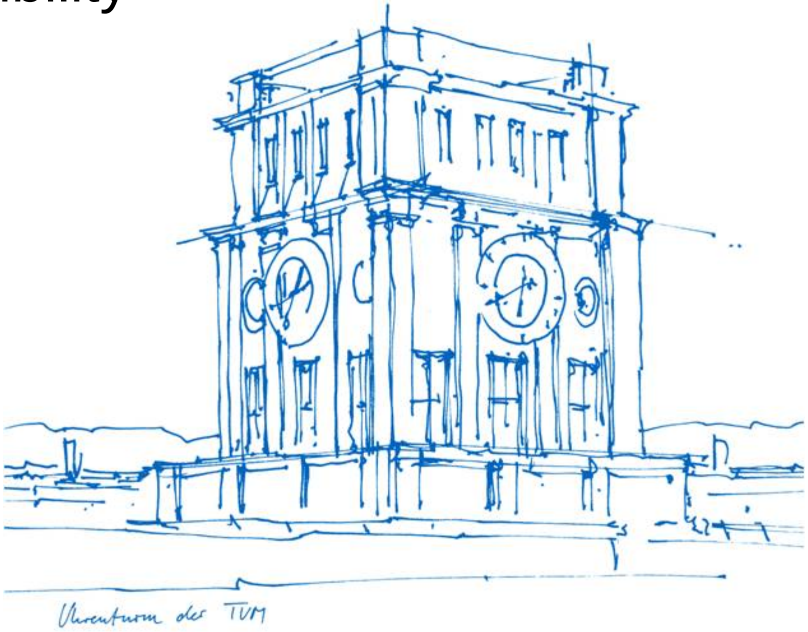
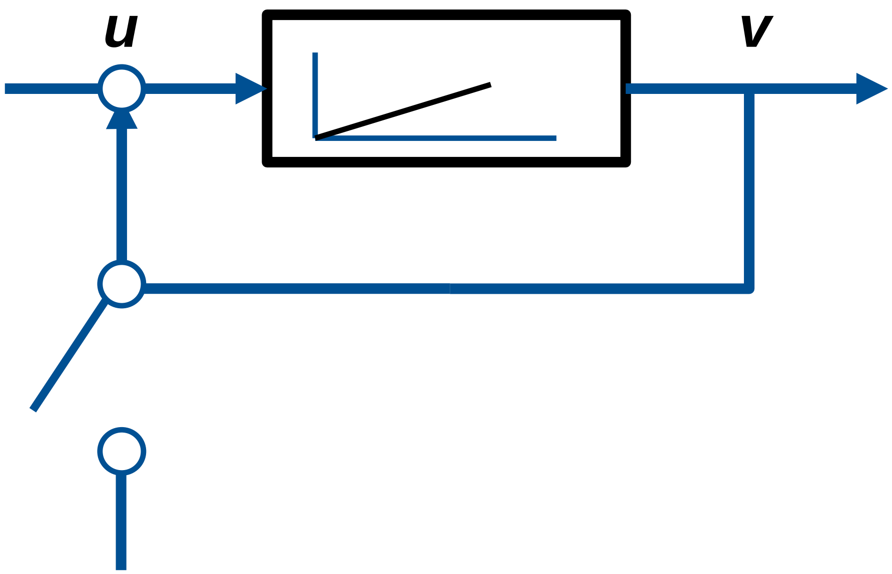


Madrid, Oktober 3rd 2019

Automation

- System acting on any input with a resulting output without controlling it



Motivation

- Hearing ability the most important sense for communication
- Speech most important tool for direct communication
- Visual sensation useful for additional information

BUT, be careful!

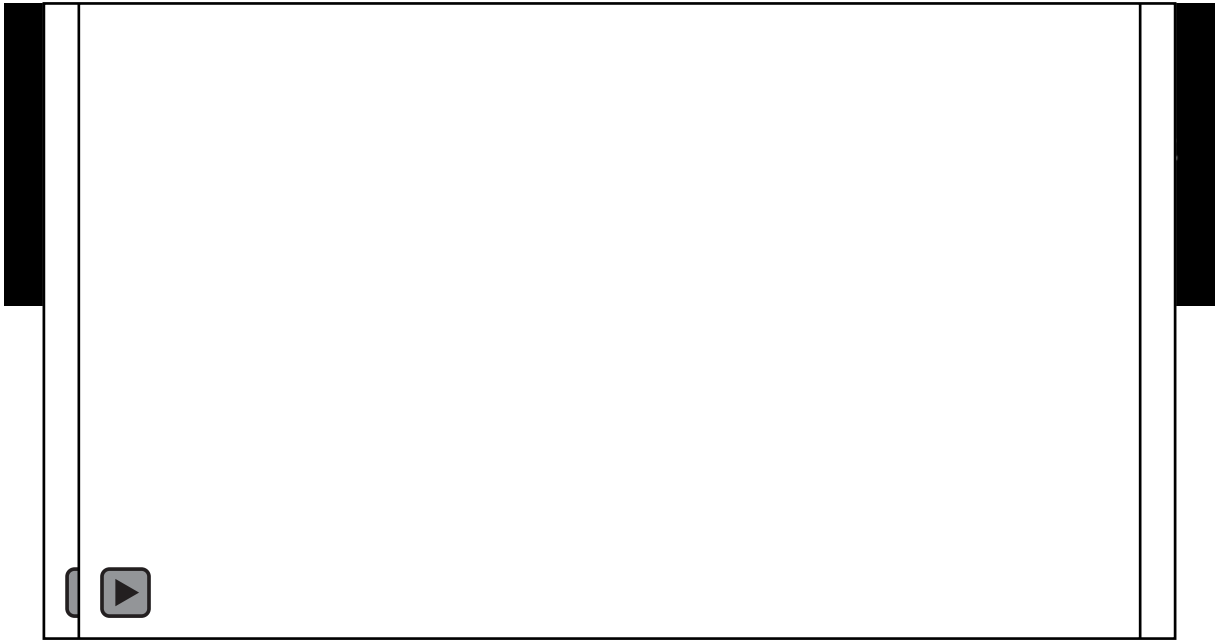
Motivation – human perception

- When hearing sounds, a process of guess work starts (Diana Deutsch)

- Perception is subjective
  - Process of interpretation is prone to errors
  - We rely on learned experiences
  - Brain creates order in chaos
  - Perception shaped by social and cultural origin (Tritone paradox)
  - Strengthened by expectations
  - Increased selection strength (mobile phone rings when waiting for a call)
  - Phantom sounds possible

Motivation – human perception

- Intermodal effects - information unified from several sources (eye for space, ear for time)



https://www.youtube.com/watch?v=PWGeUztTkRA

Motivation – previous projects

- Investigation of a church in Munich
- Complains about insufficient speech intelligibility
- What is the reason?
  - Hearing abilities
  - Room acoustics
  - Sound system
  - Speech quality of priest
- Tasks
  - Measurement of reverberation time
  - Analysis of the public address system

Motivation – workplace environment

- Open plan offices common workplace environment
- Variable setup can be important (Think Tanks, Privacy Zones)
- Compromise between speech intelligibility and background noise
- DIN EN ISO 3382-3

  „Tasks requiring intensive concentration are more affected by speech than routine tasks.“

- What happens, if security related tasks need to be completed?
- How can we design open plan offices in an efficient and productive way?
- What steps need to be taken?

Motivation – let’s summarize

- Hearing perception individual dependent
- Room acoustics is a challenging field in workplace environment
- Adequate speech intelligibility essential for safety related workplace environment
- Challenging compromise between social and technical requirements
- All aspects must be considered when designing proper workplace environments

How assessing the quality of a workplace environment?

Overview

1. Introduction

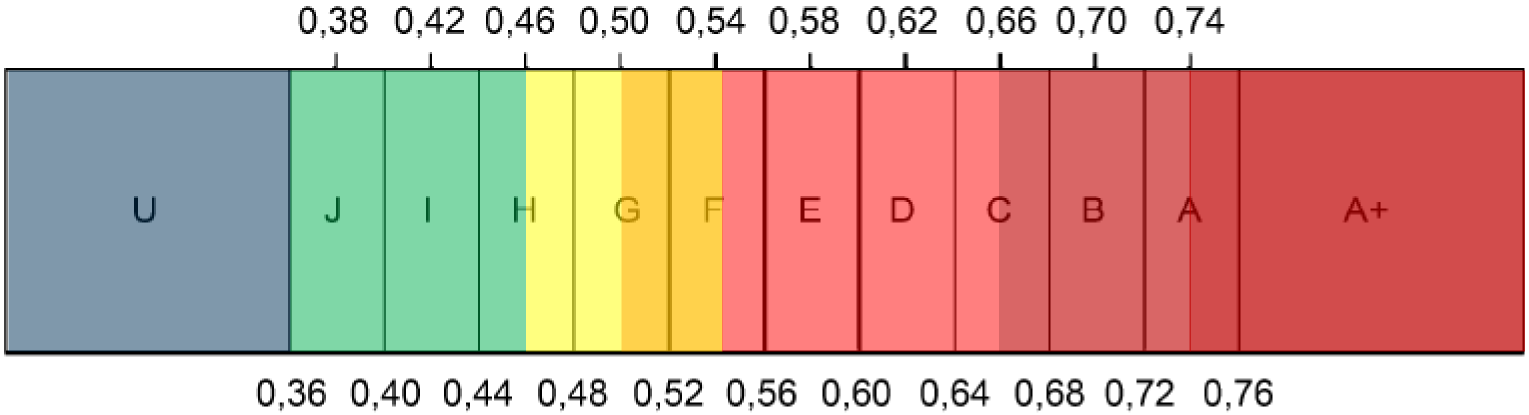
- Acoustic workspace design using empirical or experimental methods was common
- Thus cost-intensive room concepts
- Numerical investigations more flexible and cost-effective (optimization in early stage)

- Parameters of room acoustics of open-plan offices
  - Reverberation time (Sabine, Eyring-Norris)
  - Background sound pressure level

- Challenge
  - User-specific setting of speech intelligibility
  - Local varying absorption
  - Subjective perception of employees

1. Introduction

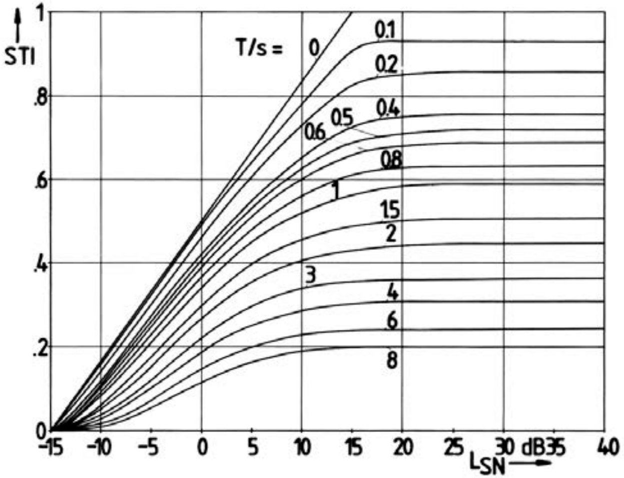
- Speech Intelligibility Index gives additional insight and defines privacy radius
- Important STI values :
  - STI > 0,75 speech understandable, distraction likely
  - STI > 0,5 distraction distance (speech understandable, distraction possible)
  - STI > 0,2 privacy radius (distraction possible)
  - STI < 0,2 no distraction, no speech comprehension



Overview

2. Theoretical background

- Linear acoustics in the high-frequency regime
  - Audible frequency range in large rooms
  - Analogy to optics (Ray-Tracing)
  - Analogy to heat conduction (Acoustic diffusion equation)
- Experimental investigations for model validation
- Speech intelligibility index
  - DIN EN 60268-16
  - Modulation transfer function
  - 14 modulation frequencies (0.63Hz – 12.5Hz) in 7 Octaves (125Hz – 8000Hz)
  - Masking effects
  - Signal-to-noise ratio



Lazarus, H. u.a.: Akustische Grundlagen sprachlicher Kommunikation, Springer-Verlag, Berlin Heidelberg, 2007

2. Theoretical background

- Speech Intelligibility Index

$$m(k,f_m) = m_T(k,f_m) \cdot m_N(k) = \frac{1}{\sqrt{1+\left(\frac{2\pi f_m T_k}{13.8}\right)^2}} \cdot \frac{1}{1+10^{(SNR_k/10)}}$$

$$SNR = L_{Signal} - L_{Noise} \qquad AM_k = \frac{I_k}{I_k + I_{am,k} + I_{rt,k}} \qquad m'_{k,f_m} = m_{k,f_m} \cdot AM_k$$

$$SNR_{eff,k,f_m} = 10 \cdot log\frac{m'_{k,f_m}}{1-m'_{k,f_m}} \qquad TI_{k,f_m} = \frac{SNR_{eff,k,f_m}+15}{30} \qquad MTI_k = \frac{1}{n}\sum_{m=1}^{n} TI_{k,f_m}$$

$$STI = \sum_{k=1}^{7} \alpha_k \cdot MTI_k - \sum_{k=1}^{6} \beta_k \cdot \sqrt{MTI_k \cdot MTI_{k+1}}$$

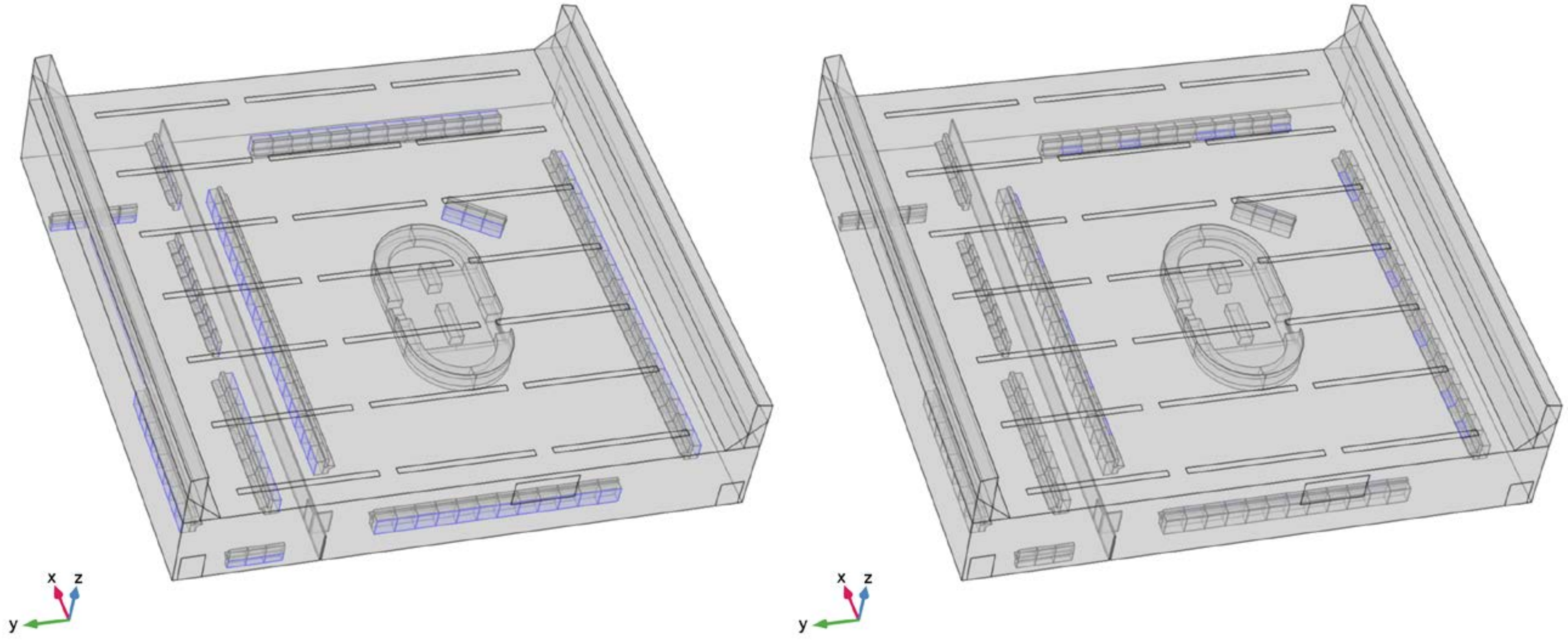
Erdt, L.: Simulating the Speech-Transmission-Index to Evaluate Speech Intelligibility in Room Acoustics Using Ray-Tracing Methods, Masterthesis 2018, TUM

Overview

1. Introduction
2. Theoretical background
3. Simulations and experiments
4. Summary and Conclusion

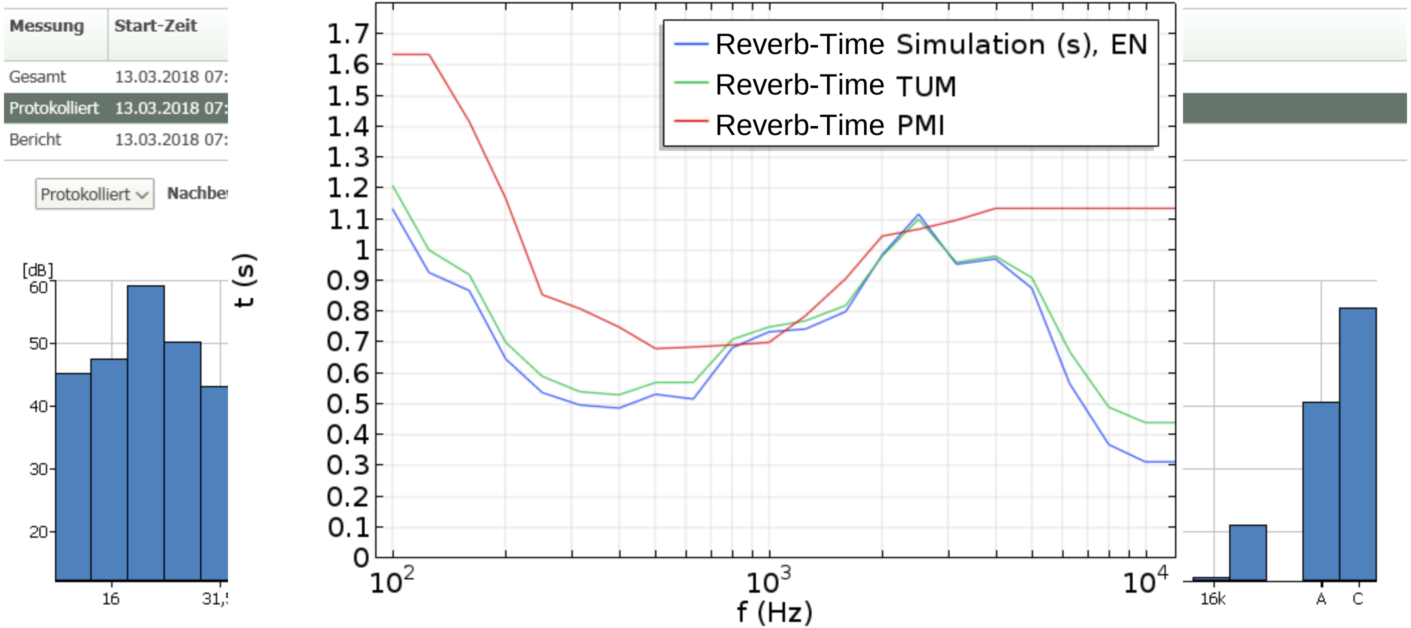
3. Simulations and experiments

- Phase1: Model development (construction plans, data sheets, allocation plans)



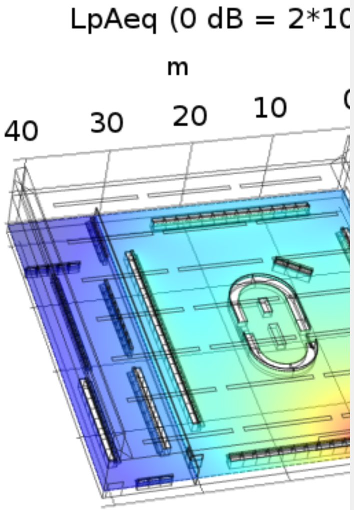
3. Simulations and experiments

- Phase 2: Experimental investigations (measurements of sources and room acoustics)



3. Simulations and experiments

- Phase 3: Source identification and integration (Differences to simulation ± 3dB)

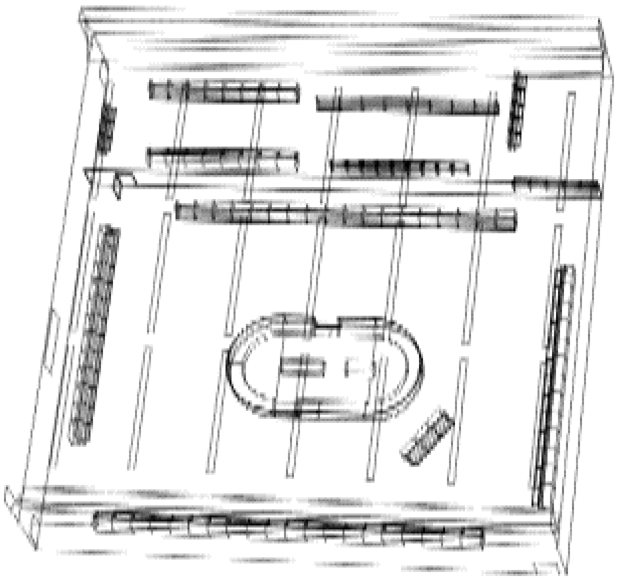


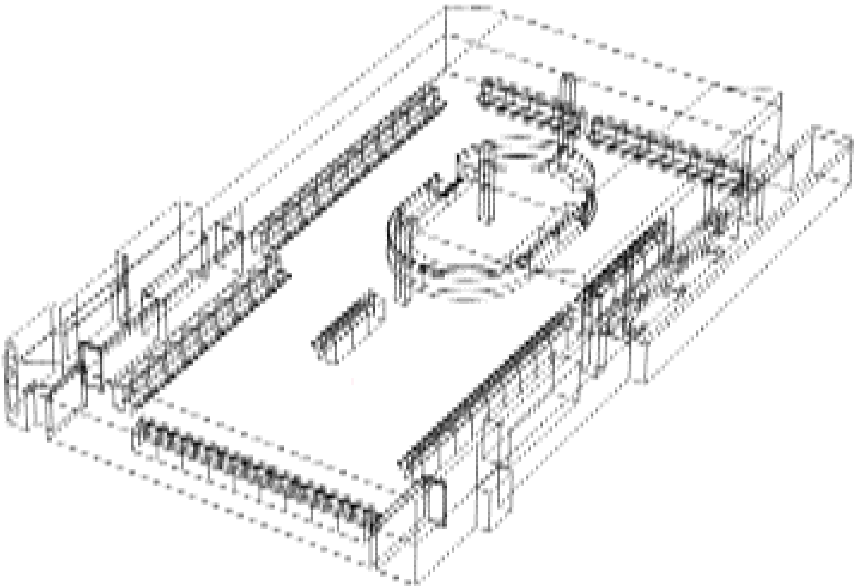
	125	250	500	1000	2000	4000	8000
INR [dB]	21	29	37	47	53	49	50
EDT [s]	0,251	0,385	0,310	0,297	0,195	0,165	0,351
D50	1,00	0,91	0,92	0,94	0,95	0,96	0,99
SNR [dB]	3	13	20	30	38	34	32
SSNR [dB]	2,8	1,5	3,8	1,7	2,2	3,5	3,5
MTI	0,05	0,50	0,57	0,52	0,55	0,59	0,60

STI male	0,55 (Fair)	% ALC	9
STI female	0,56 (Fair)	% ALC	8
STIPA	0,55 (Fair)	% ALC	9
STITEL	0,48 (Fair)	% ALC	12
RASTI	0,81 (Excellent)	% ALC	2

3. Simulations and experiments

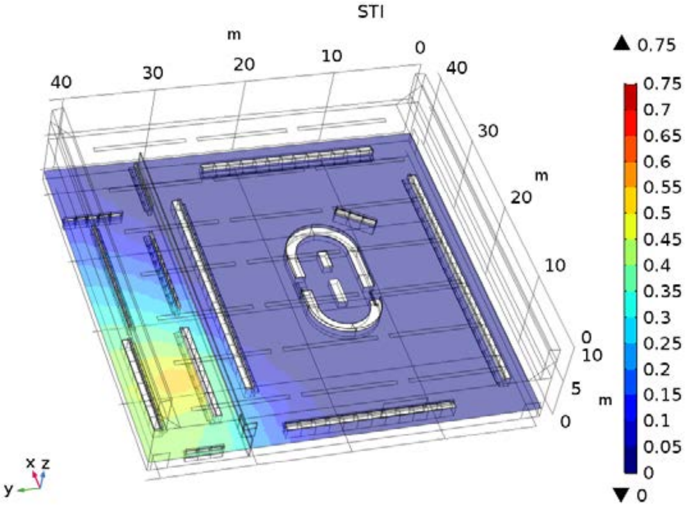
- Phase 4: Simulation of workplace scenario



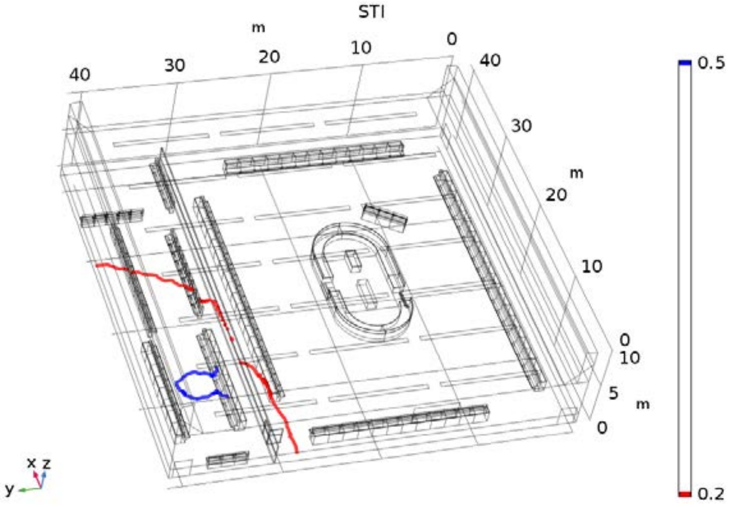


3. Simulations and experiments

- Phase 4: Simulation of workplace scenario (Speaker behind wall, MUC)



Speaker

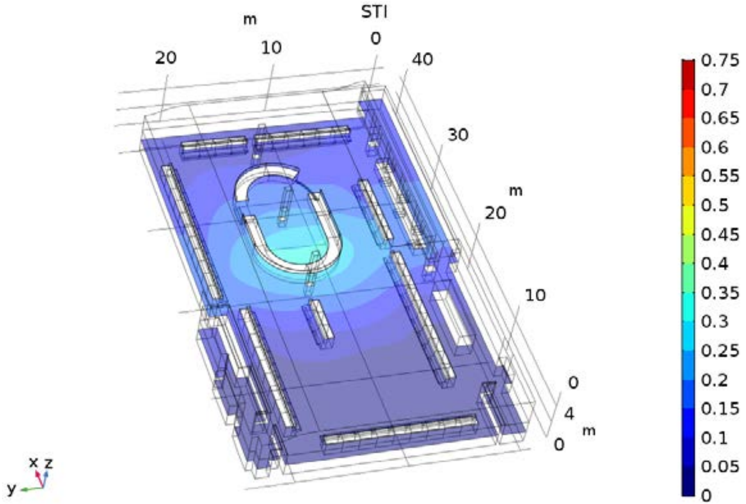


Noise sources

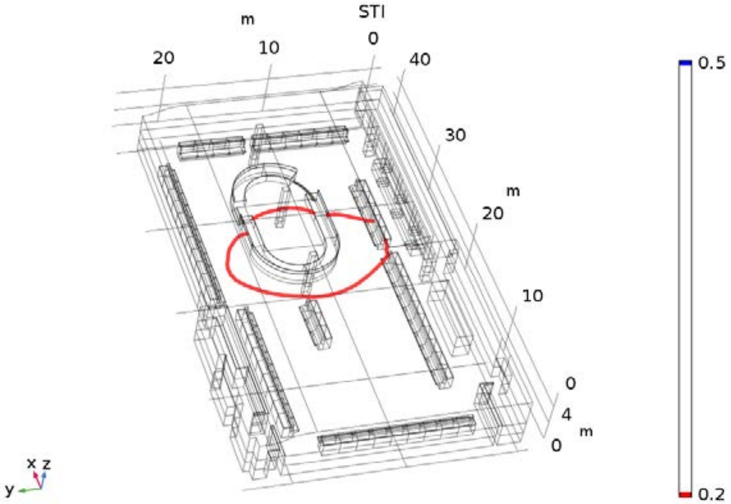
- Distraction Distance
- Privacy Radius

3. Simulations and experiments

- Phase 4: Simulation of workplace scenario (Speaker on bridge, BRE)



Speaker



- Distraction Distance
- Noise sources
- Privacy Radius

3. Simulations and experiments

- Phase 5: Validation in life operations
  - In both rooms life ops conducted
- Questionnaire for air traffic controllers after ops
- In both centers, room acoustic was a major advantage

- Simulations showed very good agreement with experiences of air traffic controllers

- In negative case, numerical tool is available to analyze measures before built
- Simulation and experiment go hand in hand

Overview

4. Summary and Conclusion

- Distraction due to noise and speech is crucial in high demanding environment
- STI an important component in the planning of the working environment
- Safe workplace environment is a well-functioning cooperation between technical and social aspects

- Further development of novel room concepts
- Seat optimization tool available with local RT's (Genetic algorithm, gradient based methods)
- Include uncertainty estimation

Thank you for your speech intelligibility