



Sound, vision and climate: Virtual Reality for the assessment of comfort in the built environment

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Building Physics for a Sustainable Built Environment



Sound, vision and climate: Virtual Reality for the assessment of comfort in the built environment

- Introduction
- Combined stress factors
- Virtual Reality and its potential
- Acoustic Virtual Reality
- Examples / Demos

- Conclusions

Urbanization is a challenge for the acoustic environment

Decrease requested

Increase anticipated

„The need for compromise between urban intervention and the consequence is evident“

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Survey and Measurements (outdoor)

Schneider,
Vallée, Ziefle,
et al.

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- Noise
- Air temperature
- Relative humidity
- Radiation intensity
- Wind
- Particulate matter

Investigation approach

- determine perception of the public on-site using a questionnaire
- capture physical values on-site using mobile measurement equipment

Interviews

Measurement

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Survey and Measurements (outdoor)

Questions during interview (examples, translated to English)

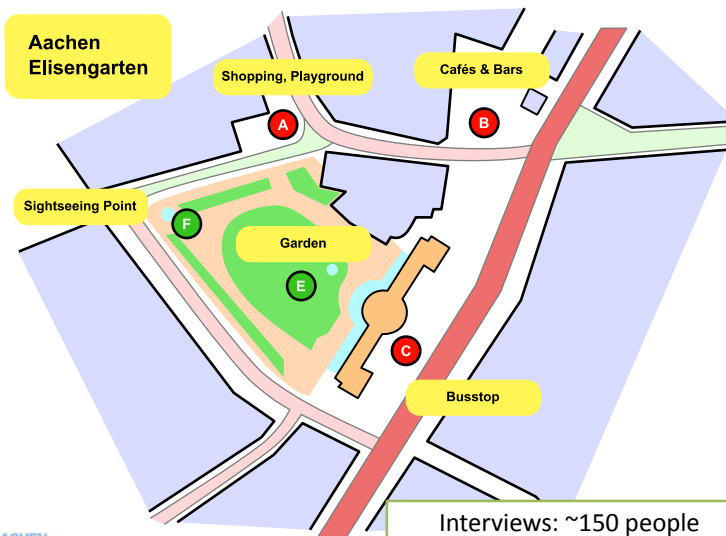


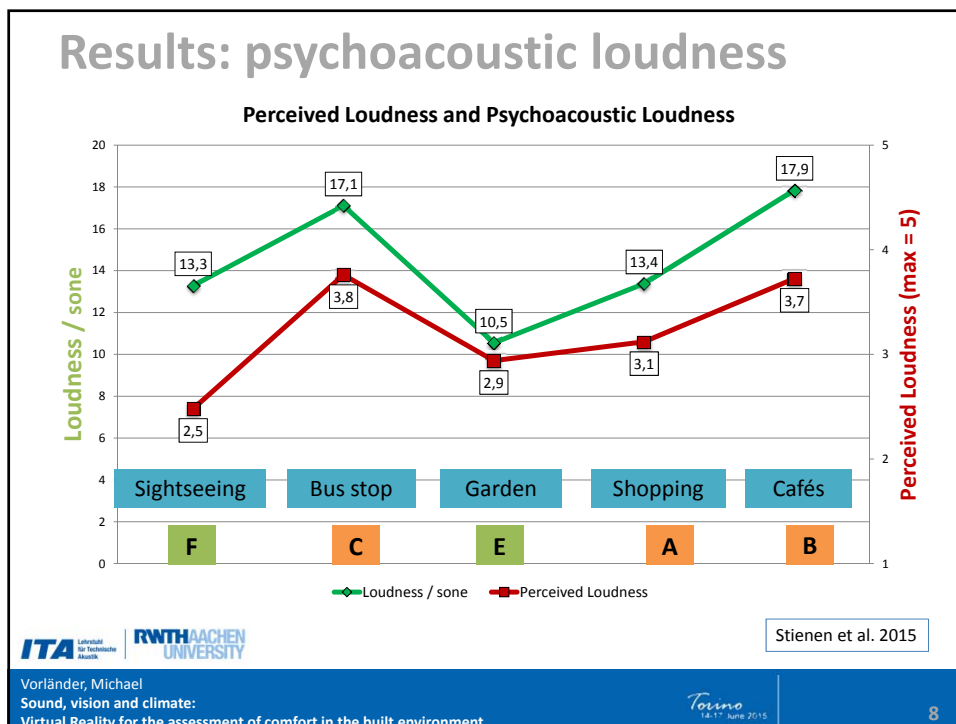
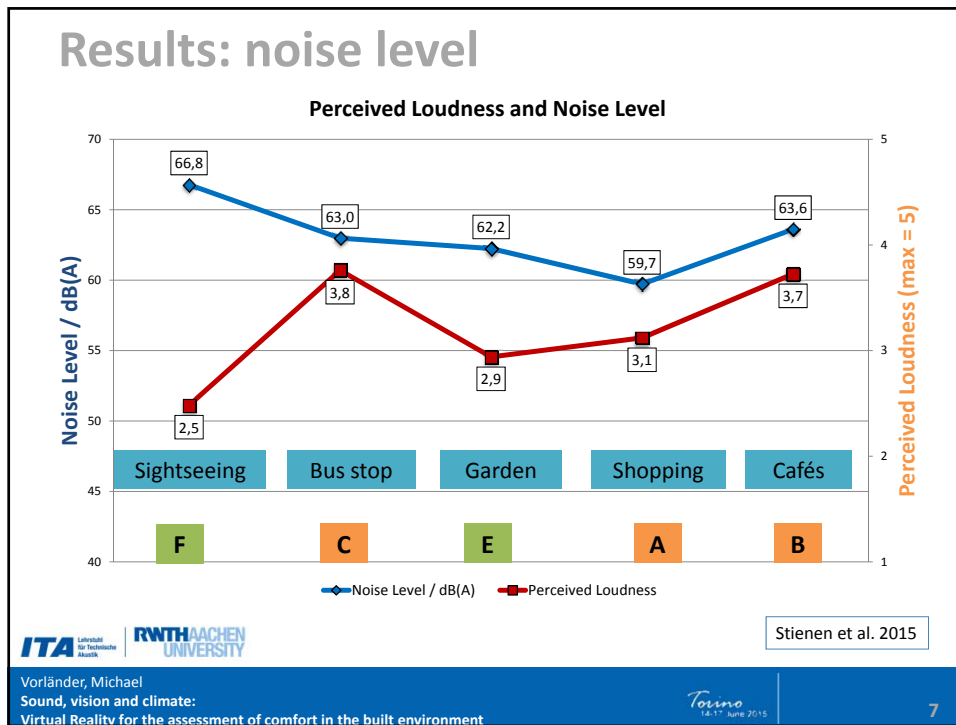
- Do you find this particular place **loud** right now?
- Do you find this particular place **annoying** right now?
- Answer: ordinales scale

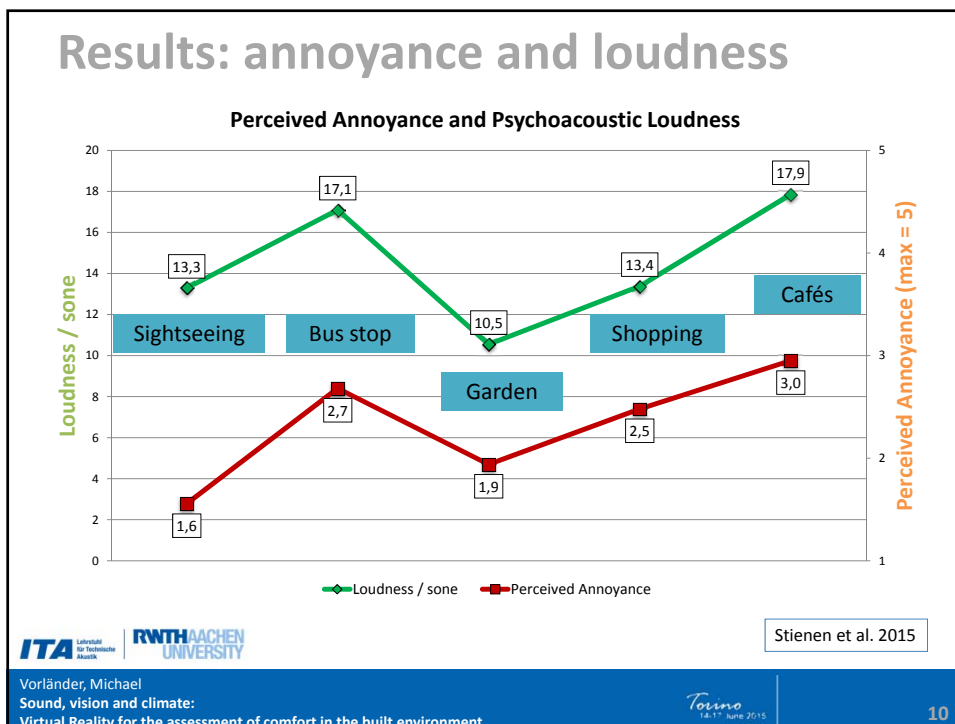
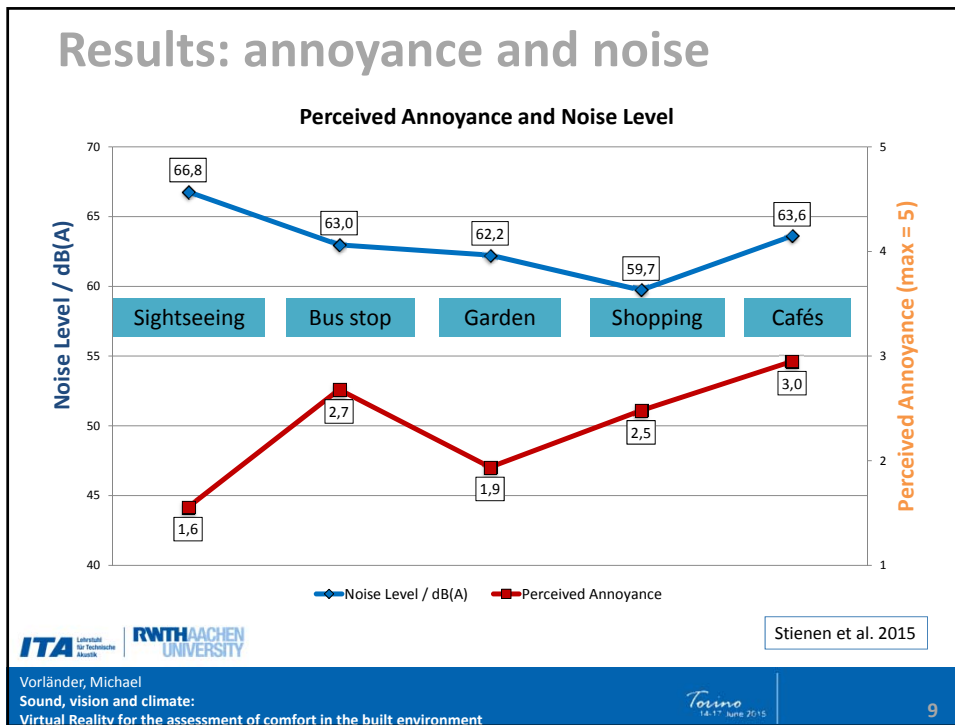
Value	1	2	3	4	5
Descriptor	no	not really	neither	a bit	yes

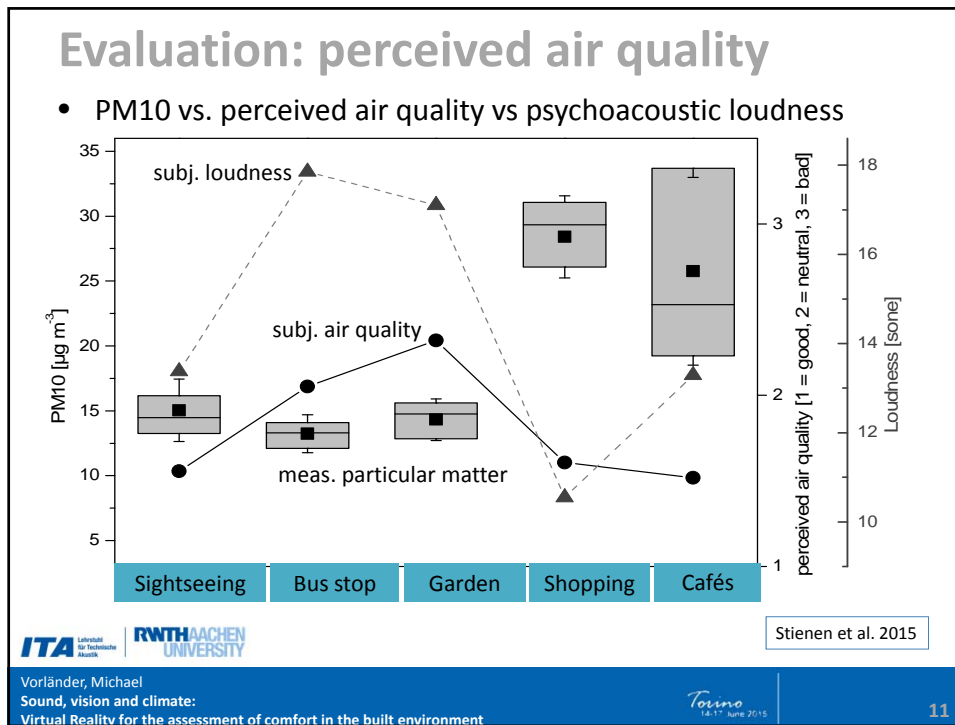
Survey and Measurements

Elisenbrunnen,
City of Aachen
Germany









Outlook – overall comfort

- Continue case studies
 - Verification of methodology with other cities
 - Extended data acquisition to gain more statistical confidence
- Statistical analysis
 - Find common factors in interdisciplinary data
 - Formulate an indicator combining different stress factors
- Simulation and modeling
 - Extrapolation of findings
 - Development of tools for urban planning
- Development of interactive presentation (Virtual Reality)
 - Visualization of stress factors
 - Auralization of urban acoustic environments

Complexity table – the acoustic part

Desired Goal	Resolution	Sound field	Presentation	Complexity
Noise levels dB(A)	Frequency bands only	Stationary	Numbers, tables, contour plots	Low
Psychoacoustic measures	Psychoacoustic bands	Stationary + transients	Numbers, tables, contour maps	High
Auralization	Domain input and output signals	Stationary + transients	Reverberated samples, interactive listening, VR	

Intuitive, comprehensible by layman

Expertise in acoustics required

„get the auditory experience directly, not hidden behind numbers“.

Combined Stress Factors on Humans in Urban Areas

Field Experiments



Simulation, Modelling, Analysis



Is this really necessary?



Goals of urban noise auralization

Audio-visual presentation to the public and/or experts

- Authored audio-visual rendering (i.e. web video with HQ sound tracks)
- Multimedia web application with moderate user interaction (i.e. pre-defined path navigation, free orientation at a location)
- Multimodal audio-visual real-time rendering (Virtual Reality)
 - For home and office use using *low-cost hardware* devices (HMD, Headphones)
 - For experts or selected groups using *virtual spaces and demonstration setups* (CAVE, Holobench, PowerWall)

Real-time auralization + visualization + ... → Virtual Reality

Intuitive, **three-dimensional** User Interface, Immersion

Virtual Reality

Multimodal Interaction:

- visual
- **acoustic**
- haptic/tactile

Interaction in real time:

- Navigation
- Manipulation

Large-scale virtual scenes

Quellenhof Hotel

Concert hall

Entrance

Eurogress building

Aachen casino

Large fountain

Main street

Small fountains

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Virtual aircraft noise scenarios

Airport Operations (VIA)

Wake Vortex (LR)

Engine Emissions (Geo)

Ground Noise Impact (LR)

3-D Visualisation (VRG)

Auralisation (ITA)

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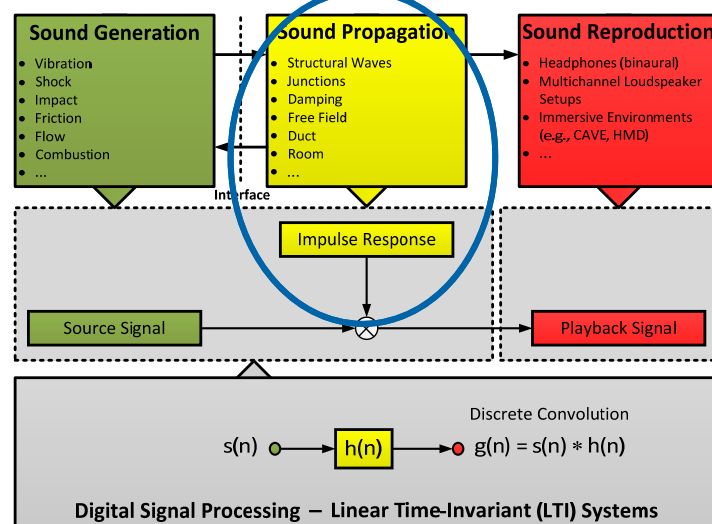
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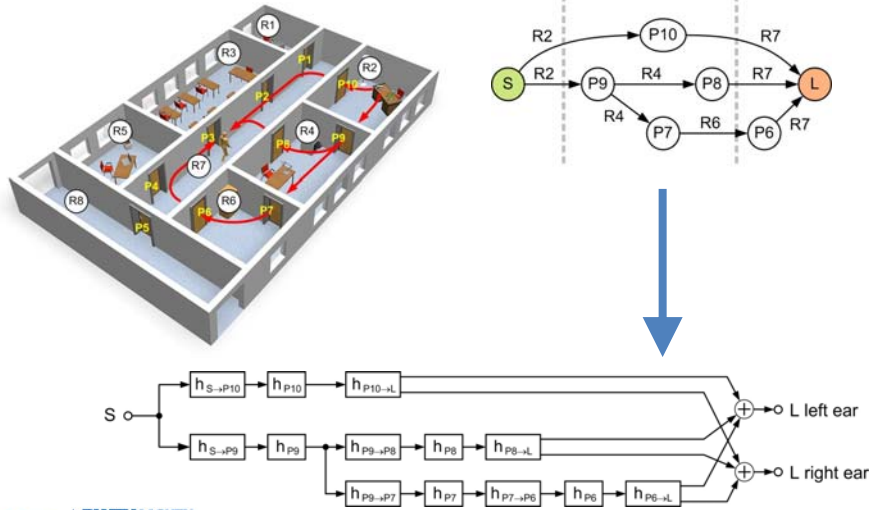
Virtual Acoustics

- Fundamentals and ingredients of VA
- Applications (indoor large, indoor small, outdoor)
- Bottlenecks, challenges

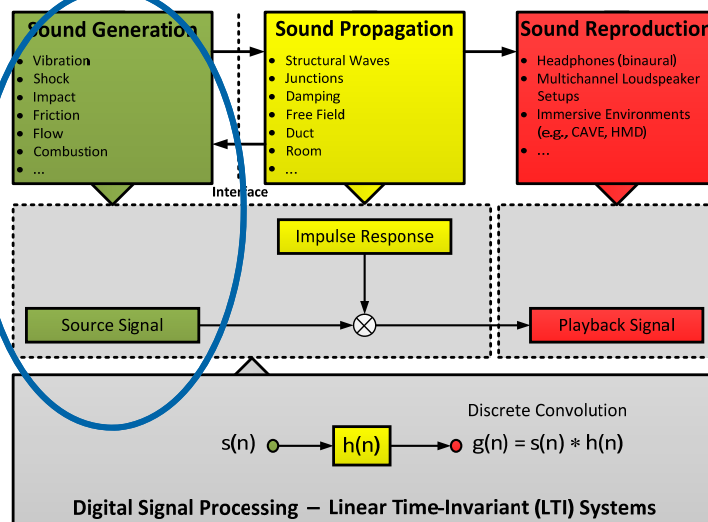
Ingredient 1 – Simulation models



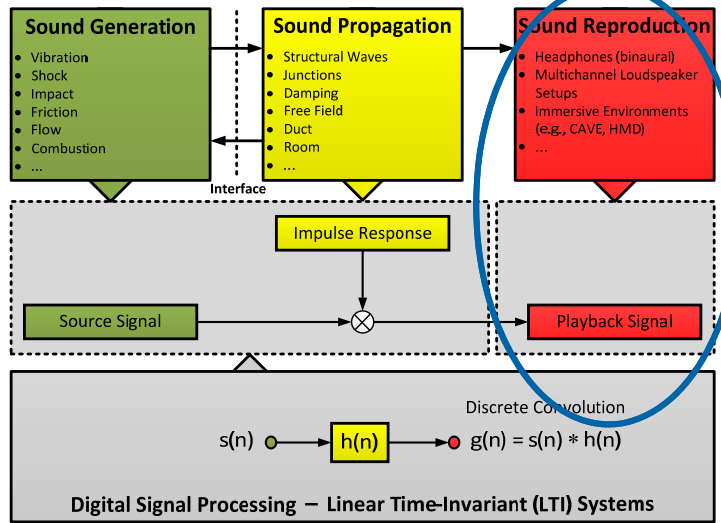
Real-time auralization of coupled rooms



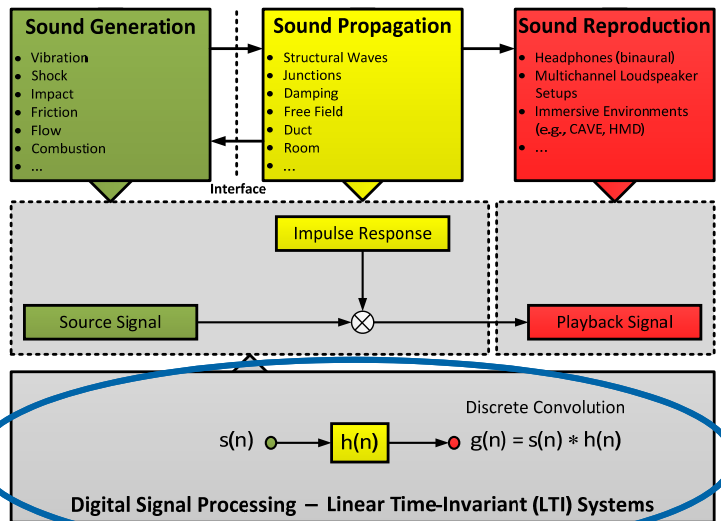
Ingredient 2 – Source characterization



Ingredient 3 – Sound reproduction



Ingredient 4 – Audio signal processing



Put that all together - and run it very very quickly

Sources

Acoustic simulation
Signal processing
Spatial Audio



Virtual Acoustics

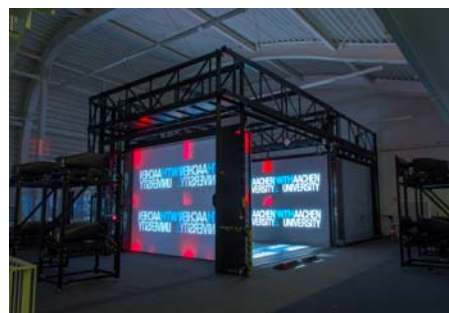
Acoustic Virtual Reality
- AVR -

real-time
multimodal
interaction

VR Hardware (aixCAVE of RWTH)

aixCAVE visualization system

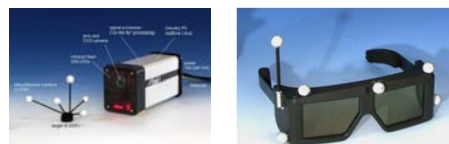
- 5-sided immersive display (no ceiling)
- Dimensions: 5.25m x 5.25m x 3.2m
- 24 Full HD+ active stereo projectors (Barco NW12, three-chip DLP, 1920x1200)
- Optical infrared tracking cameras
- Active stereoscopy (shutter glasses)



aixCAVE immersive display

aixCAVE audio system

- 12 near-field monitor speakers (KH120A)
- 9 sub woofers (ProDipe 10S)
- Wireless headphone



Infrared tracking cameras & glasses

Virtual Acoustics

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Different disciplines collaborating in a Virtual Reality space



Various data illustrated



S. Markova, Computer Aided Architectural Design
T. Kuhlen et al., Virtual Reality Group, IT Center, RWTH Aachen University

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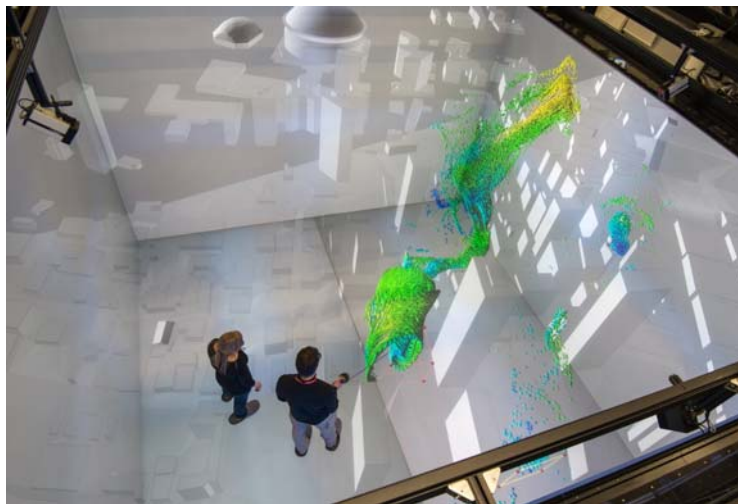
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Various data illustrated



Courtesy of
S. Markova,
Computer Aided
Architectural
Design

T. Kuhlen et al.,
Virtual Reality
Group, IT Center,
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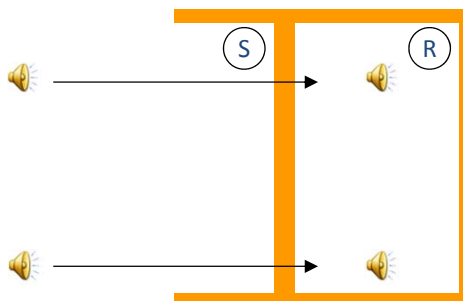
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Sound insulation

- Typical situations

- Indoor, room-to-room
 - Singing in the bathroom
 - Guitar, Piano
 - TV set, Hifi set



- Facades

- Main road, Highway, Aircraft start / landing
- Freight train, high-speed train ...

Sound insulation

Senderraum		Wand	Empfangsraum		Rw	L _{n,w}
Grundbauteil	Vorsatz	Typ	Grundbauteil	Vorsatz	dB	dB
1		Porenbeton (400 kg/m³) 100 mm	1		26.0	80
2		Porenbeton (400 kg/m³) 100 mm	2		52.2	3
3		Gipskartplatte 12.5 mm, EPS 40 mm, Vollzettel NF 1	3		48.5	0
4		Porenbeton (400 kg/m³) 100 mm	4		55.0	1
5		Porenbeton (400 kg/m³) 100 mm	5		55.0	1
6		Porenbeton (400 kg/m³) 100 mm	6		55.0	1
7		Porenbeton (400 kg/m³) 100 mm	7		55.0	1
8		Porenbeton (400 kg/m³) 100 mm	8		55.0	1
9		Porenbeton (400 kg/m³) 100 mm	9		55.0	1
10		Porenbeton (400 kg/m³) 100 mm	10		55.0	1
11		Porenbeton (400 kg/m³) 100 mm	11		55.0	1
12		Porenbeton (400 kg/m³) 100 mm	12		55.0	1
13		Porenbeton (400 kg/m³) 100 mm	13		55.0	1
14		Porenbeton (400 kg/m³) 100 mm	14		55.0	1
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16		Porenbeton (400 kg/m³) 100 mm	16		55.0	1
17		Porenbeton (400 kg/m³) 100 mm	17		55.0	1
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26		Porenbeton (400 kg/m³) 100 mm	26		55.0	1
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32		Porenbeton (400 kg/m³) 100 mm	32		55.0	1
33		Porenbeton (400 kg/m³) 100 mm	33		55.0	1
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50		Porenbeton (400 kg/m³) 100 mm	50		55.0	1
51		Porenbeton (400 kg/m³) 100 mm	51		55.0	1
52		Porenbeton (400 kg/m³) 100 mm	52		55.0	1
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62		Porenbeton (400 kg/m³) 100 mm	62		55.0	1
63		Porenbeton (400 kg/m³) 100 mm	63		55.0	1
64		Porenbeton (400 kg/m³) 100 mm	64		55.0	1
65		Porenbeton (400 kg/m³) 100 mm	65		55.0	1
66		Porenbeton (400 kg/m³) 100 mm	66		55.0	1
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72		Porenbeton (400 kg/m³) 100 mm	72		55.0	1
73		Porenbeton (400 kg/m³) 100 mm	73		55.0	1
74		Porenbeton (400 kg/m³) 100 mm	74		55.0	1
75		Porenbeton (400 kg/m³) 100 mm	75		55.0	1
76		Porenbeton (400 kg/m³) 100 mm	76		55.0	1
77		Porenbeton (400 kg/m³) 100 mm	77		55.0	1
78		Porenbeton (400 kg/m³) 100 mm	78		55.0	1
79		Porenbeton (400 kg/m³) 100 mm	79		55.0	1
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86		Porenbeton (400 kg/m³) 100 mm	86		55.0	1
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90		Porenbeton (400 kg/m³) 100 mm	90		55.0	1
91		Porenbeton (400 kg/m³) 100 mm	91		55.0	1
92		Porenbeton (400 kg/m³) 100 mm	92		55.0	1
93		Porenbeton (400 kg/m³) 100 mm	93		55.0	1
94		Porenbeton (400 kg/m³) 100 mm	94		55.0	1
95		Porenbeton (400 kg/m³) 100 mm	95		55.0	1
96		Porenbeton (400 kg/m³) 100 mm	96		55.0	1
97		Porenbeton (400 kg/m³) 100 mm	97		55.0	1
98		Porenbeton (400 kg/m³) 100 mm	98		55.0	1
99		Porenbeton (400 kg/m³) 100 mm	99		55.0	1
100		Porenbeton (400 kg/m³) 100 mm	100		55.0	1

EN 12354
 Building acoustics -
 Estimation of acoustic performance of buildings from the performance of products

Audio example:

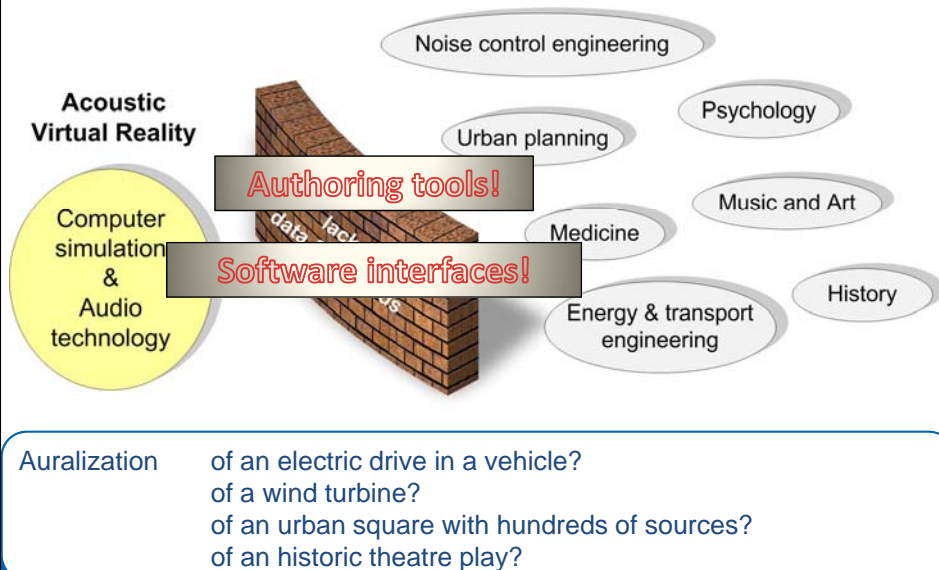
- * Source room
- * Receiving room, $D_{nT,w} = 45$ dB (enhanced by 24 dB)

Virtual Acoustics

- Fundamentals and ingredients of VA
- Applications (indoor large, indoor small, outdoor)
- **Bottlenecks, challenges**

The wall

- Virtual Acoustics is too far from the application



Conclusions

- Sound, vision and climate can be assessed in a joint approach in order to determine combined stress factors
- Numbers expressing physical or physiological data are confusing for the public, expert knowledge is required.
- Involvement of the population in large-scale projects avoids uncertainties and counterforces
- This applies to indoor (classrooms, offices, healthcare facilities ..) and outdoor (environmental noise) problems
- Virtual Reality has a very high potential to involve the population
- Including Acoustic Virtual Reality, however, requires still a big effort!
- Outlook: create easier access to the technology for architects and urban planners. There is still along way to go but first steps are being made.

Big thanks to:
Lukas Aspöck, Sönke Pelzer, Dirk Schröder,
Jonas Stienen, Frank Wefers

and 