Multidomain and context-dependent spatial approaches to acoustic well-being

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HEAD-Genuit-Stiftung

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Introduction

- Acoustic does not only mean the presence of sound waves. A sound event cannot be calculated or measured only by one numerical value. The acoustics are determined by the spectral composition and the temporal patterns.
- For this reason, the discipline of psychoacoustics has established itself, which, in addition to the simple determination of energy, can provide more differentiated, meanwhile globally standardized analyses to describe the **sound character**. Parameters such as loudness, sharpness, tonality, roughness, fluctuation help to classify the sound character of a sound event, but determining the **sound quality** requires additional information about the meaning and functionality of the sound source with consideration of the context that means the **soundscape**.
- How does the sound character fit to the sound source, what expectations and experiences does the listener have? Only through suitable listening tests can the relationship between the sound character and the sound quality be recognized, in order to recommend targeted measures and modifications through the **sound design** to optimize the acoustic effect of a sound event.

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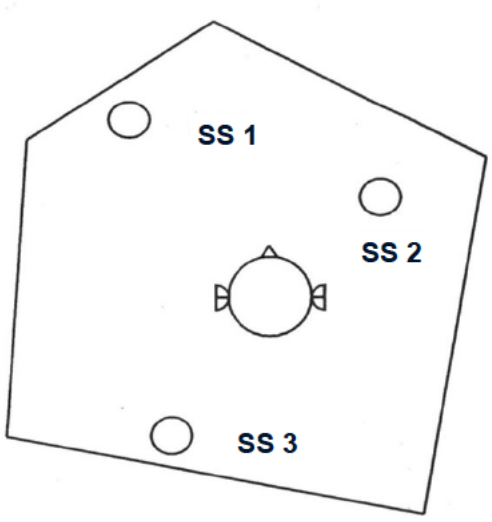
Introduction

- In daily life situations human beings are usually exposed to acoustical contributions of different sources superposing in a complex manner
- Based on binaural hearing human beings focus on certain sources and suppress other
- The ISO 12913 series Soundscape standard provide procedures to describe the acoustic environment in context and cognition and to interpret it with the help of psychoacoustics.
- Binaural measurement technology like an artificial head microphone was initially introduced in the 1980s to enable precise, reproducible and calibrated acoustic documentation of noise events to carry out an auditory assessment.
- After the aurally correct recording of sound events, the desire arose to also analysis like the human hearing describing the subjectively perceived auditory sound quality including psychoacoustic.
- The Soundscape standard ISO 12913 was the first which normatively requests binaural measurement technology and recommends psychoacoustic analysis.
- Based on this development a new research project MOSAIC "**M**ulti-d**O**main and context-dependent **S**patial approaches to **A**coust**IC** well-being" was founded by the HEAD-Genuit-Foundation.

Tasks of the human hearing

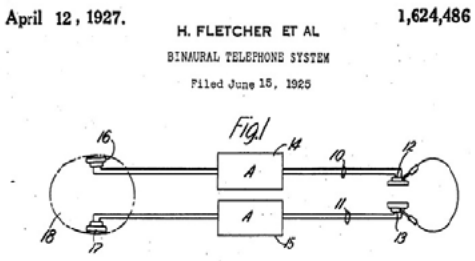
- How is the room acoustics?
- How many sound-sources?
- Which directions?
- What are the distances?
- What kind of sound character?
- What about sound quality?
- What kind of information are given?
- Does the sound fit to the sound-source?
- What are the interferences with respect to light, climate and optical design?



SS: sound-source

Historical Overview: Binaural Recording - Psychoacoustics - Soundscape

- Binaural recording has a long history


April 12, 1927. H. FLETCHER ET AL. 1,624,486
BINAURAL TELEPHONE SYSTEM
Filed June 15, 1925
Fig1

Patent US1624486A: Binaural telephone system

from June 15th, 1925, published April 27th, 1927
by: Western Electric Co

Inventors: Harvey Fletcher, Leon J. Sivian.

- Psychoacoustics, early researchers like:
  - H. Fletcher & W. A. Munson (1933) "Loudness, its definition, measurement and calculation"
  - E. Zwicker (1975) ISO 532-B
  - St. S. Stevens (1975) ISO 532-A
- Soundscape, established by R. Murray Schafer (1977)
  - The Soundscape: Our Sonic Environment and the Tuning of the World

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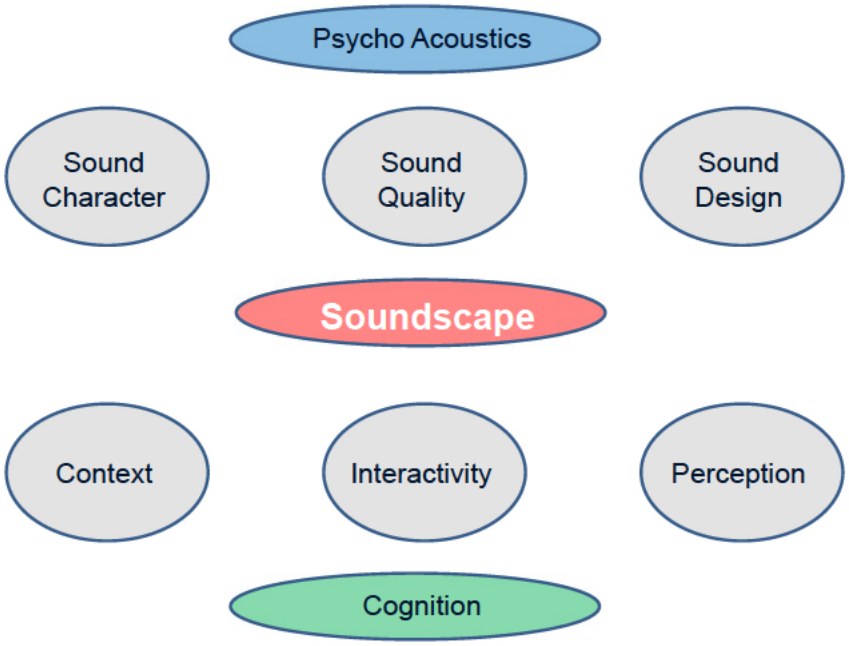
Interactive Context



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Complexity of Soundscape Analysis

- The human ear is able to classify complex soundscapes into single sound events because of its binaural hearing and its consequential directional hearing and selectivity.
- If people are complaining about noise annoyance, the actual reasons for this noise objection have to be explored first. Relevant questions should be:
  - Which of the existing sound sources causes the noise annoyance?
  - Which kinds of signal attributes like modulation or specific patterns in the time and frequency domain are creating the annoyance?
  - Is the time structure responsible for the complaints?
  - Are informative features relevant with respect to the annoyance?
  - Is the noise unpleasant or conspicuous due to modulation or noticeable patterns in time or frequency range?
  - What kind of attitude and expectation has the listener?
  - Is the sound necessary or unnecessary?
- By means of answers first successful measures can be identified for the improvement of the perceived sound quality and the acoustic analysis of the soundscape can be carried out in a more goal-oriented manner.
- Personal contact to people living in this environment is requested and necessary

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Be aware of the distinction between: sound character < - > sound quality

- **Sound character** describes the specific attributes of a sound:
  - Narrow-band or wide-band
  - Spectral contribution, low, middle, high
  - Tonal components and their relationships to other tones
  - Modulations
  - Impulsiveness
  - Stochastic
- **Sound Quality** is established as a key element with respect to successful product development
- **Sound Quality** means the ***adequacy*** [Blauert] or ***suitability*** [Guski] of a sound attached to the technical object emitting it
- It evolves from a process, in which ***recognized features*** are compared to some ***kind of reference*** [Blauert, Jekosch]

→ What is exactly the reference of the target group? Are there cultural differences of the applied frame of references?

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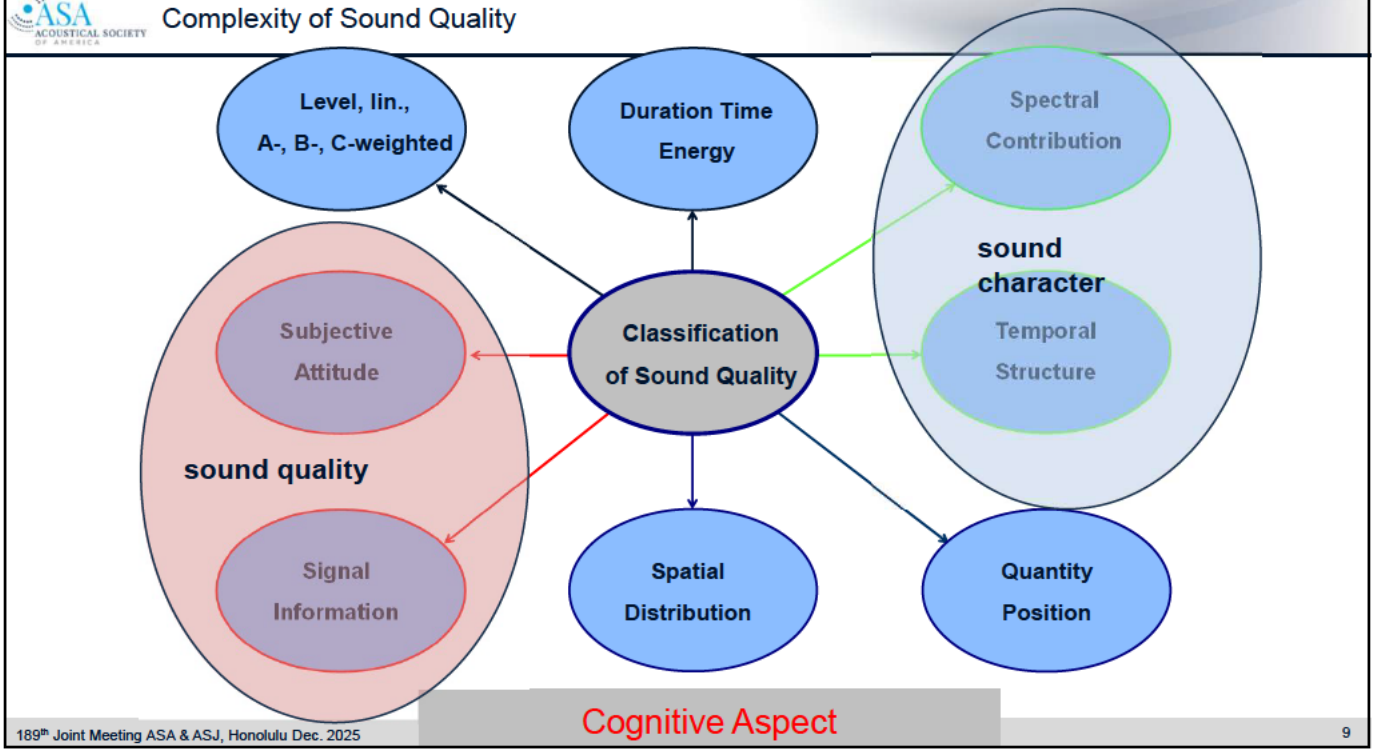
Complexity of Sound Quality



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Psychoacoustical Parameter

Loudness:	Consideration of distribution of critical bands and masking properties in the hearing, DIN 45 631, ISO 532-1

Studies (Fastl, Zwicker 2007) have shown that the **5% percentile loudness (N5)** correlates highly with the perceived total loudness valid in cases of unsteady sounds. This is implemented in DIN 45631/A1: "*since the mean value of time varying loudness compared with the subjectively evaluated loudness provides a value, which is too low, the 5% percentile loudness (N5) has to be used with respect to the perceived overall loudness.*"

Sharpness:	Weighted first moment of distribution of critical band rates of specific loudness, proportion of high-frequency spectral components to total loudness, DIN 45692
Roughness/ Fluctuation:	Time structure of the sound signal, modulation factor and level difference determine roughness & fluctuation → amplitude- and frequency modulation, DIN 38455, ECMA 418-2
Tonality:	Products emit tonally-perceived noises due not only to pure tones but also to narrow noise bands, and to same-vicinity combinations of pure tones and narrow elevated noise bands, ECMA 418-2

ECMA International - European association for standardizing information and communication systems.

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Human Perception and Soundscape

- Psychoacoustics, sound quality, cognition provide information how humans perceive and interpret their surrounding world
- What is soundscape about?
  - Definition Soundscape:
    - acoustic environment as perceived
    - or experienced
    - and/or understood by a person or people,
    - in context
    - (ISO 12913-1, 2014)
- Two major components like pleasantness and eventfulness describe soundscape
- This concept allows considering sound quality aspects beyond noise annoyance
- A good soundscape quality is not simply identical to the absence of annoyance
- Judgments cannot be fully understood by only considering acoustical quantities, since contextual parameters and interactivity are relevant for assessment of a soundscape as well

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Soundscape – Need for Binaural Measurement, ISO/TS 12913-2: Annex D, Binaural Measurement Methods -> normativ

- The international standard ISO 12913 "Soundscape" describes this relationship of perceived sound quality considering the context, while also taking into account that there are usually several spatially distributed sound sources that determine the entire sound event.
- The aurally correct recording of a complex sound event for the purpose of psychoacoustic analysis and auditory assessment is therefore normatively based on the use of binaural measurement technology.

ISO/TS 12913-2:2018(E)

Annex D
(normative)

Binaural measurement methods

D.1 General

This annex specifies how to perform binaural acoustical measurements by means of artificial head measurement systems. In contrast to recordings based on a monaural microphone, binaural acoustic measurements record sound as if a human listener is present in the original sound field, maintaining all spatial information.

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ISO/TS 12913-3: Psychoacoustic Analysis is recommended

Table D.1 – Metrics and representative single values

Parameter	Metrics to be determined for each channel separately	Determination of representative single value	Reference
Sound pressure level	$L_{Aeq,T}$, $L_{Ceq,T}$, $L_{AF5,T}$, $L_{AF95,T}$	higher value of left and right metric values	ISO 1996-1 [55]
Loudness (time-variant loudness)	N_5, $N_{average}$, N_{rmc} N_{95}, $\frac{N_5}{N_{95}}$	higher value of left and right metric values (or the average of left and right metric values)	ISO 532-1 [54]
Sharpness	S_5, $S_{average}$, S_{95},	higher value of left and right metric values (or the average of left and right metric values)	DIN 45692 [56]
Psychoacoustic tonality	T	higher value of left and right metric values (or the average of left and right metric values)	ECMA 74 [57]
Roughness	R_{10} , R_{50}	higher value of left and right metric values (or the average of left and right metric values)	[32]
Fluctuation strength	F_{10} , F_{50}	higher value of left and right metric values (or the average of left and right metric values)	[32]

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Standardization of Psycho-Acoustical Parameters

- Psychoacoustics will be more and more established:
  - Automotive field
  - Office and appliance equipment
  - Environmental noise
  - Indoor living area

- Time Variant Loudness: new ISO standard 532 is realized
- Sharpness: still only as German DIN 45692 available
- Tonality: standardization at ECMA (*)
- Roughness: standardization at ECMA 418-2 and DIN 38445
- Fluctuation: will be standardized at ECMA soon
- Standardization Soundscape, DIN/ISO 12913

- Need for transdisciplinary actions:
  - The consideration of noise perception beyond physics and noise control requires a constructive collaboration of other disciplines

(*) ECMA International - European association for standardizing information and communication systems.

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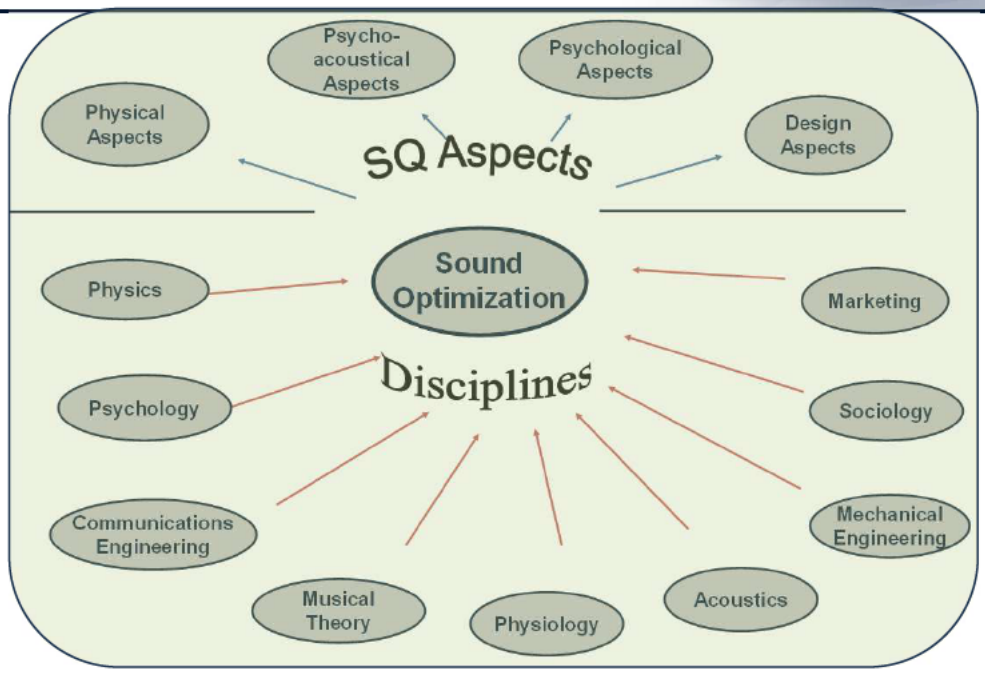
Sound Quality: Multidimensional and Interdisciplinary -> soundscape ISO 12913



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MOSAIC: Multi-dOmain and context-dependent Spatial approaches to AcoustIC well-being

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Acoustics at Germany

- In Germany DEGA –Deutsche Gesellschaft der Akustik (German Society of Acoustics)- is responsible for acoustical topics, like:
  - Noise
  - Vehicle acoustics
  - Underwater acoustics
  - Building acoustics
  - Electro acoustics
  - Ultrasound acoustics
  - Psychoacoustics
  - Virtual Acoustics
  - Speech acoustics
  - Physical acoustics
  - Aeroacoustics
- But not architectural acoustics like in US where TCAA is one of the biggest committee
- The idea arose introducing acoustics and especially psychoacoustics into the field of architecture

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MOSAIC: **M**ulti-d**O**main

- Partners from a broad range of disciplines incl. architecture, civil engineering, electrical engineering, mechanical engineering, medicine.
- Addressing multiple domains of IEQ
  - (Indoor Environmental Quality, including factors such as air quality, temperature, humidity, noise levels, *occupancy density and general mental well-being*)

Context

Indoor and urban environment

- Acoustic properties
- Other physical conditions (IEQ)
- Characteristics of public space
- Social aspects of the space
- Real spaces vs. VR
- ...

Individual person

- Activity / task
- ind. health determinants
- Personality / preferences
- Perception of control
- Level of adaptation
- ...

HLS: Healthy Living Spaces (Prof. Dr. Marcel Schweiker)

IHTA: Hearing Technique and Acoustics(Prof. Dr. Janina Fels)

FGTA: Psychoacoustics (Dr. André Fiebig, TU Berlin)

E3D: Energy-efficient Building (Prof. Dr. Christoph van Treeck)

EBC: Building- and Room Climate Technology (Prof. Dr. Dirk Müller)

IASU: Occupational-, Social- and Environmental Medicine (Prof. Dr. Thomas Kraus)

SB: Urban Development (Prof. Dr. Christa Reicher)

WB: Residential Building (Prof. Dr. Florian Fischer-Almannai)

HLS IHTA FGTA E3D EBC IASU SB WB

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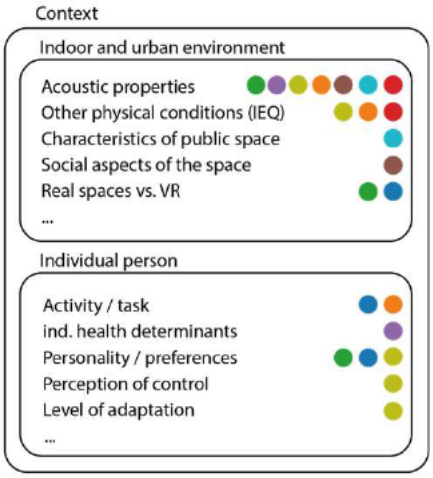
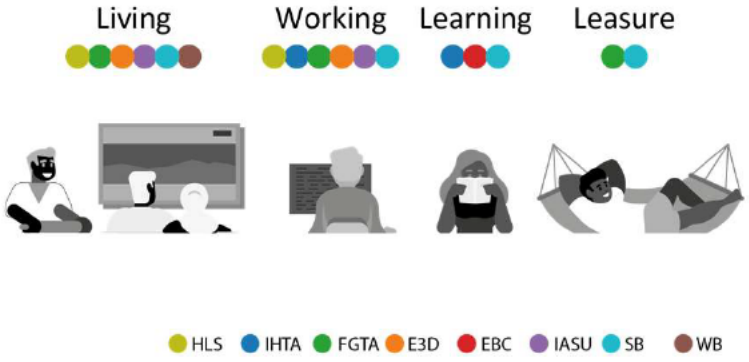
MOSAIC: context dependent

- Addressing a variety of activities and other contextual factors





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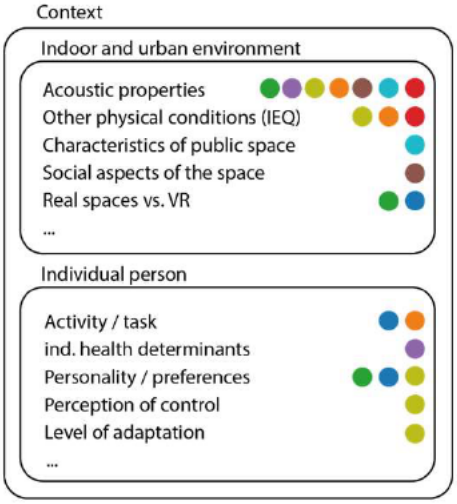
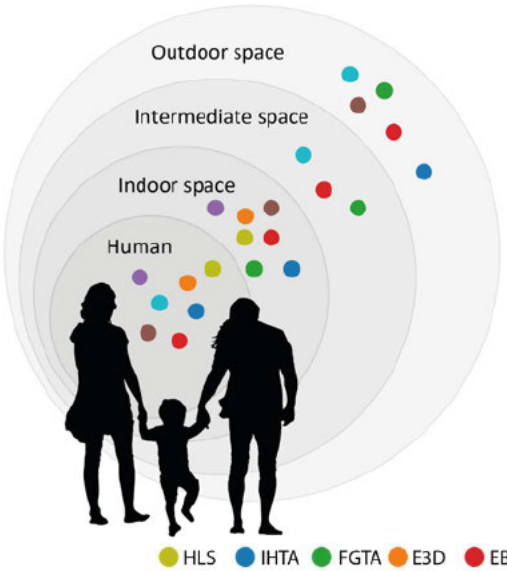
MOSAIC: Spatial approaches





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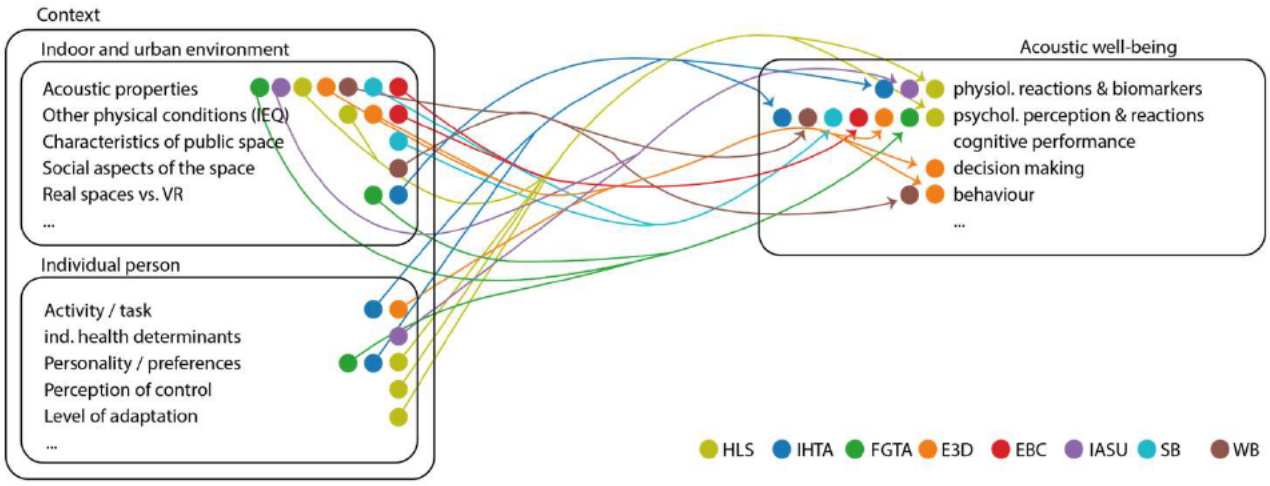
MOSAIC: **Acoust**IC well-being

- Need to define acoustic well-being.
- Addressing multiple parameters of acoustic well-being.



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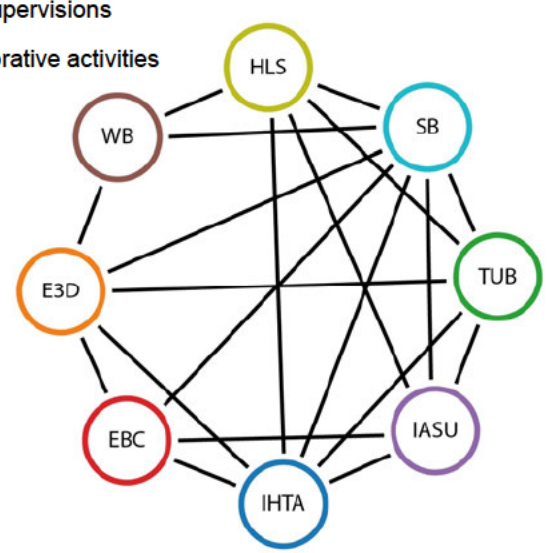
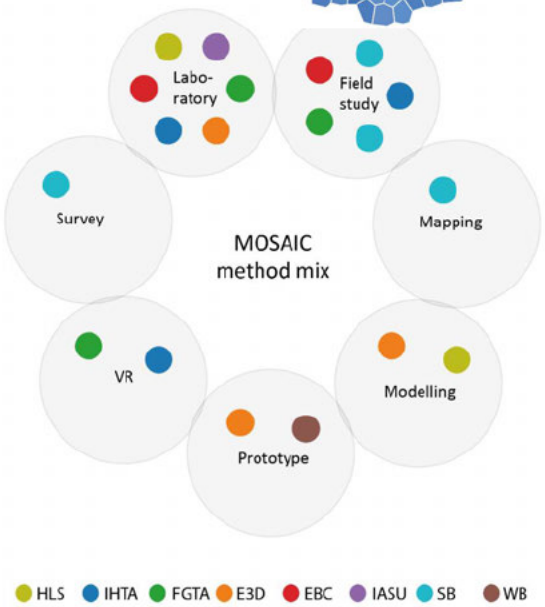
Methods and collaboration

- Mixed methods
- Joint supervisions
- Collaborative activities





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HLS: Healthy Living Spaces (Prof. Dr. Marcel Schweiker)

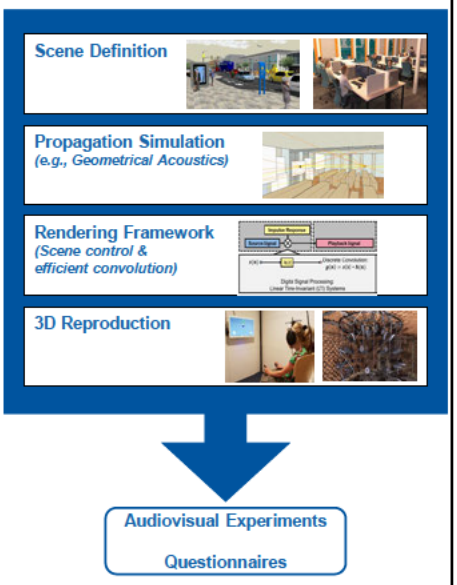
Sub-project: Control, Adaptation, and their Interaction

- **Background:** There are no known studies examining the impact of subjectively perceived control on multi-sensory stimuli, such as thermal and acoustic.
- **Goal:** To develop an approach for a multi-sensory adaptation model considering or exemplary implementation of (perceived/desired) control.
- **Intended methods:** Literature review, laboratory studies, model development.
- **Team:** Alena Wagner (PhD candidate), Dr. Amneh Hamida

IHTA: Hearing Technique and Acoustics(Prof. Dr. Janina Fels)

Sub-project: Evaluation of the feasibility of using acoustic virtual reality for studies on acoustic well-being, including components of Indoor Environmental Quality (IEQ)

- **Background:** Most studies isolate IEQ factors, lacking holistic assessment of thermal, acoustic, air quality, and lighting in learning and work.
- **Goal:** The aim of the project is to develop and validate a methodology for analyzing acoustic well-being in learning and working situations, taking into account the TAIL approach (Thermal, Acoustic, Indoor air quality, Lighting) using virtual reality.
- **Intended methods:** Literature review, Questionnaires, laboratory studies in real and audiovisual virtual environments, step by step adding IEQ-components, model development.
- **Team:** Aron Schliep (PhD candidate), Dr.-Ing. Lukas Aspöck

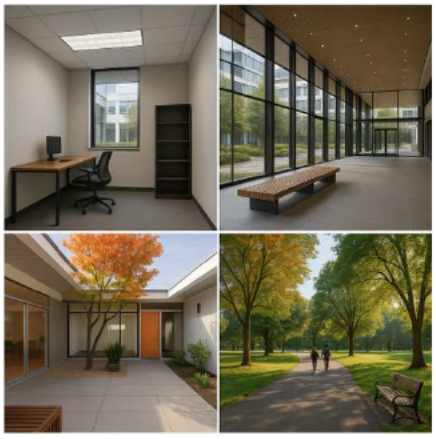


FGTA: Psychoacoustics (Dr. André Fiebig, TU Berlin)

TECHNISCHE UNIVERSITÄT BERLIN

Sub-project: Acoustic well-being in indoor and outdoor spaces. The perception of small rooms, large rooms and neighborhoods

- **Background:** Auditory perception depends not only on sound field properties but also on visual and spatial context. Enclosure, openness and geometry - apart from room acoustics - affect perceived spaciousness, clarity and comfort, yet systematic comparisons across room size are rare.
- **Goal:** To examine how acoustic comfort and clarity vary with room size and spatial context, and how controlled acoustic conditions can support consistent perceptual evaluation across these environments providing knowledge for optimization.
- **Intended methods:** Literature review, perceptual models, laboratory studies in AR/VR environments, field study.
- **Team:** Konstantin Fontaine (PhD candidate)



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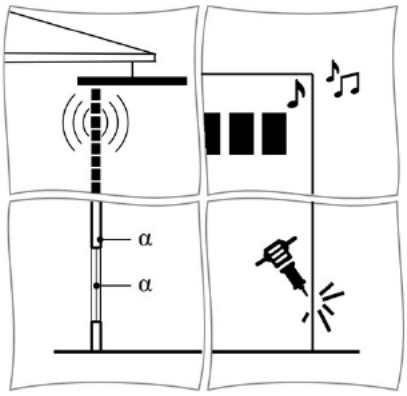
E3D: Energy-efficient Building (Prof. Dr. Christoph van Treeck)

e3D Lehrstuhl für Energieeffizientes Bauen | RWTH AACHEN UNIVERSITY

Sub-project: Soundscapes in the building lifecycle

- **Background:** The lifecycle of a building is full of sonic events (sound and noise sources), affecting people in the building on a subjective and cognitive level.
- **Goal:** Analysis and optimization of an office building's soundscapes structured according to typical sonic events in its lifecycle.
  - Type and severity of sonic events (e.g., impairments).
  - Human-related effects of the acoustic environment, also considering its interaction with other IEQ (indoor environmental quality) parameters
  - Model of lifecycle-oriented soundscapes
  - Integration into planning software
  - Optimization concepts (e.g., multifunctional materials)
- **Intended methods:** Literature review, laboratory studies (iCare-lab), surveys, modeling, conception.
- **Team:** Florian Guttenbacher (PhD candidate), Dr. phil. Marc Syndicus



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EBC: Building- and Room Climate Technology (Prof. Dr. Dirk Müller)

EBC | Institute for Energy Efficient Buildings and Indoor Climate | RWTH AACHEN UNIVERSITY

Sub-project: Acoustics in the context of the integral refurbishment of educational facilities

- **Background:** Limited budget for refurbishment of schools and classrooms, but no holistic analysis of thermal, acoustic, air quality, and lighting effects on learning and teaching performance.
- **Goal:** Refurbishment guideline of classrooms depending on type, location and boundary conditions with analysis of:
  - Effects of partial compared to full refurbishment.
  - Acceptable loads of other domains to assure acoustic comfort.
  - Acceptable acoustic loads to assure thermal comfort and IAQ (Indoor Air Quality).
- **Intended methods:** Literature research of relevant internal and external emission sources for school buildings, laboratory and field tests regarding affective, cognitive and physiological effects depending on IEQ.
- **Team:** Aleksandra Romakhova (PhD candidate), Dr.-Ing. Kai Rewitz

IASU: Occupational-, Social- and Environmental Medicine (Prof. Dr. Thom

UNIKLINIK RWTH AACHEN

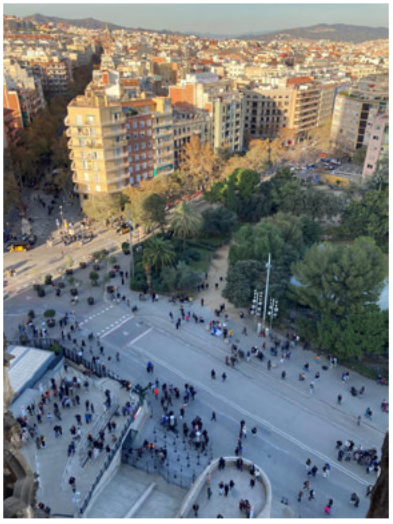
Sub-project: Determinants of Acoustic Well-Being in Vulnerable Groups

- **Background:** Vulnerable groups, such as individuals with hearing impairments, are currently underrepresented in existing soundscapes research. Most studies focus on healthy young participants, often without assessing their hearing ability beforehand.
- **Goal:** To systematically evaluate the effects of diverse soundscapes on individuals with hearing impairments and to formulate evidence-based strategies aimed at improving acoustic well-being in vulnerable groups, taking into account their distinct physiological characteristics.
- **Intended methods:** Literature review; laboratory study with three groups: normal hearing, age-related hearing impairment, and noise-induced hearing impairment; physiological measurements incl. heart rate variability (HRV: RMSSD, pNN50, LF/HF ratio), galvanic skin response (GSR), pupillometry, electroencephalography (EEG; event-related potentials, frequency analysis), breath gas analyses.
- **Team:** Christina Burkhardt (PhD candidate), Dr. phil. Michael Kursawe

SB: Urban Development (Prof. Dr. Christa Reicher)

Sub-project: Acoustic well-being in the neighbourhood

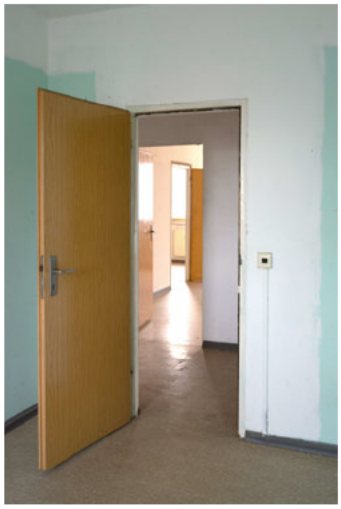
- **Background:** Urban noise remains one of the major health risks in cities. While most research focuses on indoor or building-scale acoustics, little is known about acoustic well-being in outdoor and neighborhood contexts.
- **Goal:** To explore how urban design influence acoustic well-being at the neighborhood scale and to derive planning and design principles for healthier, more resilient urban environments.
- **Intended methods:** Literature and policy review, case studies in Aachen and Berlin (mapping, surveys, soundwalks), development and modulation of urban scenarios (VR/AR simulations), comparative perception and acceptance studies, interdisciplinary collaboration within MOSAIC (acoustics, medicine, urban design).
- **Team:** Hannah Keuser (PhD candidate), Moritz Lippold (PhD candidate)



WB: Residential Building (Prof. Dr. Florian Fischer-Almannai)

Sub-project: Acoustic conditions in the flexible and shared living

- **Background:** Per capita living space (amount of square footage per person) consumption is increasing. Under-occupancy is one reason for this. New flexible forms of living are one way of reducing the trend towards under-occupancy. Current standards only partially reflect these new forms of living, and new concepts are needed in areas such as acoustic well-being.
- **Goal:** The overarching goal is to gain a better understanding of necessary standards versus individual or situational adaptations of acoustic conditions.
- **Intended methods:** A residential demonstrator will be created in a suitable existing building and the experiences of the test residents will be evaluated qualitatively.
- **Team:** Yanik Wagner (PhD candidate)



Conclusion

- Acoustic well-being is a subjective evaluation of acoustic conditions that depend on external circumstances (e.g., room design, social factors, and other factors such as temperature, smell, and lighting) and internal conditions (e.g., irritability, need for rest, health, personality). It describes a condition in which a person does not feel disturbed by acoustic events but perceives the acoustic scene as pleasant. The evaluation is context-dependent and multimodal.
- Soundscape should be used as a "shell" including environmental, natural and artificial sounds influenced by context, experience, expectations and landscape
- For the classification of Soundscape we have to listen:
  - to the sound
  - to the comments of people living in this soundscape
- New tools for soundscape research using virtual reality are under development for investigating new not exiting soundscapes before they will be realized