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Doktorski studij
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Advancing the Evaluation of Acoustic Quality in Internal Spaces for Speech and Communication: A Study of Educational Environments / Unaprijeđenje ocjene akustičke kvalitete unutarnjih prostorija za govor i komunikaciju na primjeru obrazovnih ustanova

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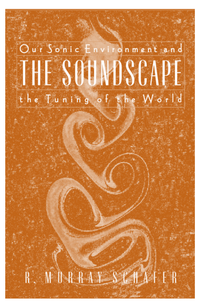
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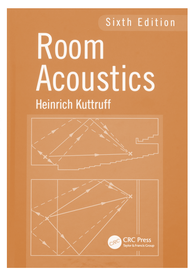
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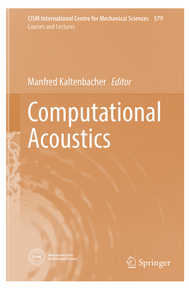
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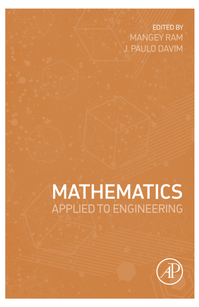
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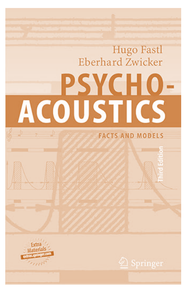
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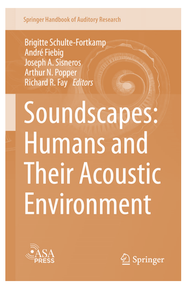
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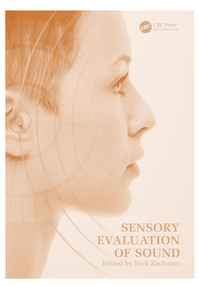
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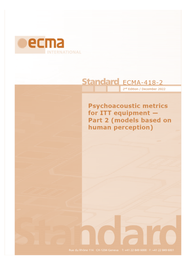
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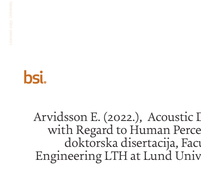
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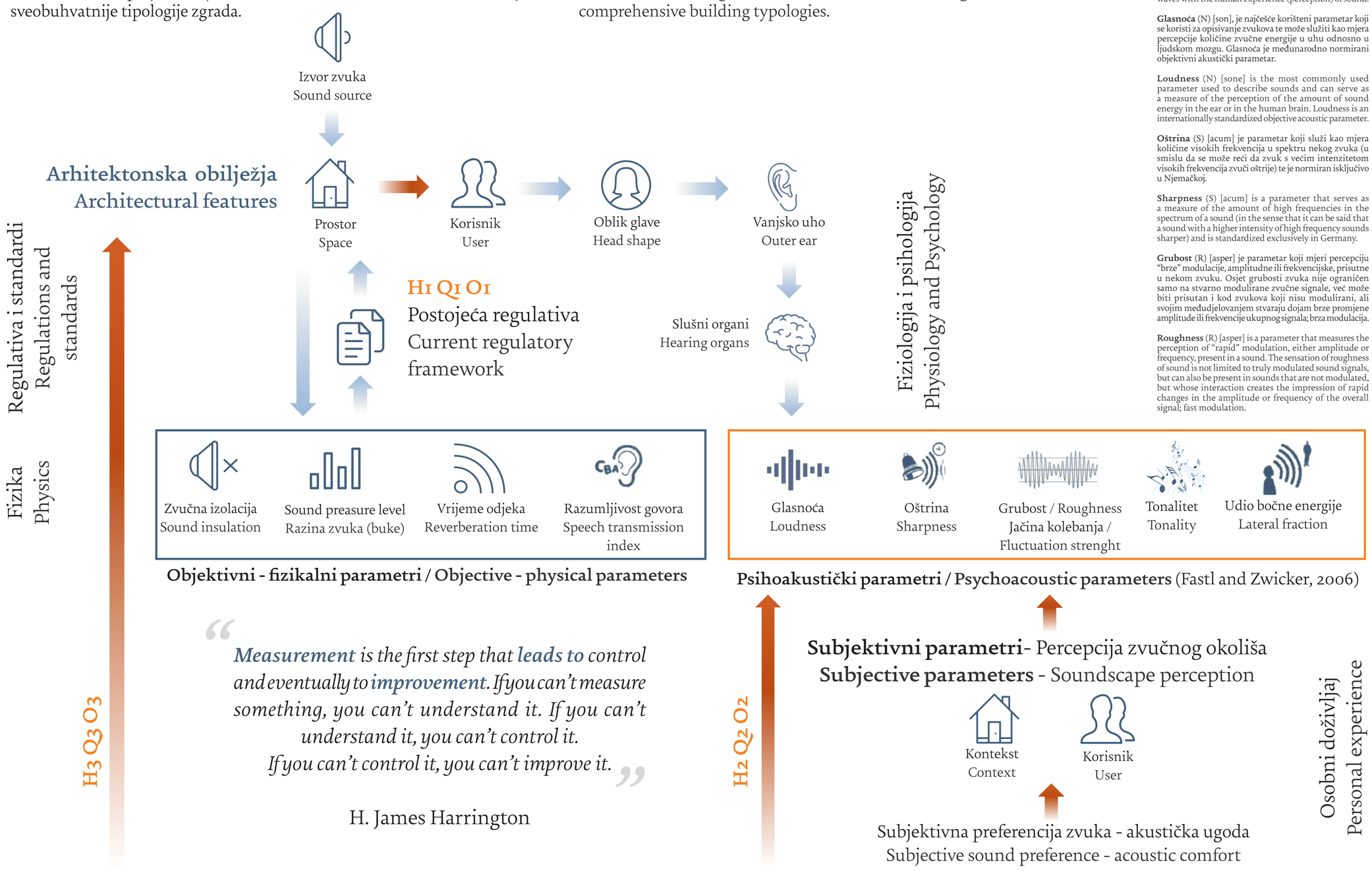
Istraživački Problem i Cilj

Prema studiji o kvaliteti unutarnjeg okoliša (IEQ), ugoda je subjektivni osjećaj zadovoljstva na koji utječu objektivni čimbenici poput toplinskih, vizualnih, akustičnih uvjeta i uvjeta kvalitete zraka. Istražujući interakciju između ljudi i izgrađenog okoliša, ovo istraživanje usredotočuje se na akustičnu ugodnost u unutarnjim prostorima, koja se **konvencionalno opisuje objektivnim, mjerljivim parametrima** poput zvučne izolacije, vremena odjeka, razine pozadinske buke i spektra (DIN 18041, ISO 3382). Međutim, nedavna istraživanja naglašavaju da **percipirana akustična kvaliteta ovisi i o ljudskoj percepciji, akustičnom okruženju i kontekstu** (Schulte-Fortkamp, 2023; ISO 12913), što dovodi do identifikacije pozitivnih atributa zvučnog krajolika koji potiču zadovoljstvo, produktivnost i oporavak (Ajiboye, 2024). Ovo istraživanje proširuje okvir akustičke evaluacije **integrirajući psihoakustičke i perceptivne dimenzije u procjenu prostora za govor i komunikaciju**. Ciljani prostori su obrazovni prostori s volumenom manjim od 300 m³, poput učionica i predavaonica. Arhitektonske značajke - geometrija, volumen, dizajn i materijali - okarakterizirane su objektivnim i percipiranom akustičnim atributima, čija se veza može opisati psihoakustičnim parametrima. Na temelju istraživanja, razvit će se model i optimalni rasponi za procjenu akustičke kvalitete prostorija za govor i komunikaciju, popraćene metodološkim smjernicama za primjenu u arhitektonskom projektiranju obrazovnih ustanova, što će stvoriti temelj za sveobuhvatnije tipologije zgrada.

Research Problem and Research Aim

According to the study of Indoor Environmental Quality (IEQ), comfort is a subjective feeling of satisfaction influenced by objective factors such as thermal, visual, acoustic, and air quality conditions. Exploring the interaction between people and the built environment, this research focuses on the acoustic comfort in indoor spaces, which is **traditionally described by objective, measurable parameters** such as sound insulation, reverberation time, background noise level, and spectrum (DIN 18041, ISO 3382). However, recent research emphasizes that **perceived acoustic quality also depends on human perception, the acoustic environment and the context** (Schulte-Fortkamp, 2023; ISO 12913), leading to the identification of positive soundscape attributes that foster satisfaction, productivity, and recovery (Ajiboye, 2024). This research expands the framework of acoustic evaluation by **integrating psychoacoustic and perceptual dimensions into the assessment of spaces for speech and communication**. The targeted spaces are educational premises with volumes below 300 m³, such as classrooms and lecture halls. Architectural features - geometry, volume, design and materials - are characterized by objective and perceived acoustic attributes, the relationship of which can be described by psychoacoustic parameters.Based on the findings, a model and new rating scale for assessing acoustic quality of rooms for speech and communication will be developed, accompanied by methodological guidelines for application in architectural design of educational facilities, forming a foundation for more comprehensive building typologies.



> *Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it.*
>
> H. James Harrington

H1 Standardi vrednovani trenutnom regulativom nedovoljno određuju zvučnu kvalitetu prostorija za govor / The standards evaluated by the current regulation do not sufficiently determine the sound quality of speech rooms

H2 poželjne karakteristike zvučnog okoliša prostorija za govor komunikaciju se razlikuju od prostora za izvođenje / desirable characteristics of the acoustic environment of speech communication rooms differ from those of performance spaces

H3 akustička kvaliteta specifičnih namjena prostorija za govor i komunikaciju za posljedicu ima bolju motivaciju i učinkovitost / the acoustic quality of specific purpose rooms for speech and communication results in better motivation and efficiency

Q1 Koja je korelacija između arhitektonskih obilježja i fizikalnih parametara s psihoakustičkim deskriptorima? / What is the correlation between architectural features and physical parameters with psychoacoustic descriptors?

Q2 Koji psihoakustički deskriptori karakteriziraju optimalan zvučni okoliš prostora za govor (obrazovnih ustanova) u odnosu na kontekst i korisnika? / What psychoacoustic descriptors characterize the optimal sound environment of speech spaces (educational institutions) in relation to the context and the user?

Q3 Koji su optimalni rasponi psihoakustičkih parametara u učionicama i predavaonicama? Kojim arhitektonskim intervencijama se postižu poželjni psihoakustički parametri? / What are the optimal ranges of psychoacoustic parameters in classrooms and lecture halls? What architectural interventions achieve the desired psychoacoustic parameters?

O1 Usporedba postojećih prostorija obrazovnih namjena s današnjim standardima i analiza akustičke kvalitete / Comparison of existing educational facilities with today's standards and analysis of

O2 Istraživanje i analiza psihoakustičkih parametara koji imaju utjecaj na percepciju prostorija za govor (učionica / predavaonica) / Research and analysis of psychoacoustic parameters that influence the perception of speech rooms (classrooms / lecture halls)

O3 Uspostava metodologije za izračun i evaluaciju psihoakustičkih parametara; prepoznavanje arhitektonskih obilježja prostora koja imaju utjecaj na percipirani zvučni okoliš / develop a methodology for calculating and evaluating psychoacoustic parameters; identify architectural features of spaces that have an impact on the perceived sound environment

Pojmovnik / Glossary

Prostori za govor i glazbu u akustici označavaju različite tipove prostora oblikovane prema primarnoj namjeni zvuka. **Prostori za govor i komunikaciju**, prema normi DIN 18041, (prema ISO 3382-2 nazivaju se obične prostorije) projektiraju se tako da osiguraju visoku razumljivost govora kroz kontrolu vremena odjeka i primjenu apsorpcijskih elemenata, čime se postiže jasno prenošenje govorne poruke, informacijska točnost, minimalna jeka i pozadinska buka.

Speech and music rooms in acoustics refer to different types of rooms designed for the primary purpose of sound. According to DIN 18041, **rooms for speech and communication** ("ordinary rooms" in ISO 3382-2) are designed to ensure high speech intelligibility through the control of reverberation time and the use of absorption elements, which achieves a clear transmission of the spoken message, information accuracy, minimal echo and background noise.

Prostori za glazbu, prema DIN 18041, u ISO 3382-1 nazivaju se prostori za izvođenje, te se projektiraju tako da omoguće punoću, prostornost, toplinu i jasnoću glazbenog zvuka, uz dulje vrijeme odjeka i kontrolirane refleksije. Time se osigurava prirodan i bogat doživljaj glazbene izvedbe u odnosu na zahtjeve prostora za govor.

Music rooms, according to DIN 18041 ("performance spaces" in ISO 3382-1), and are designed to provide fullness, spaciousness, warmth and clarity of musical sound, with a longer reverberation time and controlled reflections. This ensures a natural and rich experience of musical performance in relation to the requirements of a speech room.

Psihoakustika je znanstvena disciplina koja se bavi proučavanjem psiholoških i fizioloških reakcija na zvuk, koja povezuje fizička svojstva zvučnih valova s ljudskim doživljajem (percepcijom) zvuka.

Psychoacoustics is a scientific discipline that deals with the study of psychological and physiological reactions to sound, which connects the physical properties of sound waves with the human experience (perception) of sound.

Glasnoća (N) [son], je najčešće korišteni parametar koji se koristi za opisivanje zvukova te može služiti kao mjera percepcije količine zvučne energije u uhu odnosno u ljudskom mozgu. Glasnoća je međunarodno normirani objektivni akustički parametar.

Loudness (N) [sone] is the most commonly used parameter used to describe sounds and can serve as a measure of the perception of the amount of sound energy in the ear or in the human brain. Loudness is an internationally standardized objective acoustic parameter.

Oštrina (S) [acum] je parametar koji služi kao mjera količine visokih frekvencija u spektru nekog zvuka (u smislu da se može reći da zvuk s većim intenzitetom visokih frekvencija zvuči oštrije) te je normiran isključivo u Njemačkoj.

Sharpness (S) [acum] is a parameter that serves as a measure of the amount of high frequencies in the spectrum of a sound (in the sense that it can be said that a sound with a higher intensity of high frequency sounds sharper) and is standardized exclusively in Germany.

Grubost (R) [asper] je parametar koji mjeri percepciju "brze" modulacije, amplitudne ili frekvencijske, prisutne u nekom zvuku. Osjet grubosti zvuka nije ograničen samo na stvarno modulirane zvučne signale, već može biti prisutan i kod zvukova koji nisu modulirani, ali svojim međudjelovanjem stvaraju dojam brze promjene amplitude ili frekvencije ukupnog signala; brza modulacija.

Roughness (R) [asper] is a parameter that measures the perception of "rapid" modulation, either amplitude or frequency, present in a sound. The sensation of roughness of sound is not limited to truly modulated sound signals, but can also be present in sounds that are not modulated, but whose interaction creates the impression of rapid changes in the amplitude or frequency of the overall signal; fast modulation.

Tonalitet (T) [tu] je psihoakustički pokazatelj koji identificira tonove koji se pojavljuju u odnosu na pozadinsku buku kako bi se odredio njihov doprinos percepciji zvuka. Tonalitet akustičnog izvora jedna je od glavnih metrika koje se općenito promatraju za poboljšanje kvalitete zvuka proizvoda, zajedno s glasnoćom, oštrinom, hrapavošću i snagom fluktuacije.

Tonality (T) [tu] is a psychoacoustic indicator that identifies emerging tones over background noise to determine their contribution in the perception of a sound. The tonality of an acoustic source is one of the main metrics generally looked at to improve the sound quality of a product, together with loudness, sharpness, roughness, and fluctuation strength.

Jačina kolebanja (F) [vacil] je parametar kojim se mjere promjene amplitude, odnosno razine signala, koje se očituju u kolebanju njegove glasnoće. Za razliku od grubosti, modulacijske se frekvencije, pri kojima je izražen osjet kolebanja glasnoće, kreću od 0 do 20 Hz i u tom rasponu uho percipira amplitudnu modulaciju kao promjenu glasnoće; spora modulacija.

Fluctuation strength (F) [vacil] is a parameter that measures changes in the amplitude, or level, of a signal, which are reflected in fluctuations in its loudness. Unlike roughness, the modulation frequencies, at which the sensation of loudness fluctuations is pronounced, range from 0 to 20 Hz, and in this range the ear perceives amplitude modulation as a change in loudness; slow modulation.

Bočna energija (LF) [-] je akustički parametar koji mjeri količinu rane lateralne zvučne energije (koja dolazi sa strana) u odnosu na ukupnu ranu zvučnu energiju.

Lateral fraction (LF) [-] is an acoustic parameter that measures the amount of early lateral sound energy (that arrives from the sides) relative to the total early sound energy.

Doprinos / Contribution

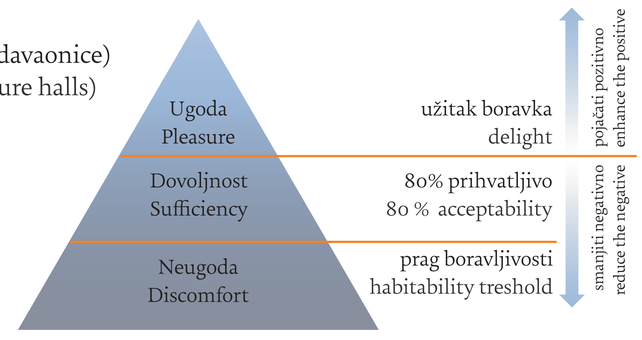
C1 _Procjena postojećeg stanja soundscape-a psihoakustičkim parametrima u prostorijama za govor obrazovne namjene (učionice, predavaonice)
Assessment of the current state of the soundscape using psychoacoustic parameters in educational speech rooms (classrooms, lecture halls)

C2 _Postavljanje mjera za postizanje željene akustičke kvalitete prostorija za govor obrazovne namjene (učionice, predavaonice)
Setting measures to achieve the desired acoustic quality of educational speech rooms (classrooms, lecture halls)

C3 _Razvoj modela za integraciju mjera u procesu projektiranja (od početka planiranja) i rekonstrukcije
Developing a model for integrating measures in the design process (from the beginning of planning) and reconstruction

C4 _Odgovor željenog akustičnog okoliša prostora na suvremene europske politike i inicijative
Response of the desired acoustic environment of the space to contemporary European policies and initiatives

C5_Psihoakustički parametri prostorija za govor obrazovne namjene mogu poslužiti kao temelj za sveobuhvatnije standarde



Altomonte et al., 2020

Konačna procjena optimalne kontekstualne akustičke kvalitete korisnika u kontekstu
Final assessment of optimal contextual acoustic quality for the user in the contex