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PERCEPTUAL OPTIMIZATION OF ACTIVE ACOUSTIC PRESETS VIA ITERATIVE MUSICIAN FEEDBACK

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Abstract

Active acoustic systems whose algorithms are adapted to a room's underlying passive acoustics can effectively modify acoustical conditions without compromising the room's inherent character. This technology is particularly valuable for those rehearsal spaces that are designed to be highly absorbent in order to control sound strength. It can bridge the gap to the concert halls musicians are accustomed to, providing good cross-communication without raising sound strength.

This paper presents a novel study investigating the artistic tuning process of an Amadeus ART Acoustics system in the orchestra rehearsal hall of the Finnish National Opera and Ballet in Helsinki.

Rather than relying solely on objective measurements, the study employed an iterative, musician-driven tuning process. Several rehearsals were conducted with the orchestra, each comparing two different active acoustic settings. Following each cycle, participants completed an adapted questionnaire based on Mike Barron's approach to evaluate room acoustics. By continuously assessing musicians' perceptions and the impact on performance, informed parameter adjustments were made immediately. To maintain plausibility and focus, a maximum of two settings were compared by musicians and conductors.

This gradual process significantly improved both the playing experience and the sonic impression, ultimately increasing consensus among musicians on the final acoustic preset. Statistical analysis of the feedback further provided insights into the evolution of survey criteria and the impact of preset adjustments on instrument sections. These findings offer a valuable and reproducible framework for tuning active acoustic systems in comparable situations.

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1. Introduction

Rehearsal spaces generally differ acoustically from the concert halls or opera houses where performances take place [1]. To prevent dangerously high sound pressure levels and ear fatigue for a full orchestra, these smaller rooms have historically relied on passive damping and absorption [2]. While damping controls the sound strength (G), it strips away the natural early and late response that musicians need for self-audibility, pitch intonation, and cross-communication.

The orchestra rehearsal hall of the Finnish National Opera and Ballet (FNOB) in Helsinki (see Figure 1) suffered from these exact challenges. Musicians described the environment as having an excessively high sound level and highly variable acoustics depending on seating location. Managing a room's G is often far more critical to musician well-being than simply focusing on traditional reverberation time, since in these smaller room volumes excessive G quickly becomes dangerous [3]. Conversely, if a room is overly

Figure 1: Renovated rehearsal hall of FNOB (Photo by Janne Hirvonen / K2S Architects).

damped to keep sound levels safe, the dry environment forces musicians to overplay and force their instruments, which severely degrades tone quality and ensemble cohesion [4]. To solve this, a dual design strategy [5] was implemented by the acoustic consultant: conventional acoustic treatments in combination with an Amadeus ART Acoustics system that restores a natural, variable, and supportive sound field while keeping G down, achieving the precise balance of an ensemble-supportive yet acoustically safe environment advocated in [3].

Active Acoustics Systems (AAS) have evolved to modern digital topologies classified as either in-line, regenerative or hybrid systems [6]. Unlike systems that overlay a synthesized "second room" on the space —often causing unnatural "room-in-a-room" or "double-sloping" perceptual artifacts [7], [8], the geometric approach of the Amadeus ART Acoustics system utilizes a 3D model of the existing architecture to generate early reflections that preserve precise spatial, temporal, and directional relationships before feeding the late diffuse field [9].

While advanced automated algorithms, such as cepstrum-based closed-loop equalization [10], provide a stable, neutral electroacoustic baseline, technical calibration alone cannot guarantee artistic trust or a natural playing experience. To transform a stable system into an environment musicians actually trust, it must undergo an on-site "artistic tuning" phase.

To bridge this gap between objective metrics and artistic satisfaction, this study presents a systematic, musician-centered tuning methodology implemented with the Amadeus ART Acoustics system at the FNOB. By combining A/B comparisons during rehearsals with Barron-style questionnaires [11], subjective performer feedback was systematically captured [12] to establish a fully accepted AAS preset.

2. Experimental Setup

The utilized room is the orchestra rehearsal hall of the FNOB in Helsinki, acoustically redesigned by Akukon Oy[1] and K2S Architects[2] shown in Figure 1.

To establish a controlled baseline for the active enhancement system, nearly 90% of room surfaces were acoustically reshaped or treated. Upper ceiling structures were shaped into convex, semi-absorptive profiles, while lower sections directly above the orchestra were fitted with flat, semi-reflective perforated plasterboard to scatter early reflections and eliminate timbre coloration. Concurrently, side walls were reprofiled with convex diffusers to enhance lateral energy dispersion, while the rear wall was heavily damped to provide greater flexibility for the active extension of the room. These treatments lowered the natural mid-frequency reverberation time (T60) to a highly controlled 0.5 s to 0.6 s compared to the

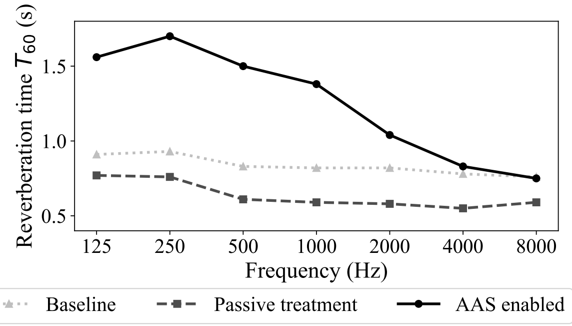

Figure 2: Reverberation time: disabled/enabled AAS.

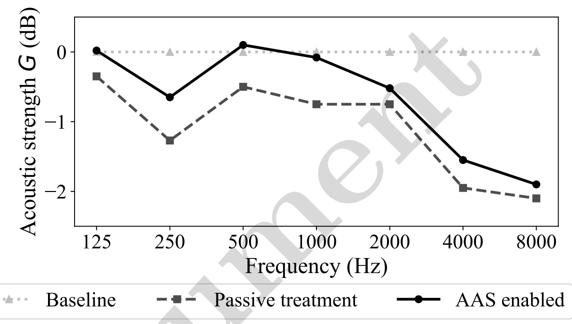

Figure 3: Acoustic strength: disabled/enabled AAS.

initial baseline of 0.8 s (see Figure 2). Additionally, it reduced the room's natural G by 0.5 dB to 2.0 dB at mid frequencies (see Figure 3).

2.1. Active acoustic setup

To decouple the late reverberation time from the room's physical loudness while providing controlled geometric reflections for improved cross-communication and spatial impression, an Amadeus ART Acoustics system was integrated into the acoustically dry passive room. The system captured and processed the hall's natural sound field using 25 microphones and 119 loudspeakers (Figure 5).

When activated, the system extended the mid-frequency reverberation time from its passive 0.6 s to 1.4 s (Figure 2), while adding a negligible 0.5 dB to the overall G (Figure 3). Because this electronic increase was small, total G remained below the original, unrenovated baseline, confirming that the system decoupled late reverberant energy from physical loudness. These changes are also reflected in the acoustic clarity

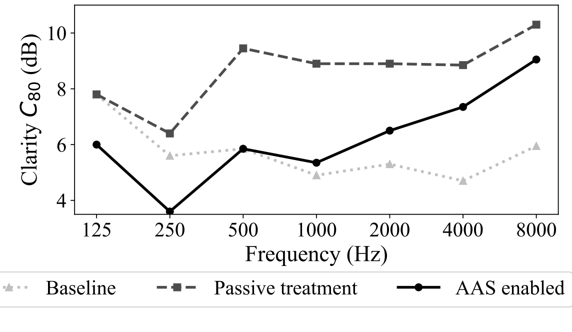

Figure 4: Acoustic clarity (C80): disabled/enabled AAS.

[1]https://akukon.fi/
[2]https://k2s.fi/

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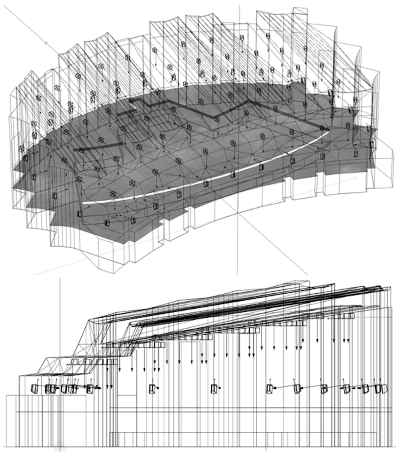

Figure 5: Sketch of loudspeaker and microphone layout.

(C80, Figure 4): the passive-only treatment improved clarity across all bands through the added absorption, while activating the AAS introduced late reflections that reduced measured C80 - though at mid and high frequencies, values remained close to the baseline.

Both the orchestra and venue management required a single, optimized acoustic setting for daily rehearsal use rather than multiple user-selectable scenarios. Two concepts were initially compared: Setting A applied a symmetrical extension of the room's diffuse decay, compensating for the missing late reverberant energy of the dry room; Setting B instead applied a pronounced geometric extension toward one side of the room, keeping the stage area relatively dry while using controlled geometric reflections to improve lateral communication between musicians. Subsequent optimization proceeded from the asymmetric concept.

2.2. Tuning procedure

The transition from the physically treated rehearsal room to an optimized AAS environment followed a structured measurement, simulation, calibration, and evaluation process. Initial room impulse response measurements were conducted by Akukon Oy in the original hall to identify critical reflection paths and establish an accurate and calibrated Odeon[3] room acoustic model. Following completion of the physical renovation, the AAS was commissioned through a multi-stage technical tuning process.

2.2.1. Technical tuning

The procedure began with loudspeaker calibration, deployment of the geometric venue model, and configuration of target reflection patterns and reverberation characteristics. Passive Loop Tuning was then applied to characterize individual loudspeaker–microphone transfer paths without active feedback; based on the measured impulse responses, the system automatically derived level corrections and parametric equalization filters to achieve the target response.

Subsequently, Active Loop Tuning optimized the frequency response of the running feedback system, minimizing narrow-band resonances, increasing loop stability, and ensuring uniform, natural decay across the frequency spectrum.

[3]https://odeon.dk/

2.2.2. Artistic tuning

After technical commissioning, the system entered an iterative artistic tuning phase involving orchestra rehearsals, individual feedback, and comparative evaluation of acoustic presets. Adjustments focused on late energy distribution, spatial weighting, reverberation characteristics, and the balance between stage support and overall room impression. Optimization also included adapting the physical seating arrangement to strengthen the interaction between musicians and the extended acoustic environment.

Final verification measurements under typical rehearsal conditions confirmed a stable mid-frequency reverberation time of approximately 1.4 s while maintaining controlled overall sound strength. Following multiple cycles of objective measurement, subjective evaluation, and artistic refinement, the musicians and conductors agreed on the final acoustic settings.

2.3. Feedback form

Rather than a single overall rating, key attributes like clarity, reverberation, and envelopment are judged as distinct perceptual dimensions, since standardized, spatially averaged descriptors like ISO 3382-1 [13] cannot capture performers' location-dependent perception (early reflections, spatial energy distribution, instrumental response on stage). This work extends Barron's listener-oriented set [11] to performers on stage, adding criteria for ensemble communication, self-perception, and instrument interaction.

The resulting questionnaire comprised nine parameters - **clarity**, **balance (sectional)**, **balance (overall)**, **reverberation (appropriateness)**, **reverberation (quality)**, **envelopment**, **warmth and presence**, **instrumental response**, and **overall impression** - each rated 1 (poor) to 5 (excellent), with an optional comment field.

To limit memory bias, ratings were collected via direct pairwise comparisons: identical excerpts were performed under two alternating AAS configurations across four rounds. Comments were cross-referenced with system parameters to guide adjustments to reverberation, spatial weighting, and delay structures, and further refined through post-rehearsal discussions among musicians, conductor, acoustic consultants, and the Amadeus engineering team, distinguishing global from section-specific needs.

3. Results

This section reports mean questionnaire ratings per criterion, round, and instrument section, followed by an excerpt of subjective musician feedback.

3.1. Statistical evaluation

On average, 64 musicians rated each preset per round; since responses were anonymous and unlinked

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Table 1: Number of respondents per setting (A-H).

	Strings	Woods	Brass	Perc.	Other	**All**
A	38	9	9	5	2	**63**
B	37	9	9	5	2	**62**
C	38	9	10	5	2	**64**
D	37	9	10	5	2	**63**
E	39	9	10	5	2	**65**
F	39	9	10	5	2	**65**
G	38	9	10	5	2	**64**
H	40	9	11	4	2	**66**
All	**306**	**72**	**79**	**39**	**16**	**512**

across settings, differences were assessed as independent samples (Table 1 gives sectional respondent numbers). Rating differences were assessed using two-sided Mann-Whitney U tests, with p-values corrected within each family of simultaneously reported tests (values below 0.05 were significant). Effect sizes were quantified via the rank-biserial correlation r and classified with Cohen's correlation-coefficient thresholds.

3.1.1. Criteria ratings

Figures 6-9 show mean ratings of all nine criteria as radar charts across the four rounds. In round 1 (Figure 6), symmetric preset A is compared against asymmetric preset B; B rates marginally higher across all criteria except warmth and presence, with a composite average of 3.90 vs. 3.84. No criterion reaches significance ($p > 0.05$); only clarity shows a small effect ($r = 0.109$).

In round 2 (Figure 7), presets C and D show only slight, non-significant differences ($p > 0.05$), with a small effect for reverberation (appropriateness) ($r = -0.164$). Beyond minor AAS adjustments, a seating change likely dominated the results of round 2: round 1 placed woodwinds centrally, supporting cross-communication and sectional balance, while in round 2 they were moved out to the far-left, likely lowering both ratings. Comparing round 1 to round 2, sectional balance and envelopment differ significantly ($p < 0.05$); the small negative effect on the composite ($r = -0.107$) is consistent with this round-to-round dip.

Round 3 (Figure 8) shows a significant improvement over round 2 for both presets ($p = 0.04$), coinciding with a return to the original seating arrangement. Preset E increased the reverberation decay time, whereas preset F only raised the AAS level. Preset E rates marginally higher overall; no criterion reaches significance, though small effects appear for reverberation (appropriateness) and overall impression, suggesting the longer decay benefited musicians more than a higher AAS level alone. Preset E's 0.2 s longer decay was therefore adopted as the basis for round 4.

In round 4, ratings improve further; as in the previous rounds, no criterion differs significantly between the two presets. Comparing round 3 to round 4, however, sectional balance differs significantly (p = 0.01). Setting H rates higher across all criteria except reverberation (quality) and sectional balance, though none of these differences reach significance; envelop-

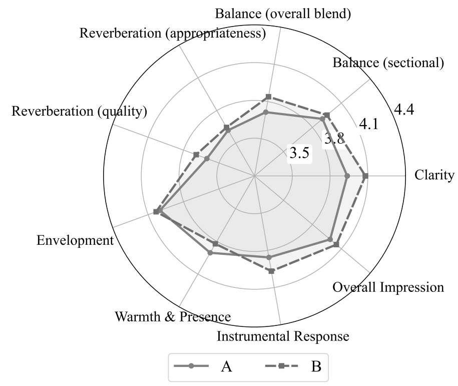

Figure 6: Round 1 mean ratings for settings A and B.

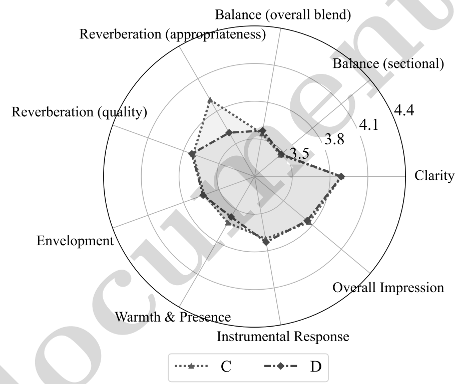

Figure 7: Round 2 mean ratings for settings C and D.

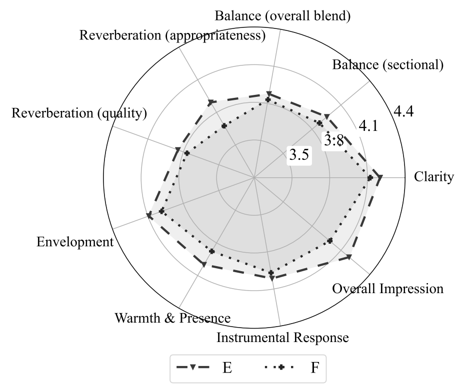

Figure 8: Round 3 mean ratings for settings E and F.

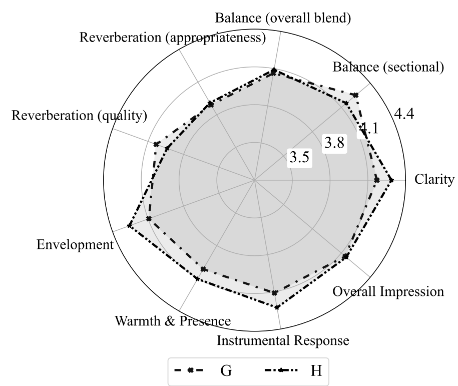

Figure 9: Round 4 mean ratings for settings G and H.

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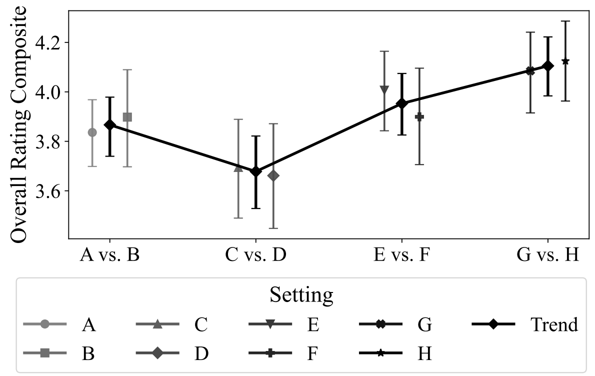

Figure 10: Mean ratings and 95% CI per session.

ment shows the largest movement ($r = 0.132$, small effect). Only minor preset adjustments were made in round 4, targeting inner- and cross-sectional communication via small changes to the AAS's geometric configuration: one setting refined the cross-sectional feed, the other only slightly adjusted the geometry. These marginal changes are weakly reflected in the ratings, but still detectable.

3.1.2. Overall rating composite

With excellent internal consistency (Cronbach's $\alpha = 0.939$), each respondent's nine ratings were averaged into a single composite score per setting and round. Figure 10 shows the per-setting composite means with 95% bootstrap confidence intervals; the black line connects the pooled means across the four rounds.

Within any single round, no significant difference was found between the two compared presets ($p > 0.05$, $r < 0.10$ throughout), consistent with the per-criterion results above. Across the 36 within-round comparisons (9 criteria × 4 rounds), none reached significance, confirming that no preset was ever judged conclusively better than its counterpart on a given comparison round.

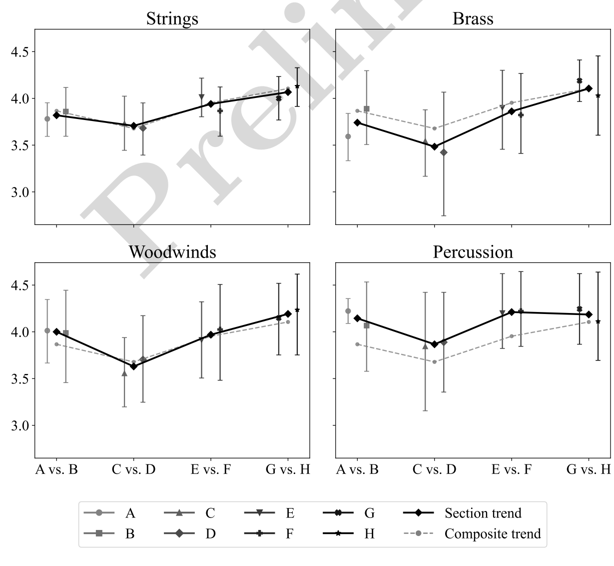

Figure 11: Mean ratings and 95% CI per section.

Across rounds, however, a clear trend emerges: the pooled composite dips to its lowest value in round 2 (3.68) before rising to its highest in round 4 (4.11). At the level of individual presets, D is lowest-rated (3.66) and H highest-rated (4.13). Comparing every individual preset directly against H (BH-corrected across all 28 preset-pair comparisons — a separate, more granular correction scope than the round-level trend above), presets A, C, and D differ significantly from H ($p_{AH} = 0.048$, $p_{CH} = 0.048$, $p_{DH} = 0.041$), with medium effect sizes ($r_{AH} = 0.305$, $r_{CH} = 0.307$, $r_{DH} = 0.325$). This indicates a medium-sized improvement in the performance experience over the course of the tuning process. Overall, 25 of the 280 pairwise preset comparisons reached significance after correction, concentrated in sectional balance and envelopment and predominantly contrasting the initial presets against the later presets.

3.1.3. Instrument section ratings

Figure 11 shows the evolution of the overall rating composite (not individual criteria) across rounds, broken down by instrument section. The solid line marks each section's own trend; the dashed grey line repeats the overall composite trend for reference.

Strings, the largest section (Table 1, $n = 40$), track the overall trend closely. Woodwinds appear most sensitive to the preset changes, swinging both above and below the overall trend across rounds. Brass rates consistently below the overall trend, suggesting different acoustic priorities than strings and woodwinds. Percussion rates highest on average among all sections but shows no further gain between last two rounds. Because section sizes range from $n = 4$ (percussion) to $n = 40$ (strings), confidence intervals are correspondingly wider for the smaller sections.

As a complementary, standard-based stratification, sections were grouped per ISO 23591:2021 [14] into quiet-acoustic (strings, woodwinds) and loud-acoustic (brass, percussion) categories. The round-1-to-4 composite improvement reaches significance for quiet-acoustic instruments ($r = 0.209$, $p = 0.024$), while the loud-acoustic group does not reach significance ($p = 0.090$) — plausibly a consequence of its smaller sample size, rather than a genuinely weaker effect.

3.2. Subjective evaluation

To capture qualitative dimensions beyond the numerical ratings, participants could add individual comments after the questionnaire and join a brief group discussion.

A prominent theme was the reduction in physical playing effort. Instrumentalists reported playing more freely and with less force; one player noted, *"I found in both settings that I don't need to push for my sound at all. I can play very lightly"*. This was called an *"exceptional difference compared to before, very inviting to play"*, particularly beneficial during long rehearsals. Importantly, this support did not compromise analytical clarity: musicians reported precise

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self-monitoring, with one woodwind player noting it was *"very clear if I have a good reed or bad reed"*.

The system also improved mutual audibility across the large orchestral setup. Participants reported that *"the electronic acoustics significantly enhance the sense of cohesion of the sound produced by all musicians [...] which is beneficial for ensemble playing"*. String players described a *"much better connection to celli and bassi across the room"* and found it *"much easier to play together"*, including demanding tasks like synchronized pizzicatos and precise rhythmic coordination.

Finally, some participants identified a potential conflict between acoustic support and rehearsal realism. One player observed that the simulated environment was *"too good... because in the pit it will be much worse"*. This highlights a trade-off: a fully realistic simulation may be desirable, but a transparent, supportive environment is more effective for analytical rehearsal. Consequently, it was decided not to reproduce the pit acoustics, prioritizing instead a transparent environment where musical details could be clearly evaluated and trained.

4. Conclusion

This study presented an iterative, musician-driven tuning process for an Amadeus ART Acoustics system during orchestral rehearsals at the FNOB. While no significant differences were found between paired presets within individual tuning rounds, the overall listening and performance experience improved significantly from the first to the final round. Comparisons between the earliest presets and the highest-rated preset H yielded medium effect sizes ($r = 0.305$–0.325). A final verification survey conducted after completion of the tuning process yielded an overall satisfaction rating of 4.2/5.0, further supporting the positive progression observed across the four documented tuning rounds.

The tuning process demonstrated that the optimal rehearsal acoustic was not solely determined by the electronic acoustic parameters, but by the interaction between the AAS, room geometry, and musician positioning. The resulting environment provided the perception of a significantly larger acoustic space while preserving the clarity, precision, and sound pressure control required for professional rehearsal work.

This questionnaire-driven framework extends Barron's and Kahle's listener-oriented methodologies to a performer-centered, on-stage context, bridging the gap between rigid ISO 3382-1 parameters and the situational demands of performing musicians. The same structured, pairwise-comparison protocol is transferable to other AAS commissioning projects; parts of it - such as scheduling comparison rounds once technical-tuning convergence criteria are met - could be automated, while musician judgment remains the final arbiter of acceptance.

References

[1] T. Lokki, J. Nummela, and T. Lahti, "An electro-acoustic enhancement system for rehearsal rooms," in *Proc. of the European Acoustics Association (EAA) Symposium on Architectural Acoustics*, 2000.

[2] T. Lokki, J. Pätynen, T. Peltonen, and O. Salmensaari, "A Rehearsal Hall with Virtual Acoustics for Symphony Orchestras," in *Audio Engineering Society Convention 126*, 2009.

[3] J. H. Rindel, "On the importance of sound strength in music rehearsal rooms," in *Proc. of the 48th DAGA Conference on Acoustics*, Stuttgart: Deutsche Gesellschaft für Akustik e.V., 2022.

[4] M. Cairoli, "Wooden Rehearsal Rooms from the Construction Process to the Musical Performance," *Acoustics*, vol. 6, no. 1, pp. 114–133, 2024.

[5] C. Hough, N. Boulter, and S. Tait, "The use of electroacoustic enhancement systems in the design of orchestral rehearsal rooms," *J. Acoust. Soc. Am.*, vol. 157, no. 4, 2025.

[6] W. J. Cassidy *et al.*, "Active acoustic enhancement systems: A review," *J. Acoust. Soc. Am.*, vol. 159, no. 4, 2026.

[7] W. J. Cassidy, P. Coleman, R. D. Mason, and E. De Sena, "Naturalness of double-slope decay in generalised active acoustic enhancement systems," in *Proc. of the 27th International Conference on Digital Audio Effects (DAFx24)*, 2024.

[8] L. Błasiński and J. Kociński, "Perception of reverberation length in rooms with Active Acoustics Enhancement Systems," in *Proc. of the 10th Convention of the European Acoustics Association Forum Acusticum 2023*, Turin, 2023.

[9] V. Werner, S. Neeten, and F. Kaiser, "Evaluation of a Geometric Approach to Active Acoustics," in *Proc. of the Institute of Acoustics*, 2023.

[10] S. Neeten, C. Frischmann, F. Kaiser, and V. Werner, "Objective assessment of coloration in active acoustic systems: Real-room measurements with time-invariant filter equalization," *J. Acoust. Soc. Am.*, vol. 157, 2025.

[11] M. Barron, "Using the standard on objective measures for concert auditoria, ISO 3382, to give reliable results," *Acoustical Science and Technology*, vol. 26, no. 2, 2005.

[12] E. Kahle and J.-P. Jullien, "Subjective Listening Tests in Concert Halls: Methodology and Results," in *Proc. of the 15th International Congress on Acoustics (ICA)*, 1995.

[13] ISO, "Acoustics – Measurement of room acoustic parameters – Part 1: Performance spaces," no. ISO 3382-1:2009. Geneva, Switzerland, 2009.

[14] ISO, "Acoustic quality criteria for music rehearsal rooms and spaces," no. ISO 23591:2021. Geneva, Switzerland, 2021.

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