The Impact of Classroom Acoustics on Student Well-Being and Noise Disturbance at the University of Pescara, Italy

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Abstract

Concerns about noise conditions in schools have led many countries to introduce standards or guidelines for school acoustics design.
The aim of this paper is to investigate the extent to which classroom acoustics affect perceived well-being and noise disturbance at the University of Pescara in Italy. Approximately 100 students aged between 20 and 30 participated in the study, during which room acoustic measurements were taken, and noise levels were monitored in accordance with the national standard UNI 11532. To validate the measurements, a questionnaire was used, following the ISO 12913 standard.
In addition to the empirical study, a numerical model was developed using ODEON, a widely recognized room acoustics simulation software. This model was employed to simulate and analyze the acoustic conditions in the classrooms under various scenarios, providing additional insights into the acoustic environment.
The results of the correlation between subjective responses and objective measurements will be used to design more positive and inclusive learning environments.

1. Introduction

The Indoor Environmental Quality (IEQ) stands as a critical determinant of the holistic educational experience, significantly influencing the well-being, concentration, and performance of students within the confines of school environments (Tahsildoost et al., 2018).

From an acoustic quality standpoint, ensuring adequate speech intelligibility is crucial. Students positioned in the front rows, adjacent to the professor, experience better auditory clarity compared to those seated at the back of the classroom. It is evident that in the rear sections of spacious classrooms, the teacher's voice weakens, and excessive reverberation poses challenges to effective listening (Bin Yahya et al., 2010; Burfoot et al., 2022).
Addressing high background noise levels presents a complex challenge in the context of school buildings. Background noise stands out as a pivotal factor influencing speech intelligibility. Essentially, ambient noise levels (external noise), student behaviour, and noise from internal service equipment significantly contribute to the overall background noise (Bistafa et al., 2000).
The acoustic quality of classrooms can significantly impact students' learning, concentration, and overall well-being (Caniato et al., 2022; Granzotto et al., 2022). An environment that is too noisy or has acoustic issues can compromise the effective transmission of information, negatively affecting teaching activities (Recalde, 2021).
Since most learning activities in classrooms involve oral communication, the intelligibility of spoken words, defined as the percentage of correctly understood speech items in relation to the overall speech, is crucial for successful development (Mealings, 2023; Di Loreto, 2023).
Literature extensively explores students' evaluations of teachers' speech intelligibility. However,

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there is a noticeable research gap regarding teachers' perception of students' speech intelligibility, particularly within the realm of classroom acoustics. In the context of the (Subramaniam, 2019) project, the practice of graduate students routinely conducting presentations and talks in classrooms was examined. This practice is subject to evaluation and grading, contingent on their communication skills and delivery.

In Pellegatti et al. (2023) good acoustic quality in classrooms becomes essential to create an optimal learning environment, in fact in the last year soundscape research in indoor environments has been gaining attention for its potential to contribute to the design of supportive, healthier, and more comfortable spaces.

Visentin et al. (2023) addressed the indoor soundscape of classrooms for primary school children aged 8 to 10 years. Utilizing questionnaires based on pictorial scales, the study explores perceived loudness and affective dimensions such as pleasantness and arousal. Both the actual soundscape and the children's ideal soundscape are investigated. The study reveals that the most frequent sounds in classrooms come from the students themselves, including voices and movements, followed by traffic.

The aim of this study is to identify challenges related to the acoustics of university classrooms using a holistic approach. This approach encompasses not only traditional measurements of acoustic parameters but also psychoacoustic factors, taking into account the subjective perception of students. Throughout the research, a calibrated numerical model was developed using empirical measurements, complemented by a listening test to assess students' satisfaction and perceived pleasantness. The results reveal a significant correlation between objective measurements and the listening test outcomes, providing valuable insights for classroom design. This correlation offers a comprehensive understanding, considering not only conventional acoustic parameters but also students' perception and satisfaction levels, to optimize the acoustic environment of university classrooms. In this work, two sections are included. In the first, the case study, the measurements equipment of the room and the calibration of numeric model are evaluated. In the second section, the outcomes of the simulations are compared with the subjective findings from the acoustic survey conducted in the same classroom.

2. Material and Methods

2.1 Room Acoustics Metrics and Measurements Equipment

The university building is situated in the central area of Pescara city, near road traffic and other environmental noise sources. For the assessment of acoustic quality, the A34 classroom, belonging to the engineering Faculty of the G. D'Annunzio University, was chosen as a case study.

Classroom R-34 has a volume of 771 m^3, an average height of 4 meters and a base area of 192.2 m^2.

The classroom does not have a sound-absorbing acoustic ceiling and has wooden chairs and tables. The windowed surface occupies 1/3 of the total surface of the concrete perimeter walls. Fig. 1 shows the R-34 classroom, and the measurement positions as required by UNI 11532-2:2020 (2020).

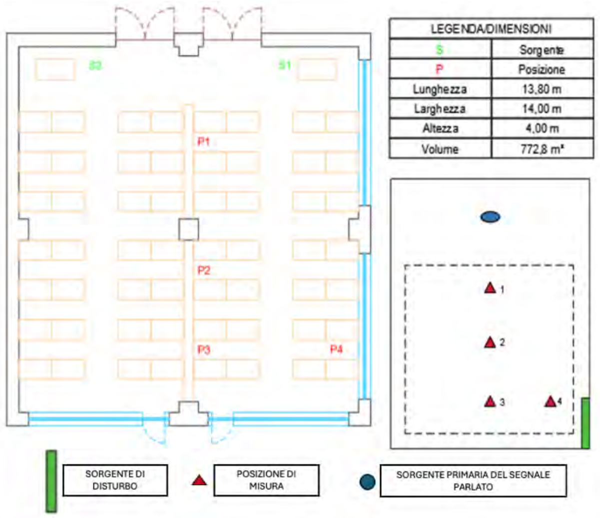

Fig. 1 – Plan of R-34

The equivalent sound pressure level of the noise level of technological systems was measured in accordance with UNI EN ISO 16032 in phase - stationary conditions (ISO, 2005).

The acoustic measurements highlighted: the background noise and the equivalent sound pressure level in the classroom when the mechanical system was on.

The measurement of RT time (T30) was performed according to the ISO 3382-2 standard (ISO, 2008) which requires measurements to be made for at least two source positions and three microphone positions. The measurement of the Speech Transmission Index (STI) was derived from the impulse response measures and background noise measures with the indirect methodology proposed by the EN 60268-16 standard (ISO, 2020).

For the STI parameter, the UNI 11532 standard requires measurements to be made for at least one source position and four microphone positions.

All investigations were carried out using the SAMURAI Room Acoustic commercial software (licensed by SPECTRA S.p.A).

The sound field, in the case of intelligibility measurements, was excited using a self-built directional sound source, NTi-Talkbox, in compliance with 11532, consisting of a speaker with a diameter of 100 mm, powered by an MLS signal; the measurements of the RT time were carried out by means of a dodecahedral source, fed with a line-sweep signal. The acquisition of impulse responses was achieved by taking the output signal of a B&K 2250 sound level meter.

Table 1–3 shows the results of measurements for each measurement point and the STI mean value.

Table 1 – Results of rt measurements by octave bands

Frequency [Hz]	RT-full Classroom [s]	RT occupated by 80% of people [s]
125	2.16	1.71
250	2.57	1.58
500	2.09	1.25
1000	2.12	1.20
2000	2.35	1.15
4000	1.88	1.02

Table 2 – Results of full L_{amb} and L_{int} measurements by octave bands

Frequency [Hz]	L_{amb}-full Class-room [dB(A)]	L_{int}-full Classroom [dB(A)]
125	24.6	36.7
250	33.7	42.8
500	31.9	44.6
1000	32.1	47.9
2000	28.2	47.0
4000	20.2	34.0

Table 3 – Speech transmission index (sti) for sinle point, mean and speech quality in accordance with cei en 60268-16.

Measurments Positions	STI	STI, mean Classroom	Speech quality in accordance with CEI EN 60268-16
P1	0.36	0.26	BAD
P2	0.23		
P3	0.22		
P4	0.22		

The psychoacoustic analysis to evaluate the sound level perception of the classroom was measured in accordance with ISO 532-2 (ISO, 2017) with head and torso simulator B&K, type 4100. The head and torso simulator enables maintaining the shape, size and acoustic impedance of the head and torso of the listener; it is also able to maintain unaltered the directionality of the sound.

Fig. 2 shows the results of measurements for Loudness during the lesson in frequency range from 20 Hz to 20 kHz.

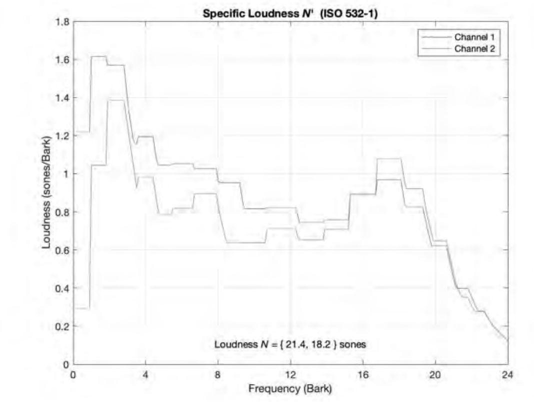

Fig. 2 – Specific Loudness N' (ISO 532-1). Channel 1 is the right ear and Channel 2 is the left ear of the binaural head

Table 4 shows the results of psychoacoustic parameters calculated from the binaural recording.

Table 4 – Psychoacoustic parameters divided into right and left channel

Parameters	Channel 1	Channel 2
Loudness [Phone]	88,3	89,2
Sharpness [Acum]	1,56	1,54
Fluctation Strenght [Vacil]	0,082	0,135
Roughness [Asper]	0,34	0,51

2.2 Questionnaire and Subjective Evaluations

Qualitative analysis was conducted through subjective responses provided by students during a listening test, focusing on their overall impression of acoustic comfort, annoyance, pleasantness, and unpleasantness of sounds, as well as the general environmental comfort encompassing temperature and lighting within the classroom. The questionnaire, developed based on ISO 12914-2 (Aletta et al., 2019) with modifications addressing general comfort aspects, was shared with students during academic lessons. Participants were specifically instructed to describe the sound environment within the classroom and their experiences during lessons. The questionnaire was administered in Italian, and the ensuing results highlight significant and distinctive elements identified throughout the evaluation. The decision to carry out the analysis in Italian underscores the emphasis on capturing participants' subjective experiences within their specific cultural and linguistic context.

Fig. 3 shows the results of the subjective investigation about participants.

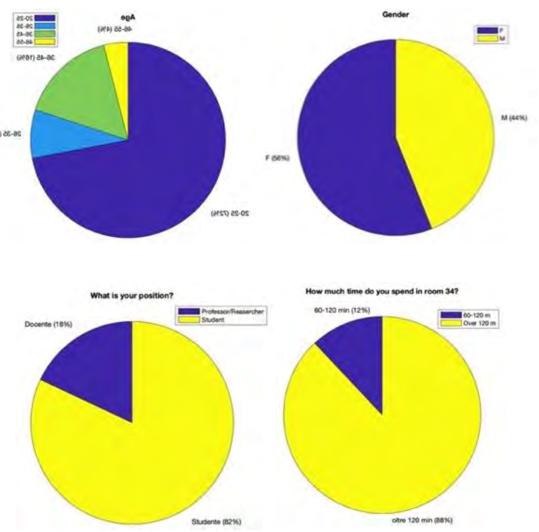

Fig. 3 – Demographic characteristics pie chart

A total of 98 respondents completed the questionnaire. Most of the respondents came from students (82%). Other respondents were from a professor and researcher (18%). The majority (62%) reported visiting room 34 every day, the minority (6%), reported irregular visits.

The overall perceived acoustic quality of the sound landscape is low, as participants rated it an average of 2.1 on a scale from 1 to 5.

Specifically, 56.2% of participants reported poor acoustic quality, 19.5% indicated it as sufficient, and only 4.9% characterized it as good.

These findings indicate a notable discrepancy between objective measurements of background noise, which comply with regulations, and the subjective perception of individuals, who did not express a positive judgment.

3. Results and Discussion

3.1 Statistical Analysis

Considering the results of simulations and according to the background literature, a statistical analysis was conducted for the case study. The proposed correlation model between the measurements of acoustic quality versus the subjective test response is based on a polynomial function, according to the following Eq. 1:

$$y = ax^3 + bx^2 + cx + d \qquad (1)$$

Where:
- Y represents the subjective test response,
- X denotes the acoustic quality measurements,
- a,b,c,d are the coefficients of the polynomial function.

This polynomial model was selected based on its versatility in capturing non-linear relationships, and Eq. 1 provides a mathematical expression to quantify the correlation observed in the case study.

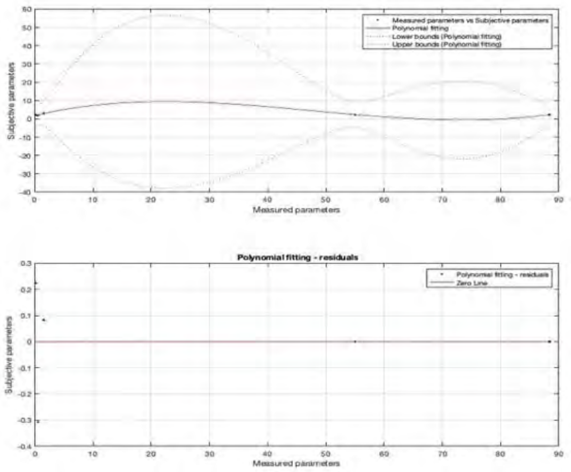

Fig. 4 – Best fit polynomial curve and residuals of the measured value vs subjective value

Table 5 – Result of the polynomial regression

DFE	SSE	R^2	adRs	RMSE
1	0.17	0.81	0.14	0.28

The result of the correlation shows the statistical significance is indicated by the $R^2 = 0.89$ and this represents a good correlation between the variables (Fig. 4; Table 5).

This data shows interesting relationships offering a nuanced understanding of the complex interplay between measured acoustic quality and subjective responses.

Despite the objective measures in accordance with the background noise legislation, there is a significant discrepancy with the subjective perceptions of the participants. For example, although a relatively low percentage of participants rated the acoustic quality as poor, subjective data shows a positive correlation with objective measurements. This indicates the complexity of interpreting acoustic quality based solely on technical measurements, suggesting the need to also consider the subjective perspective of individuals. The correlation between measurement data and listening test results provides a more comprehensive and multifaceted picture of the acoustic quality of the soundscape, underlining the importance of an integrated approach to acoustic analysis.

3.2 Numerical Model

In order to create positive and inclusive learning environments, a simulated model utilizing ODEON room acoustic software was developed. The process began with calibrating the model through measurements acquisition. This involved applying absorption coefficients to a geometric model, which, in turn, simulated the acoustic phenomena using a ray tracing algorithm. ODEON's material optimization system employs eight independent genetic algorithms, each corresponding to a specific octave band. The algorithm initiated with a random step, generates individuals in the population with varying absorption coefficients within a user-defined range, forming an initial generation. The evolutionary process ensues, filtering and selecting the best individuals as parents to produce offspring inheriting advantageous traits. This iterative process continued until solutions converge based on predefined criteria. The calculation persists until reaching a solution minimizing errors, aiming to reduce them to a minimum, though not necessarily achieving perfection. In the case study simulations, a tuning process adjusted absorption coefficients of the temple structure to ensure simulated average reverberation times closely matched on-site measurements, with a deviation of no more than 1 JND (5%) for each octave band frequency. In Fig. 4 are reported the best fitting and last error decrease between measured and calibrated absorption in the frequency range from 125 to 4000 Hz (Fig. 5).

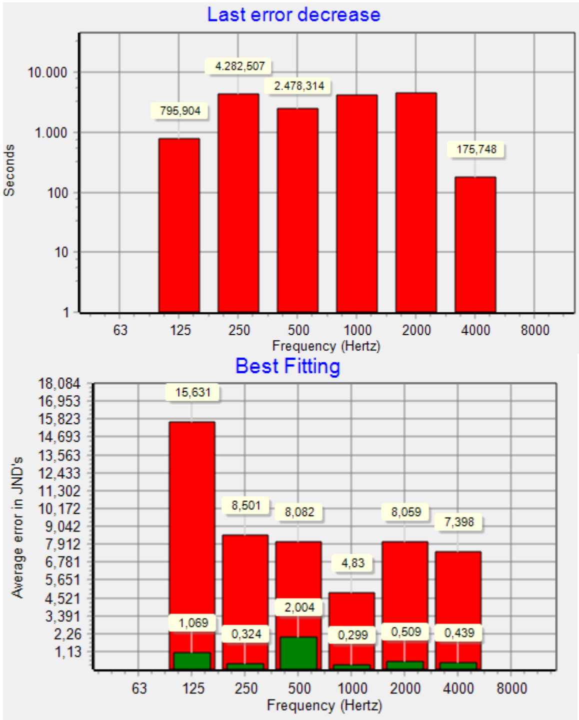

Fig. 5 – Best fitting and last error decrease of the GA model

Table 6 presents the main absorption coefficient values used in the simulations after the described correction.

Table 6 – Absorption coefficient after calibration with GA in Odeon from 125 Hz to 4 KHz

Material	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Windows	0.418	0.127	0.153	0.031	0.016	0.019
Plaster	0.043	0.020	0.030	0.047	0.039	0.030
Desks	0.161	0.148	0.150	0.161	0.124	0.146
Doors	0.309	0.138	0.106	0.007	0.026	0.016
Floor	0.011	0.012	0.053	0.042	0.052	0.033

Fig. 6 shows the result of the reverberation time after calibration and measurement.

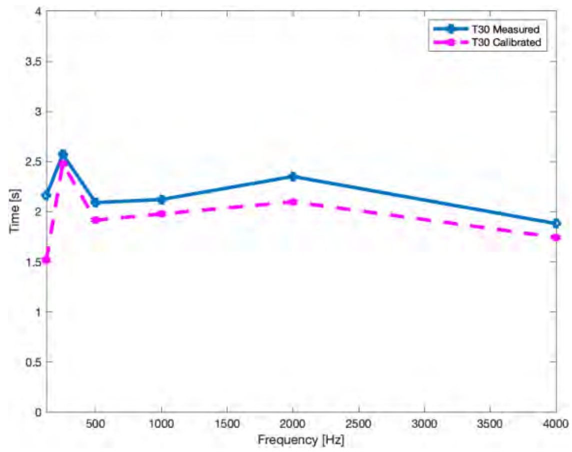

Fig. 6 – R34 simulation: T30 measured vs calibrated

The implemented process played a crucial role in formulating acoustic correction solutions. Notably, it was decided to introduce a 40 cm acoustic baffle with predetermined absorption coefficients, adhering to the UNI 11532-2 standard.

Fig. 7 shows the result of the reverberation time after acoustic correction and calibrated model.

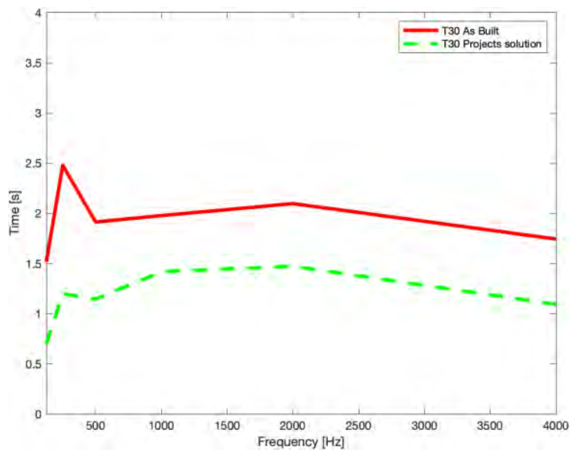

Fig. 7 – R34 simulation: T30 acoustic correction vs calibrated

By implementing the simulated model using ODEON room acoustic software, calibrated with meticulous measurements and an evolutionary process guided by genetic algorithms, we aimed to create more positive and inclusive learning environments. The extensive efforts involved in simulating acoustic phenomena, fine-tuning absorption coefficients, and minimizing errors have culminated in a successful outcome.

By strategically incorporating a 40 cm acoustic baffle with well-defined absorption coefficients, in accordance with the UNI 11532-2 standard, the acoustic correction solutions were thoughtfully chosen. As a result of these interventions, the room's acoustics have now reached an optimal state.
This is verified also to evaluate the intelligibility in the simulated R34 room.
Table 7 shows the result of STI for single points in room R34 after the acoustic correction.

Table 7– Speech transmission index (sti) for single point, mean and speech quality in accordance with cei en 60268-16

Measurements Positions	STI	STI, mean Classroom	Speech quality in accordance with CEI EN 60268-16
P1	0.65		
P2	0.62	0.61	EXCELLENT
P3	0.60		
P4	0.59		

The meticulous approach to this process has allowed us to accomplish our intended goal of creating an environment that not only meets but surpasses the desired acoustic standards, contributing to a more conducive learning atmosphere.

4. Conclusion

The study emphasizes the importance of incorporating subjective perspectives into the design of educational spaces, surpassing mere adherence to acoustic regulations. Utilizing acoustic simulations, specifically with ODEON, the environment was tailored based on loudness—an objectively measured parameter. This approach, centred on objectively evaluating environmental pleasantness, yielded more robust outcomes. Designing classrooms to meet both regulatory requirements and incorporate subjective considerations, particularly through loudness management, proved effective in creating spaces that transcend silence, fostering a pleasant and reassuring atmosphere.
Future research will focus on implementing and refining this approach. The study's scope will extend to the entire university campus for a comprehensive evaluation. Hearing tests will be repeated, adjusting methodologies based on initial results. This extension will strengthen conclusions, providing a solid foundation for designing and optimizing academic environments. The goal is to integrate practices that consider acoustic subjectivity, contributing to environments that meet technical regulations and user-perceived needs.

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