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Objective and Subjective Assessment of PET-Felt Recycled Panels as An Acoustic Treatment in the Meeting Rooms

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ABSTRACT

This study presents the performance of the PET-felt recycled panels for the room acoustic treatment. As the objective parameters, Reverberation Time (RT) and Speech Transmission Index (STI) were measured with B&K DIRAC, an omnidirectional loudspeaker, and power amplifier in the meeting room at the Department of Interior Design, Bilkent University, Ankara, Turkey, before the acoustic treatment. Following ISO 12913-2 Method A, Perceived Affective Quality (PQA), Appropriateness, and Assessment of the Acoustic Environment were measured. Fifteen participants who were occupants of the meeting room were selected for the questionnaire survey to be conducted using the snowball method. The findings showed that the reverberation time was five seconds at 1 kHz, which is insufficient, and the acoustic quality could have been better for the speech-purpose room. PET-felt recycled acoustic panels were applied to the ceiling and walls as a solution. After the acoustic treatments, all procedures were repeated with the same. The results showed that significant improvements have been provided in both objective and subjective assessments. RT was in the optimum range. The participants found the meeting room with PET-felt recycled panels more pleasant and eventful after the acoustic treatment.

1. INTRODUCTION

Acoustic deficiencies due to lack of absorption in indoor spaces may sometimes render significant buildings unfit for their purpose, especially the ones used as speech auditoria. A person perceives the acoustic quality of space on three different levels: aesthetically represented by the architecture, ergonomically by the spatial layout, and functionally relating

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to how well the sound waves are transmitted into space (Fuchs, 2013). Acoustic comfort is the perceived state of well-being and satisfaction with the acoustic conditions in an environment (James,1994). The goal of achieving acoustic comfort, which is both a qualitative and quantitative procedure, is the reduction of possible variables that can provoke discomfort in occupants. For instance, to reduce noise levels outdoors and indoors, a quantitative evaluation of parameters, such as sound insulation and sound absorption coefficients of building and finishing materials, is considered (Antoniadou, 2017).

When sound enters or originates in a space, its behavior is affected by the room materials and volume. The hardness and the stiffness of bare materials used as finishes (stone, metal, glass, and plaster) in the built environment cause the repeated reflectance of the soundwaves, resulting in auditory problems such as high reverberation and amplified noise, especially in schools and offices (Puglisi et al., 2021). Issues related to acoustic comfort seem to be the rule rather than the exception in indoor education environments, making them unfit for their purpose (Topak & Yilmazer, 2022; Bottalico et al., 2020)

For speech purposes, it is equally crucial to ensure good speech intelligibility for the audience and prevent the excessive vocal effort of the speaker (Alfolsi et al., 2012). Speech intelligibility, defined as the percentage of correctly understood speech items compared to the overall, is directly affected by Reverberation Time (RT) and speech signal-to-noise ratio (SNR) (Zang et al.). It is empirically measured with acoustic parameters such as the Speech Transmission Index (STI) and Clarity (C50). Various acoustic treatments, such as absorbers and diffusers, can control RT. The formers are adequate for reducing the reverberant sound level, while the latter permits uniformly distributed sound energy in the room (Cox & D'Antonio, 2017). On the other hand, resonant structures are usually used to treat low-frequency problems (Fasllija & Yilmazer, 2023). These reactive structures are mass-spring systems with damping to absorb the system's resonant frequency.

The literature shows that the models continue in the field of engineering. However, there needs to be more information about the transition of these models in architectural applications and their performance. This study presents the performance of the PET-Felt recycled panels for the room acoustic treatment.

2. MATERIALS AND METHOD

This study starts by explaining the production of PET-Felt recycled acoustic panels. It follows the measurement of the meeting room in the real environment before and after the acoustic treatment. Further, to validate the efficiency of PET-Felt recycled acoustic panels in different conditions, the simulation of the meeting room, supported by ODEON Room Acoustic software, is also provided. In addition to the objective measurements, Perceived Affective Quality (PQA), Appropriateness, and Assessment of the Acoustic Environment were measured subjectively by 20 grad students and instructors using the space recently.

2.1. PET-Felt Recycled Acoustic Panels

Production of PET-Felt recycled acoustic panels gives PET packing wastes a second chance; all products are made of approximately 50% recycled PET and premium polyester fibers with no chemical binders (Figure 1). All production processes and supply chains target the use of safe, non-toxic, antibacterial, and healthy raw materials by using renewable energy resources.

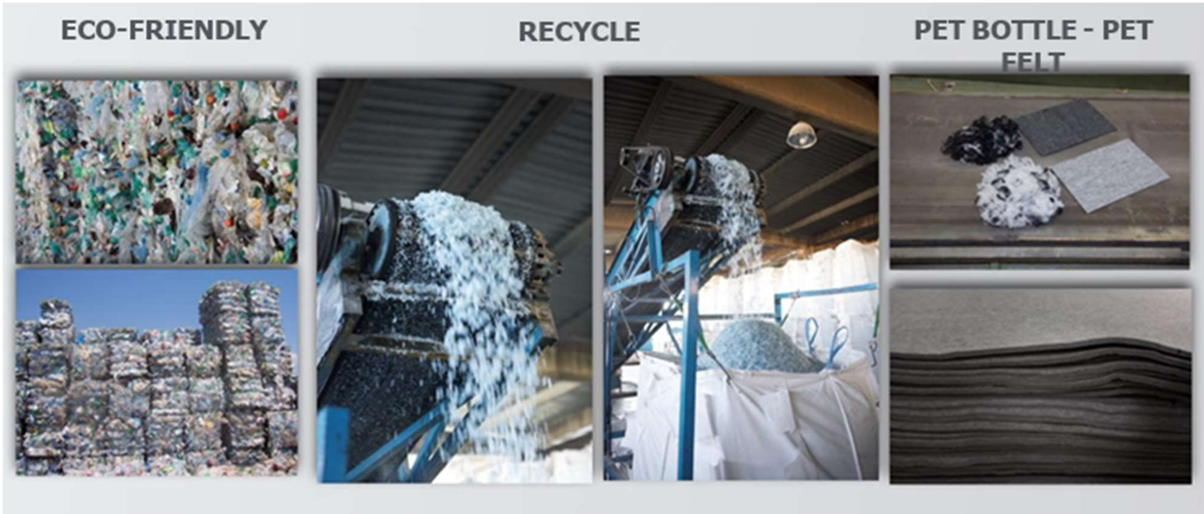

Figure 1: The production process of the PET-Felt recycled panels (Feltouch, 2024).

PET-Felt products are thoroughly tested using internationally recognized standard test methods to ensure high acoustic performance. The products are rated according to ISO 11654 and EN 354, as well as ASTM C423, at accredited laboratories (Figure 2). It ensures that the customers receive reliable and consistent acoustic results from the products (Feltouch, 2024).

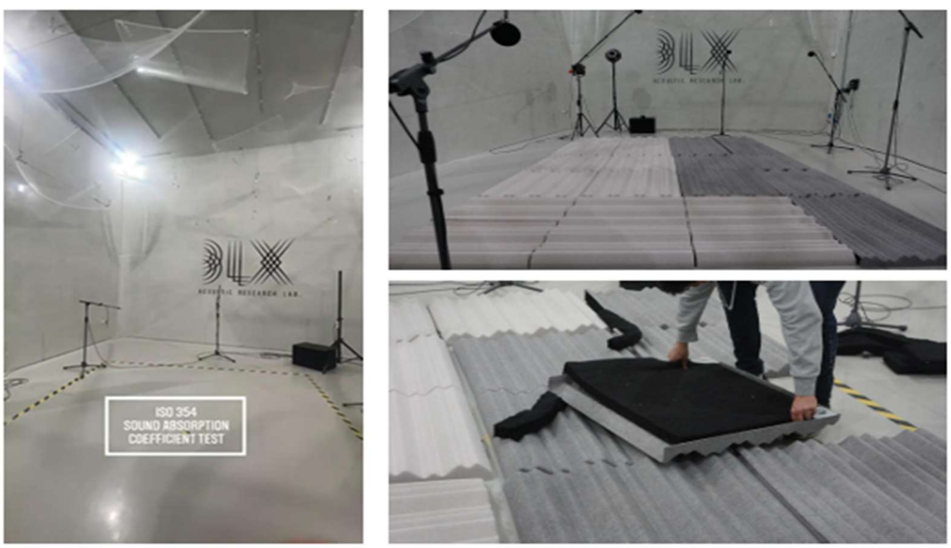

Figure 2: A view from the accredited laboratories to measure Reverberation Time (RT) at different frequencies, based on EN 354 and ASTM C423.

2.2. Settings of the Meeting Room

The meeting room in the Department of Interior Architecture and Environmental Design at Bilkent University was chosen (Figure 3). This room lacks acoustic treatments and has dimensions of 10.12 m length and 5.47 m width, with a height of 3.6 m and a suspended ceiling measuring 0.5 m. It is designed as a meeting room exclusively used by graduate students. Four cracker clouds on the ceiling (Figure 4) and six 3D panels on the wall (Figure 5), recycled from PET and processed with felt materials, were used to achieve better speech intelligibility. The

Noise Reduction Coefficient (NRC) is 0.75 for that recycled panel used on the ceiling and wall in the meeting room.

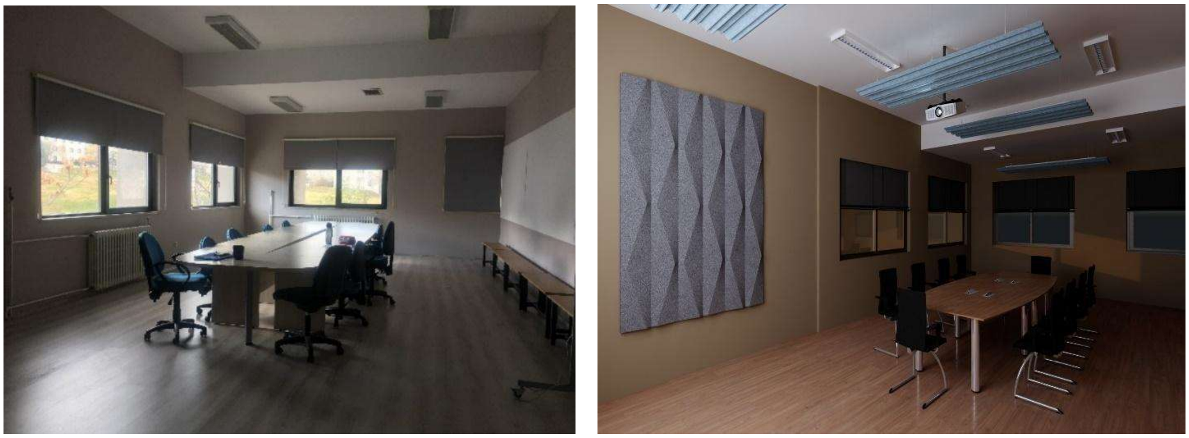

Figure 3: A view from the meeting room (Author) (Left) and 3D view simulation of the PET-Felt recycled acoustic panels both on the wall and ceiling (Feltouch, 2024) (Right)

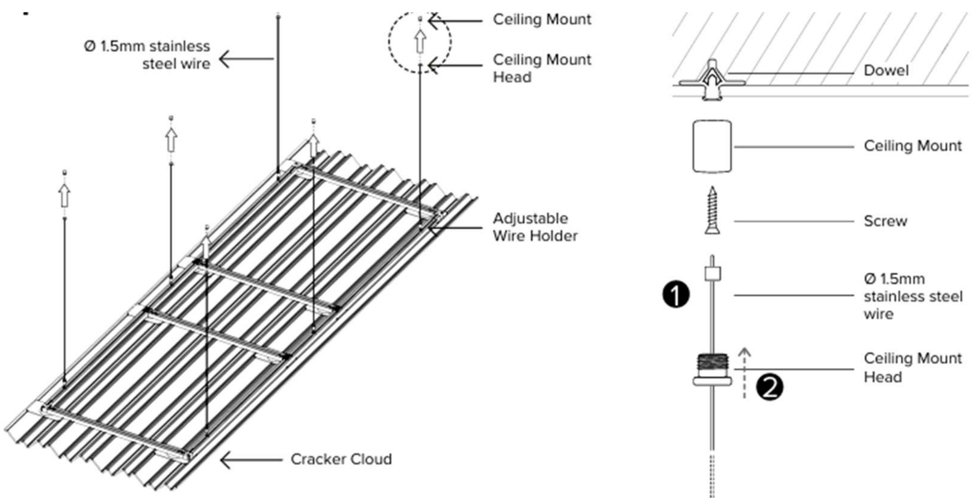

Figure 4: Application of the PET-Felt recycled acoustic panel on the ceiling: The ceiling mount head is attached to the suspension wire. Secure the ceiling mount and ceiling mount head to each other.

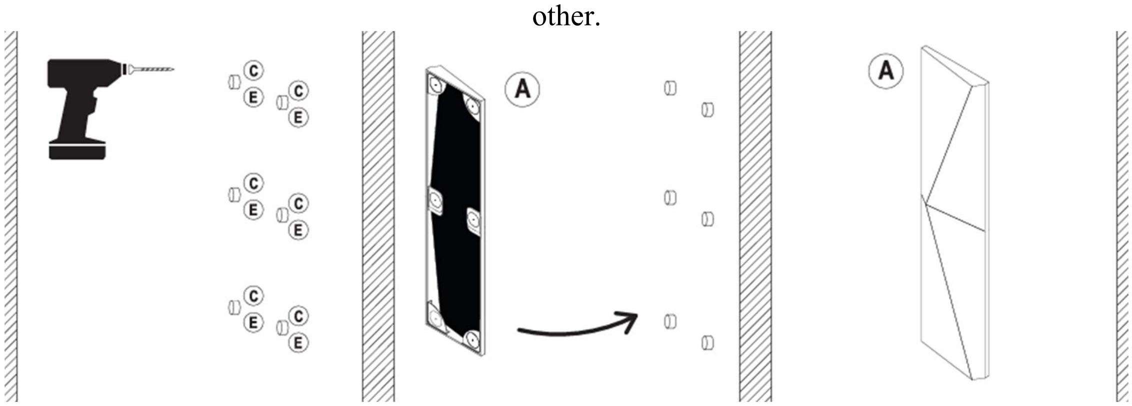

Figure 5: Application of the PET-Felt recycled acoustic panel on the wall:
Fix the magnets(left); Fix the acoustic panel to the magnets/velcro on the wall (middle); The wall panel is fitted (right).

2.3. Reverberation Time (RT) Measurement

2.3.1. In-situ measurement

The measurement of RT30 followed the ISO 3382-2:2008 standard for measuring room acoustic parameters. That was done using the DIRAC version 4.0 software, a building acoustic analyzer. A Bruel & Kjaer type 4006 omnidirectional speaker and a B&K Power amplifier type 2716 were used as the sound source. The signal, sampled at 48 kHz, was recorded by a B&K 2230 Sound Level meter microphone at each receiver position. The extrapolation of data for RT30 and STI utilized the same building acoustic analyzer software. The background noise levels were evaluated in the precise locations of the receivers in the meeting room. The room underwent field testing to measure its existing acoustic parameters and evaluate the effectiveness of the PET-Felt recycled material in a simulated environment. The measurements, consisting of Reverberation Time (RT30, s) and Speech Transmission Index (STI), were carried out on weekends when the meeting room was unoccupied yet furnished with desks and chairs, as depicted in Figure 6.

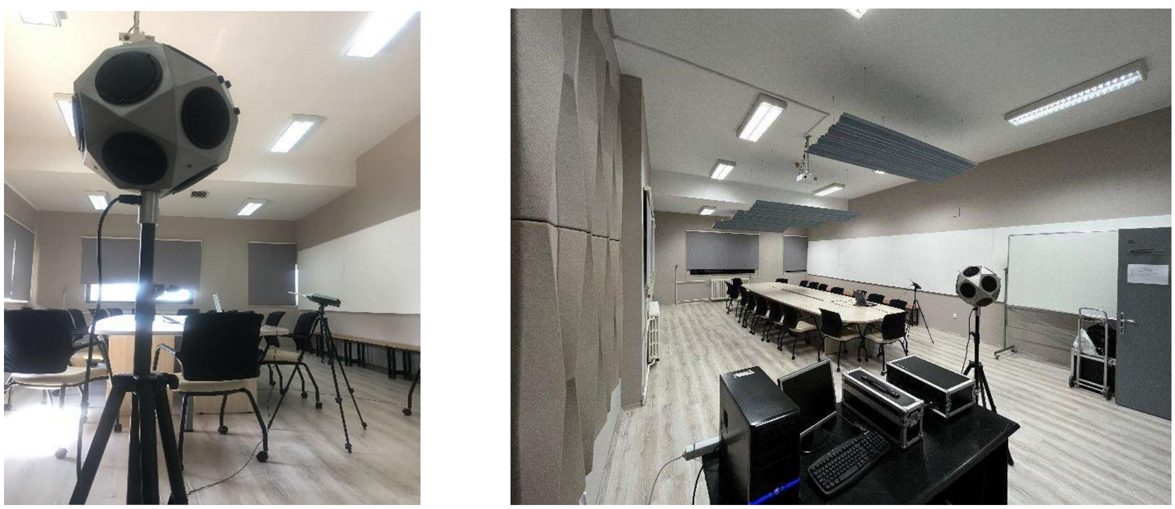

Figure 6: In situ measurements of the classroom (Author) Before the application (left) and after the application (right)

The configuration includes a single source positioned 2m from the whiteboard, centrally aligned with the room layout. Four receivers are situated at a minimum distance of 1.5m from the walls, as illustrated in Figure 7. The source's height was adjusted to 1.5m from the ground, simulating a standing teacher. In contrast, the receivers were set at 1.2m, representing sitting students.

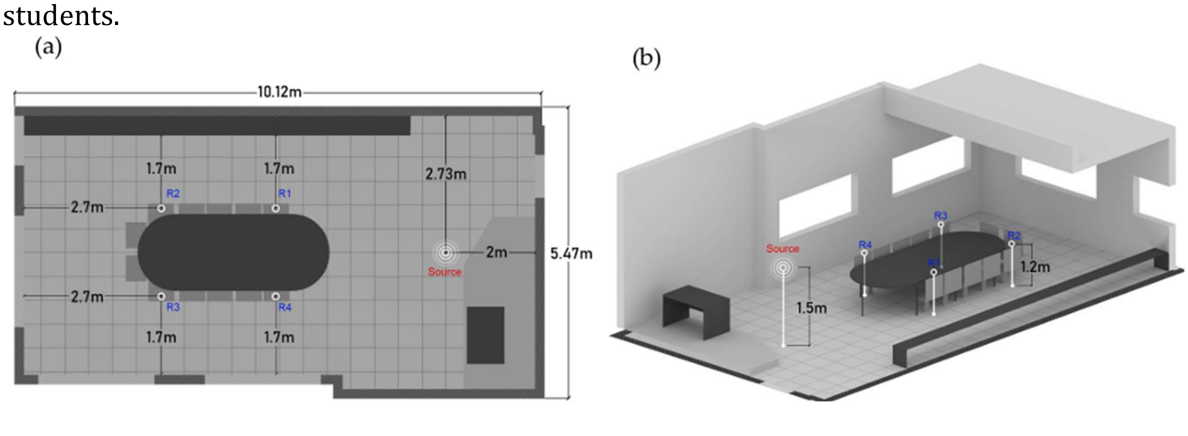

Figure 7: (a)Position of source and receivers; (b) Height of source and receivers

2.3.2. **Acoustic simulation of the meeting room**

The meeting room involved creating a 3D model of a classroom using SketchUp 2017. This model was then imported into ODEON Acoustics Software version 16 (Education ver.) using the SU2Odeon plug-in. The modeling process followed the state-of-the-art recommendations for geometrical acoustics (Vorlander, 2008), which require surfaces with dimensions larger than 0.35m. The positions of the source and receivers remained unchanged (Figure 8).

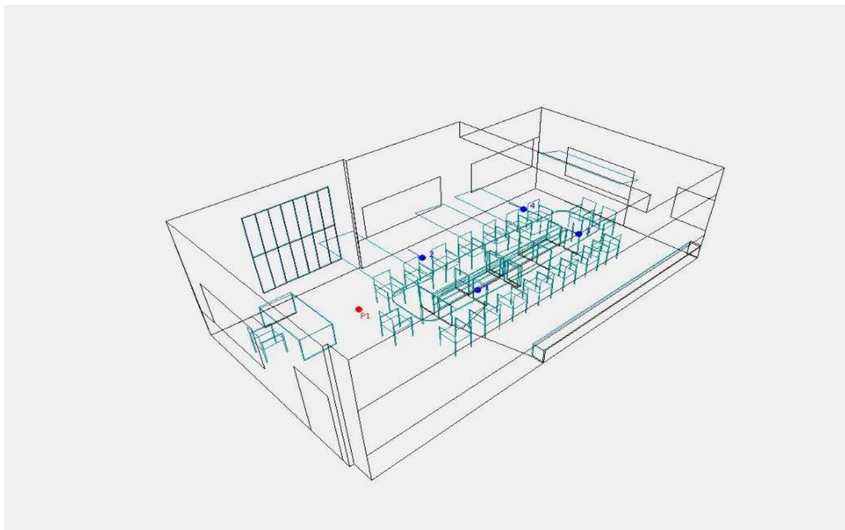

Figure 8: Source and receivers' positions in ODEON simulations.

The sound absorption coefficients of materials were initially assigned based on prior literature (Cox & D'Antonio, 2017; Vorländer, 2008). These values were refined through an iterative trial and error calibration process to satisfactorily match the measured and simulated RT30. The calibration was considered complete when the disparity between the measured and simulated RT30 values for each receiver was less than 5% of the measured value or Just Noticeable Difference (JND) (ISO 3382-2:2008).

The scattering coefficient was consistently established at 0.01 for all surfaces. The meeting room underwent an acoustic assessment, modeling, and calibration to guarantee that any treatment in the simulated model accurately reflected real-life acoustic conditions. After being implemented as a wall panel of an area of $25m^2$ in the case study modeled in ODEON 16, a comparison of the meeting room's acoustic indexes before and after the intervention unveiled the impact of this treatment on the overall acoustic conditions of the space.

2.3.3. **ISO 12913-2 Method A: Perceived Affective Quality (PAQ)**

It was necessary to evaluate the effectiveness of the structure not only through objective parameters but also through subjective assessments in architectural contexts to close the developmental cycle of a sustainable material. Since 2008, the International Organization for Standardization (ISO) has published three sections of the ISO 12913 series focusing on soundscape. ISO 12913-1:2014 outlines the concept and framework of the soundscape. At the same time, ISO/TS 12913-2:2018 provides methodological guidelines for conducting soundscape studies, including standardized metrics and instruments for data collection protocols related to the subjective evaluation of acoustic environments. ISO/TS 12913-3:2019 covers topics related to data analysis in soundscape research, complementing its predecessor. This series is called the Perceived Affective Qualities (PAQs) model or the ''soundscape circumplex''. ISO 12913-2:2018 Method A, involving questionnaires on a 5-Point Likert scale, outlines eight PAQs as subjective measurements of an acoustic environment, available only in English.

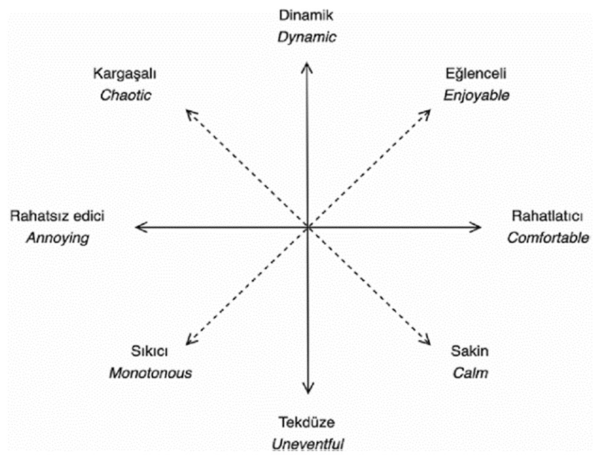

Figure 9: 2D circumplex in Turkish (Yilmazer et al., 2023).

To ensure accurate subjective assessments of the acoustic environment in the Turkish context, we also conducted a study to develop the Turkish version of the eight PAQs attributes outlined in the soundscape standard during this research. A corpus-driven approach was used to highlight the socio-cultural context from a linguistic perspective to develop the Turkish version of the soundscape PAQs (Figure 9). Bilingual laypersons from across Turkey were involved in constructing a large-scale Turkish Corpus of soundscape attributes (Yilmazer et al., 2023).

3. RESULTS

3.1. Reverberation Time (RT) and Speech Transmission Index (STI) in the Meeting Room

The meeting room's measured and calibrated RT30 values are given in Figures 10 and 11. The current values deviate from the recommendations provided by standards (Daniels & Bodkin, 2015) that belong to the specific building typology and volume.

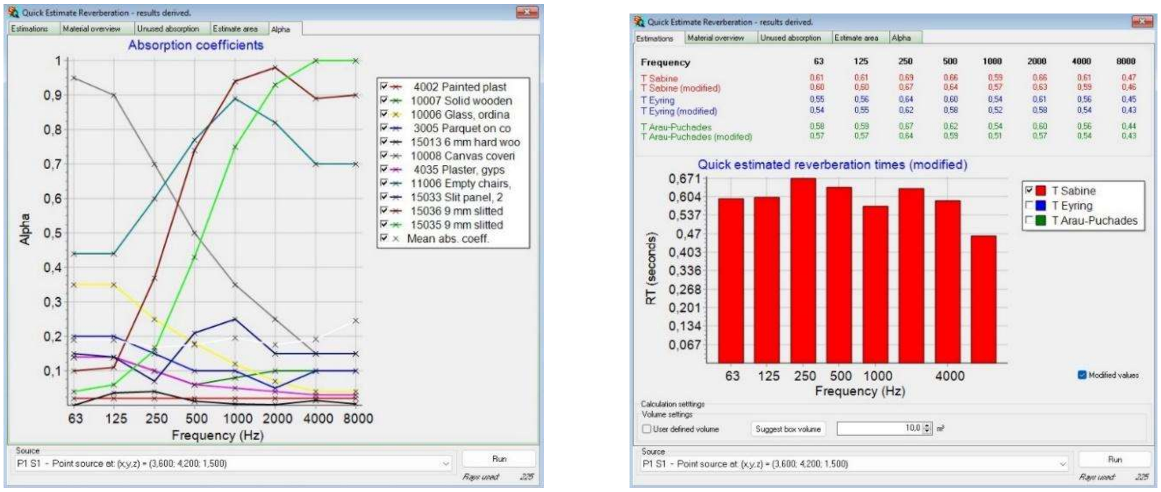

Figure 10: Alpha values of the materials used ODEON 16 and T30 graphics after treatment

For meet; ng rooms with a volume of less than 250m^3, the RT30 should not surpass 0.8s within the frequency range of 500Hz to 1000Hz in unoccupied, furnished conditions. However, in the examined case study, these values significantly surpass the recommended limits, averaging around 2s in the mid-frequency range.

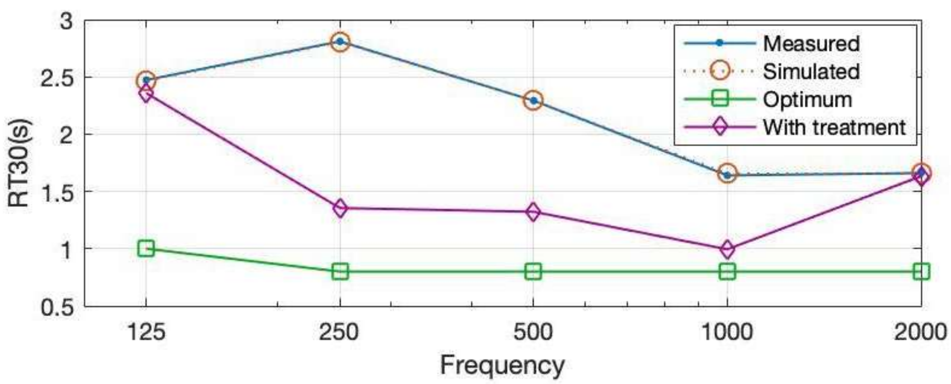

Figure 11. RT30 values for measured, simulated, and treated conditions compared to optimum ones

In addition to RT30, the acoustic comfort related to speech intelligibility in the meeting room was objectively evaluated using Speech Transmission Index (STI) values. As a metric for speech, the STI assesses how noise and room reflections impact speech intelligibility from the source to the receivers. STI was measured according to Noise Criteria 45 (NC45) in this case study. Across the four receivers in the room, the STI values fall within the fair range (Zhang et al., 2021), ranging from 0.48 for R1 and R3 to 0.5 for R2. R4's values were 0.49 and 0.67 after the treatment (Table 1).

Table 1. STI values for each receiver before and after treatment

STI	R1	R2	R3	R4
Before PET-Felt recycled acoustic panel treatment	0.48	0.5	0.48	0.49
After PET-Felt recycled acoustic panel treatment	0.67	0.67	0.67	0.67

3.2. **Perceived Affective Quality (PQA) in the Meeting Room**

The following results show the sound sources (Q1), soundscape affective assessment (Q2), soundscape appropriateness (Q3), and overall assessment (Q4). Data were collected from 20 meeting room users with a mean age of 32,4. Participants were grad students and instructors. The sound is dominated by human activity during the meeting and the class. Natural sounds like birds chirping and environmental sounds like traffic are also heard.

As shown in Figure 12, the participants found the space *calmer*, *less pleasant*, *less eventful*, *less chaotic*, and *less monotonous* before the acoustic treatment. After the treatment, PQA became *more chaotic*, *monotonous*, and *eventful*. At the same time, they are both found *vibrant*, *annoying,* and *eventful*. These questions answered the Soundscape Method A's first (Q1) and second questions (Q2).

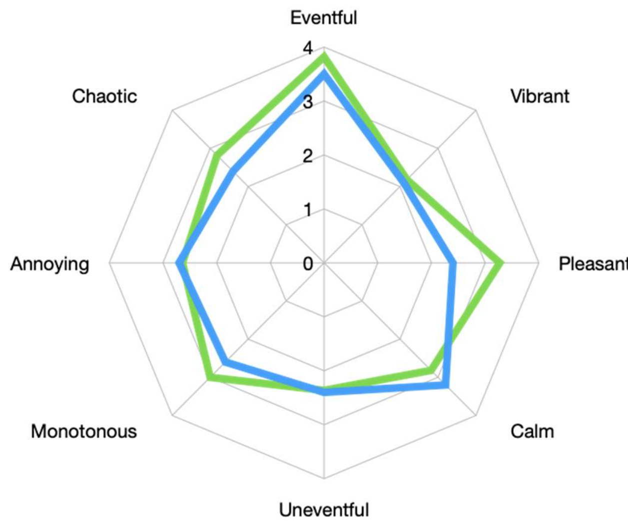

Figure 12: Perceived affective quality (PAQ) values from the users before (blue line) and after (green line) the treatment with PET-Felt recycled acoustic panels.

4. **CONCLUSION**

In conclusion, the lack of cooperation between the two disciplines, architecture and acoustics, can render significant buildings unfit for their purpose, such as educational spaces. Problems related to speech intelligibility and noise are the rule rather than the exception in indoor education environments. Bearing that most meeting rooms have a large proportion of "non-native speakers" and the occupants' illnesses that temporally impair hearing, the importance of the speech purpose room acoustics prevails. Literature shows that prolonged exposure to exceeding levels of noise can lead to several adverse human health issues such as fatigue, stress, hearing loss, high blood pressure, sleeping disorder, psychological disorders, hypertension, obesity, cognitive impairment in children, coronary heart disease, diabetic type I and II. Hence, manipulating sound reflections that impact how the sound propagates and is ultimately perceived becomes very important. This study investigates the performance of the PET-felt recycled panels for the room acoustic treatment for incorporating better sound within the project's design, ultimately delivering a better user experience.

5. ACKNOWLEDGEMENTS

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