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Original Article

Acoustical Quality for Media Auditorium: Analysis of the Current Situation and A Proposal for Improvement

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ABSTRACT

The functional quality of media auditoriums relies on acoustic performance, especially in multi-purpose space where speech and music are listed. In this analysis, the quantitative assessment of the acoustic performance of a Media Auditorium in Erbil, Iraq is developed and goals are to determine the design interventions to improve its acoustic adaptability. The approach of quantitative case study was chosen which involved a combination of in-situ acoustic measurements and digital simulation. The surveying of the architecture was recorded in terms of geometry and material characteristic of the hall, and the sound pressure level (SPL) of the hall was also tested on-site along with reverberation time (RT). Spatial acoustic analysis was done with the help of a calibrated 3D model created in Revit and loaded into Grasshopper with the help of Pachyderm and Fluffy Fish plugins. It has been found that fabric finishes and upholstered seating have a good high-frequency absorption, but insufficient low-frequency absorption below 250 Hz. Measured RT values (1.6-1.85 s) were appropriate to the tiny musical acts but slightly excessive for speech. Proposed interventions-installing high-performance absorptive materials on rear walls—reduced reverberation and optimized early reflections, enhancing the auditorium's versatility for diverse event types.

Keywords: Acoustic quality, Auditorium, Reverberation time (RT), Sound absorption.

1 Introduction

An appropriate acoustical environment into auditoriums is marked by controlled reverberation, even distribution of sounds, balanced frequency response, and the fact that disruptive echoes are absent. The criteria mentioned are well defined in the architectural acoustics standards and manual including ISO 3382, that quantitatively describes the acoustic properties of a room, including reverberation time (T30), early decay time (EDT), and such quantitative measures of clarity as C50 and C80, and sound strength (G) [1]. Adherence to these parameters is essential to ensure reasonable speech intelligibility and musical sound in the large-volume auditoriums [2]. As multi-purpose auditoriums become more popular, it becomes necessary to allocate space to facilitate speech, conferences, and music performances, each having its own acoustic needs, especially in the reverberation time and at low-frequency response [3] [4]. Reverberation time (RT) is thought to be one of the most used parameters to measure the acoustic performance of enclosed spaces. The reverberation time has a direct impact on the perceived room sound quality and clarity of sound [5]. Even though the excessive reverberation can be minimized by the use of absorptive materials, traditional porous absorbers tend to work best at mid and high frequencies, while providing limited absorption at lower frequencies [6]. The use of membrane absorbers is thus widely used to improve low-frequency performance over the resonance mechanism, with materials and construction details being essential to the performance [7][8]. Although there is a lot of simulation software, such as CATT-Acoustic, and Pachyderm has predictive qualities, the accuracy in such software is dependent on the level of complexity in the room design and assumptions adopted in terms of sound absorption and diffusion [8] [9]. This paper explores the acoustical behavior of Media Auditorium in Erbil, making the following contributions to the field of architectural acoustics research: Firstly, it offers an assessment of the acoustic properties

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of the multipurpose auditorium in Erbil, where there is limited information about acoustic studies and design standards using the combined approach of field testing and computational simulation. On-site acoustic measurements were done to measure the baseline values the efficiency of the frequency-targeted materials of reverberation time, sound pressure level distribution, and sound absorption materials. A three-dimensional model of the auditorium was elaborated in detail with the help of Revit, and parametric analysis of the material properties and the configurations of the surfaces was done with the help of Grasshopper. The resulting output of the simulation, such as sound pressure level distribution and reverberation times are presented. The proposed design solutions to enhance the performance of acoustics based on the combined measurement and simulation were to make specific material changes and absorbers location. The effectiveness of such interventions was analyzed through the comparison of the pre- and post-optimization final acoustic parameters.

2 Research background

Previous research auditorium acoustics have mainly concentrated on either material absorption behaviour or geometry optimization in architecture to attain desirable performance in acoustics. Experimental studies of the sustainability of sound absorbing materials have revealed that the medium particle sizes (0.31-2.5 mm) of wood by-products have been found to have greater sound absorption in the frequencies of 50-1400 Hz. Combined measurements of impedance of tubes with Johnson Champoux Allard Pride Lafarge (JCAPL) modeling showed that the absorption and speech intelligibility levels were the same as with commercial perforated acoustic panels, suggesting possible architectural applications [10]. These results show the possibility of sustainable materials to satisfy acoustic performance goal and lower on environmental impact though their ability to perform at low frequencies is still low without further thickening or backing cavities.

Integrated architectural–acoustic approaches has shown that a compromise between speech clarity and musical richness can be successfully achieved by means of thoughtful modification of geometry and the distribution of materials by applying Sabine based reverberation analysis together with parametric surface optimization [11]. These studies showed that the acoustic performance can be tuned by modulating surface inclination, diffusion patterns as well as material distribution without necessarily using absorptive treatments. This is especially beneficial in massive auditoriums, where the heavy absorption can interfere with the quality of music

As Le Serre Hall in Villa Erba Convention Center confirmed, variable acoustic elements can be used to produce a reverberation time of 0.9-1.2 s speech and 1.5-1.9 s music with acceptable values of speech transmission index (STI) proved with the help of simulation [12]. These findings were corroborated by acoustic simulations, and the values of speech transmission index (STI) were found to be in reasonable limits of intelligibility. The results of these findings highlight the usefulness of variable acoustics in meeting the needs of multiple functions of a single space.

Retrofit of old performance spaces, such as the Cavallino Bianco Theatre, focused on the enormous impact of ceiling geometry and absorptive wall treatments in reducing excessive reverberation and enhancing intelligibility [13]. The same results were cited in the Beniganim Auditorium where the change of ceiling inclination and addition of more absorptive material lowered the T30 values and improved auditory clarity as confirmed by the ODEON simulation [14]. These experiments indicate the important contribution of the ceiling design and vertical sound reflections in controlling reverberation and early reflections.

The research will be based on the theory of room acoustics, which associates the behavior of sound in the enclosed space with the geometry of space, the absorption of materials, and the energy decay caused by frequency. The reverberation time (RT/T30), and sound absorption coefficient (a) are the main acoustic indicators under consideration that are determined according to ISO 3382-1[1]. Reverberation time is a global attribute of acoustic decay and absorption coefficients give information on the frequency dependence of the performance of the materials utilized in the space. According to the literature acceptable reverberation times of multipurpose auditoriums to be between 0.8-1.2 and 1.4-2.0 s speech and music respectively [3]. The frequency range (500-2000Hz) is considered to be the most significant as far as speech intelligibility is concerned, and low frequency (125-250Hz) is the one that is most relevant in terms of acoustic warmth and is harder to manage as far as the thin porous absorbers are limited in their effectiveness [2]. In spite of these provisions, there is little research that has been done to touch on the current media auditoriums in Erbil. Specifically, there are limited investigations that combine field testing and parametric simulation models, which are founded on the ISO 3382-1, which helps to measure the frequency-specific intervening materials and ensure that they meet the suggested acoustic requirements in speech and multipurpose uses.

2. 1 Acoustic Parameters According to standard

Auditoria is a multifunctional space which will accommodate speech, music and audiovisual performances. Acoustical quality of these spaces is decisive factor of user comfort, speech intelligibility and general auditory perception. Poor acoustic condition such as high reverberation, insufficient absorption or uneven sound distribution, can expressively degrade performance quality and communication, regardless of architectural aesthetics [6]. In order to have objective assessment and comparability of acoustic performance, international standards offer systematic procedures of measuring, analyzing and interpreting acoustic parameters. The most common standards used in measuring the acoustics of an auditorium include ISO 3382-1, ISO 60268-16, ISO 354 and ISO 11654, which are all standards that deal with room acoustics, speech intelligibility and the sound absorption properties. The ISO 3382-1: Acoustics: Measurement of room acoustic parameters Part 1: performance spaces is the standard of the procedure of measuring the main acoustic parameters in the auditoria, concert halls and theaters [1]. This standard is concerned with objective descriptors of room impulse responses as measured by omnidirectional sound sources on the one hand, and calibrated microphones on the other hand. Reverberation time (RT) is one of the most important parameters stated by ISO 3382-1; it is the duration of time that it takes to reach a level of 60 dB below the original sound when the source of sound is turned off. The RT is calculated in octave bands that go up to 125 Hz to 2000 Hz and they indicate the frequency-related nature of sound absorption and reflection in the space [1]. The acoustics of an auditorium has a great dependence on the absorption level of interior materials. The ISO 354: Acoustics -Measurement of sound absorption in a reverberation room defines the procedures required in labs to identify the sound absorption coefficient (a) of surfaces and materials [17]. Measurements are done in octave bands that normally range low to mid frequencies such as 125 Hz to 2000 Hz that are essential to speech and music perception. These absorption coefficients are fundamental inputs to acoustic modeling and simulation software applied in the process of designing the auditorium [2]. When applied to research, the data of ISO 354 can be objectively compared to the various acoustic materials and give the scientific foundation of the choice of wall, ceiling, and seating finishes to influence the reverberation time and achieve acoustic comfort [15].

3 Methods and Materials

Information would be collected from articles, books, literature surveys and thesis. To obtain the required idea, the analysis in this article showed in the following advances:

3. 1 Specifications of the auditoriums

To analyze and evaluate the acoustic characteristics of the Media Hall in Erbil, Iraq, an in-depth analysis of the characteristics was made. Media Hall is located on 30 m Street, and has a seating capacity of approximately 656 seats. The hall is equipped with a huge entrance hall, which can accommodate up to 200 occupants "Figure 1". The total floor area of the hall was found to be 690 m² "Table 1". Since Media Hall was designed to be multi-functional, it was intended for various functions such as cultural events, conferences, public gatherings, and music, meaning that the acoustic performance and properties a critical factor in ensuring suitability for diverse uses.

Table 1: Details of Media Hall in Erbil.

Media Hall					
L	W	Area m2	Volume m3	D Max.m	No. of Audience
33	21	690	5337	26.77	656

Figure 1: Media Hall in Erbil city.

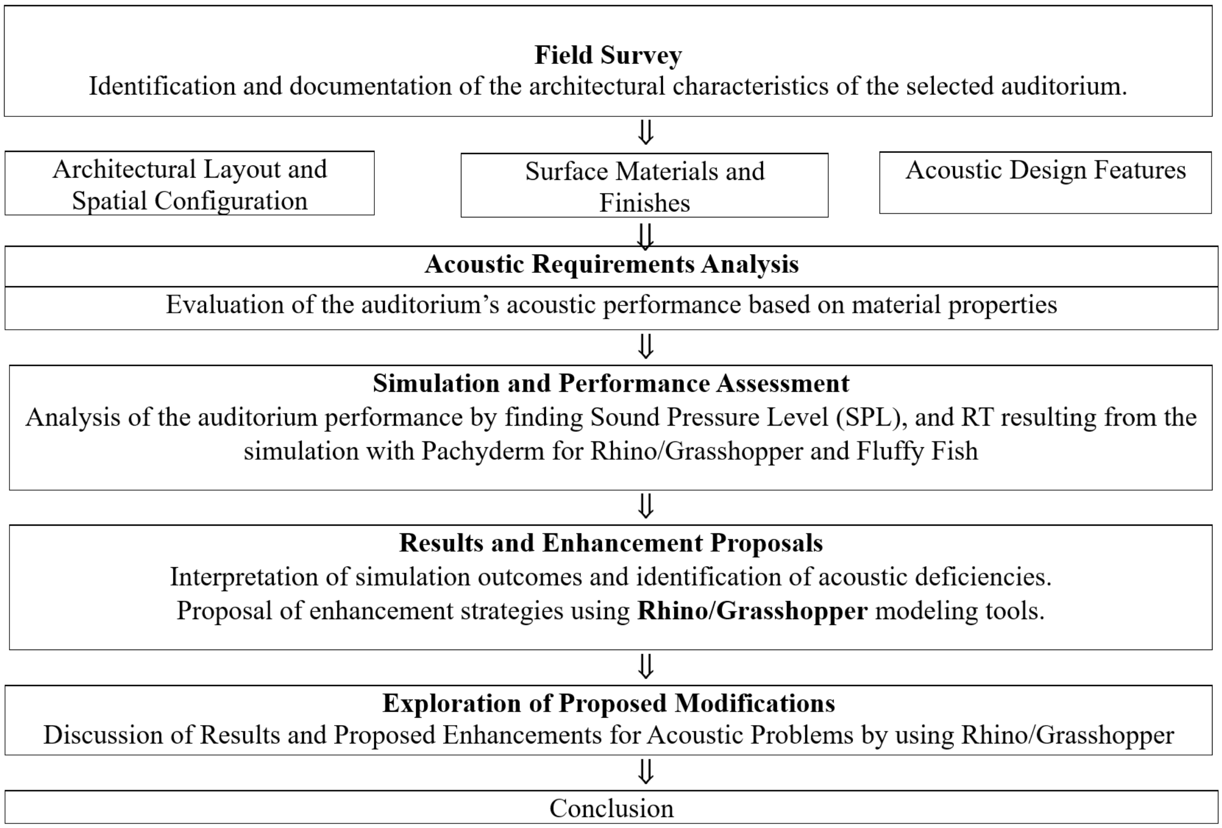


Figure 2: Methodological Framework (Authors).

3. 2 Field Survey and Descriptive Analysis of the Existing Auditorium

The first part of the methodology, as depicted in Figure 2, entails conducting a field survey and descriptive analysis on the Media Hall in order to create an accurate baseline for the acoustic simulation that follows. This part of the methodology concentrated on collecting data on the physical and architectural features of the auditorium that have a direct impact on its acoustic performance. The field survey for this part of the project was divided into three major parts: architectural layout and spatial configuration, surface materials and finishes, and existing acoustic design features. Architectural layout and spatial configuration were collected through on-site observation and architectural drawings, including hall geometry, seating configuration, stage placement, ceiling height variation, and audience capacity. All these factors were critical in determining the volume and sound propagation in the acoustic simulation environment.

Surface materials and finishes have been identified for all major elements of the hall. These include floor surfaces, wall surfaces, ceiling surfaces, seating surfaces, and stage surfaces. The type of material used has been noted, which is then used to determine the acoustic absorption coefficient. The acoustic design features have been studied to identify any existing acoustic design strategies. These features include wall surfaces with fabric finishes, floor surfaces with carpet finishes, seating surfaces with upholstery, and ceiling surfaces with reflective or absorptive finishes. The presence, distribution, and purpose of these features have been qualitatively evaluated to understand their impact on the acoustic performance. This is an essential part of the field survey, which provides the basic input required to develop the digital model of the Media Hall. It ensures that the simulation is carried out accurately to assess the impact of proposed acoustic design strategies.

For the assessment of the acoustic properties of the auditorium, three receiver points were specified within the simulated environment. As depicted in Figure 1, these receiver points were placed strategically at various locations within the audience seating area, at the front, middle, and rear of the auditorium, in order to assess the spatial variations of sound pressure level (SPL) and reverberation time (RT) within the auditorium. The acoustic properties were evaluated at each of these locations and then compared and averaged in order to assess the acoustic uniformity within the auditorium. The height of the receiver point was set to match the ear level of the occupants within the auditorium.

3. 3 Core Acoustic Simulation Workflow in Grasshopper

Grasshopper has an integrated acoustic simulation via its ecosystem of plugins that allow sound to be taken into consideration in the design environment. Parametric modelling enables acoustic assessment to be made at the early design phases, which would break interoperability problems with individual modelling and simulation tools [15]. Recent work has termed this combined methodology as parametric acoustics and it has found several methods in which parametric modelling and acoustic simulation can be used to improve the process of architectural design. Pachyderm is one of these plug-ins which calculates room acoustic performance [16]. Acoustic simulation process in Grasshopper as described in "Figure 3" using Pachyderm. The process incorporates components for defining material and geometry (GeoSrc and Poly Scene), receiving points (StatRec), as well as direct sound simulation, image source simulation, and Raytracing. The Energy-Time Curve (ETC) component is responsible for illustrating how a sound wave decays out in an enclosure, while toggles and sliders control variables such as simulation settings ray count. This configuration allows for an efficient testing of the room's acoustic properties within a parametric design context. The ray propagation through the Pachyderm simulation was managed by defining a maximum reflection order of five bounces, beyond which the energy of the rays was considered to decay and was no longer taken into account for the Energy-Time Curve (ETC) computation. Hence, the distance traveled by the rays was indirectly limited by the number of reflections and the absorption properties of the surfaces. Although no fixed maximum ray travel distance was explicitly defined, the chosen reflection order and the absorption properties of the surfaces ensured that the rays traveled a sufficient distance to simulate the reverberation within the hall.

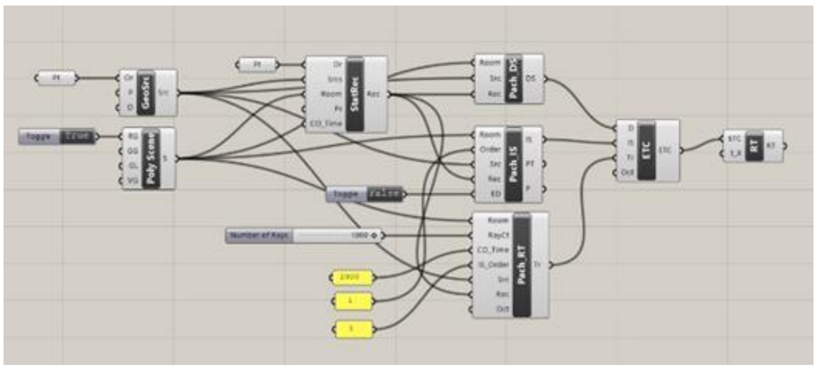


Figure 3: Acoustic simulation workflow in Grasshopper using Pachyderm.

3. 3 Visualization & Interpretation Setup

The workflow entails visualizing results of acoustic simulation using PachVis to show results of RT60, Clarity, and Strength. There is also data sorting and assessment components that assist in determining crucial results that are illustrated either through graphic or geometry approaches based on color. This is accompanied by elements such as Preview or Swatch that make use of gradation of color that enables one to identify areas of undesirable acoustics as per "Figure 4".

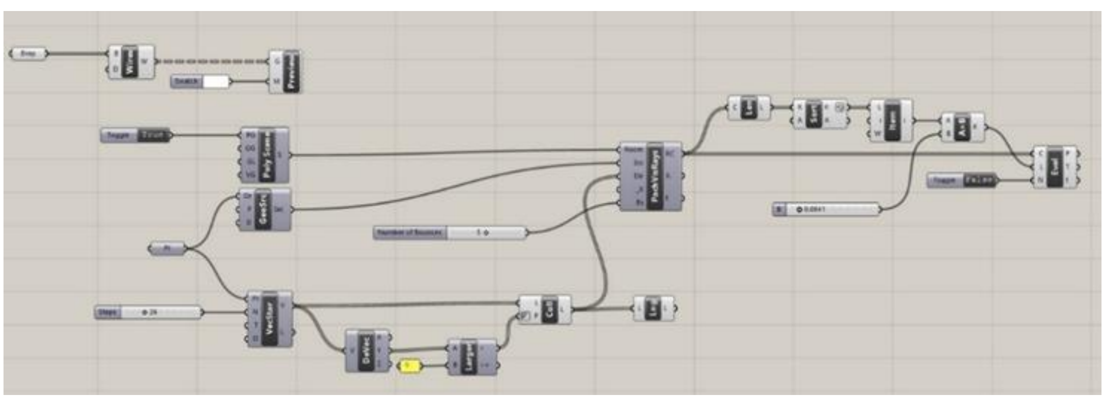


Figure 4: Visualization & Interpretation Setup.

3. 4 Numerical Data Output (ETC and Reverberation Time Calculation)

In this stage, numerical data concerning the acoustics of the Media Hall were extracted using the Pachyderm simulation tool. The most important numerical data extracted and used for the quantitative assessment of the acoustics of the Media Hall were the Energy-Time Curve (ETC) and the corresponding reverberation time (RT) values for specific receiver points, which were positioned in the audience area. The ETC is a curve showing the time dependence of the energy level of the sound emitted from the source. Using the output of the ETC, reverberation time values (RT60) were calculated for specific octave bands, ranging from 63 Hz to 8000 Hz.

Multiple receiver points have been specified to accommodate the spatial variability of acoustic performance. This ensures that the results are representative of the entire hall, as opposed to localized conditions. The RT values have then been averaged to assess the overall acoustic uniformity. The values have also been compared with the recommended reverberation time ranges for speech as well as musical performance. These numerical outcomes are the basis on which the results have been presented in Section 4, allowing direct comparisons to be made between the existing acoustic state and the proposed material interventions. RT60 values have been specified as the basis on which the assessment will be carried out, as they are commonly used in the assessment of auditorium acoustic performance.

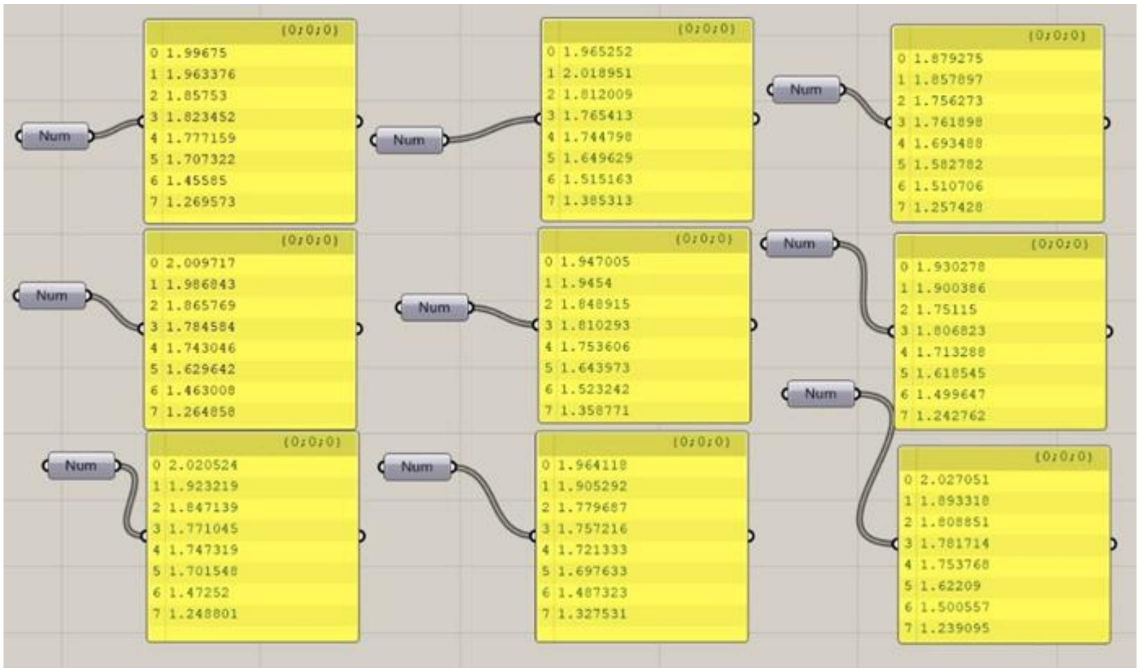


Figure 5: Calculations in Pachyderm.

3. 5 Input Parameters for Acoustic Simulation

The acoustic simulation carried out with Pachyderm for Rhino/Grasshopper was based on a set of input parameters related to geometry, materials, sources, receivers, and simulation control. The input parameters were carefully selected to accurately reflect the existing state of the Media Hall, as well as to ensure consistency between the existing state and the post-intervention state. The input parameters related to geometry included the three-dimensional geometry of the room, which comprised details such as the size of the hall, volume, seating arrangement, stage arrangement, ceiling geometry, and audience area distribution. The input parameters related to materials included frequency-dependent sound absorption coefficients, which were assigned to all major surfaces, including floors, walls, ceilings, seating, and stages. These coefficients were obtained from manufacturers' information and existing acoustic literature, and they were defined over an octave band range extending from 63 Hz to 8000 Hz.

The parameters of sound sources consisted of the number and position of sound sources, which were set to mimic the position of loudspeakers/speakers in the hall, as shown in Figure 1. The characteristics of sound sources were set consistently throughout all simulations to ensure comparability between the existing and proposed conditions. The parameters of receivers consisted of three receiver points located at different areas within the audience seating area, such as the front, middle, and back areas. The sound pressure level (SPL) and reverberation time (RT) were computed at each receiver position and then averaged. The parameters controlling the simulation consisted of raytracing-based analysis with Pachyderm software, maximum reflection order set to five bounces, octave bands, and energy-time curve (ETC) analysis for reverberation time calculation. The parameters were set consistently throughout all simulations to ensure comparability between the existing and proposed conditions.

3. 6 Simulation assumptions

In the acoustic simulations, an idealized room geometry was used, with frequency-dependent values of material absorption coefficients taken from the literature. Sound sources were assumed to be omnidirectional, and the effect of air absorption and background noise was neglected. The audience effect was represented by the absorption characteristics of upholstered seating. These assumptions are commonly used in acoustic simulations. Accordingly, the simulation results are intended for comparative evaluation between existing and proposed conditions rather than absolute prediction of in-situ acoustic performance

4 Results and Discussions

4. 1 Sound Absorption Coefficient

Sound absorption is an important factor in interior spaces to improve acoustics and control reverberation. Sound absorption is affected by material type, surface characteristics, and density, with a coefficient value of 1.0 signifying total sound absorption. "Table 2" presents different materials in Media Hall with their absorption coefficient values at 125 Hz, 500 Hz, 2000 Hz, and 4000 Hz.

Table 2: Acoustic Materials and Respective Absorption Coefficients – Media Hall.

Element	Material	125 Hz	500 Hz	2000 Hz / 4000 Hz
Floor	Carpet Terrazzo tile	0.06 / 0.02	0.06 / 0.02	0.06 / 0.04 0.15 / 0.05
Wall	Timber Fabric Solid wooden door	0.40 / 0.20 / 0.10	0.30 / 0.35 / 0.08	0.20 / 0.50 / 0.08 0.10 / 0.60 / 0.10
Ceiling	Gypsum board	0.07	0.07	0.05 / 0.05
Stage Floor	Carpet	0.06	0.08	0.06 / 0.15
Seating	Upholstery fabric Plastic armchair	0.18	0.59	0.68 / 0.70

From this data, it's obvious that Media Hall has strong high-frequency absorption ability carried out through fabrics on walls and seating areas, which will make speech intelligible. Weakness lies in low-frequency control, as most materials have a low absorption rate at 250 Hz except timber walls. The combination of all reflection surfaces (terrazzo, gypsum ceiling, and wooden doors) and absorption materials (carpet, upholstered seating, and fabric) is semi-live acoustic environment because it is suitable for speech but unbalanced overall, with lacks low-frequency control.

4. 2 sound pressure level (SPL) Measurements

From the data provided, sound pressure level (SPL) measurements ranging from 62.5 Hz to 8 kHz for three speakers, recorded at three receivers, and average measurements for all three speakers. Speaker 1 has an average SPL of 1.752982, Speaker 2 an average of 1.753264 (fractionally higher than Speaker 1's average SPL measurements), and Speaker 3 an average of 1.741989 (fractionally lower than Speaker 1 and Speaker 2's average SPL) as seen in "Figure 6". Overall, it is seen that SPL is generally decrease with increased frequency, with a more prominent drop above 1 kHz. Speaker 3 constantly shows slightly lower SPL values, whereas Speakers 1 and 2 display similar performance.

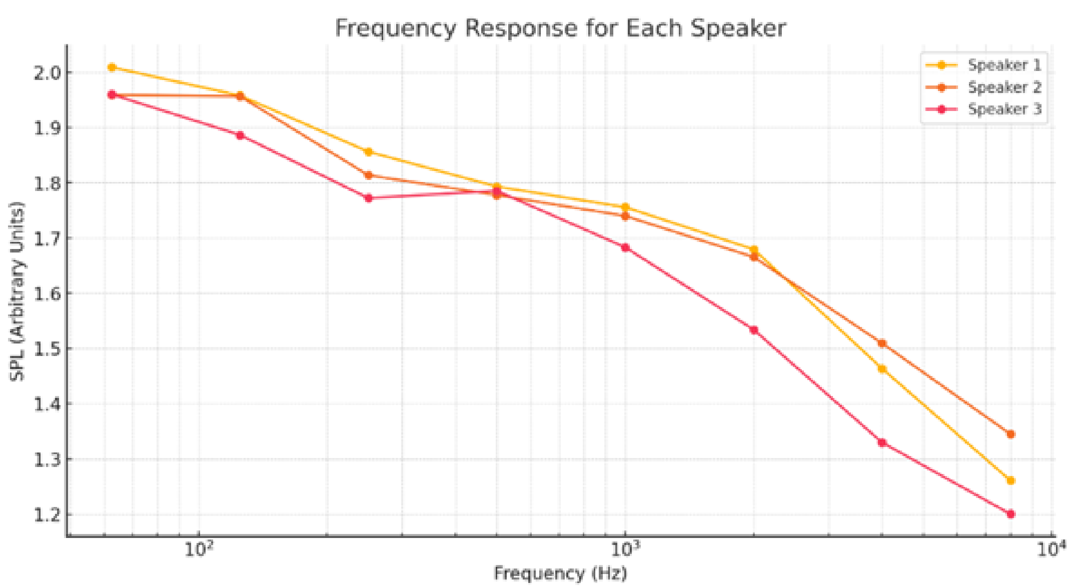


Figure 6: Frequency response.

4. 3 Reverberation time Measurements

One of the most crucial variables in analyzing the acoustic performance of the auditorium is reverberation time. The average of RT values is represented in the following graph:

These data will be compared with a recommended value of reverberation time in an auditorium. It is seen that reverberation time measured in Pachyderm for Rhino/Grasshopper and in Fluffy Fish lie between 1.2 and 2.0. Ignoring those values in the lowest frequency 63 Hz and in the highest frequency 8000 Hz. In all three speakers, there is a consistent reduction in reverberation time (RT) as frequency increases, indicating more efficient absorption of high-frequency by room surfaces. RT measures are comparable for all receivers, indicating equal acoustics. Low frequencies (62.5-250 Hz) have longer RTs due to low absorption, and mid-to-high frequencies (500 Hz-8 kHz) have increasingly shorter RTs, indicating efficient control of sound energy. Average RT values vary between 1.6 and 1.85 seconds, generally comparable with lower bounds of concert halls, suitable for small musical performances. But these values are slightly on the higher side for speeches and conferences requiring shorter reverberation time for optimal clarity, as indicated by "Figure 7".

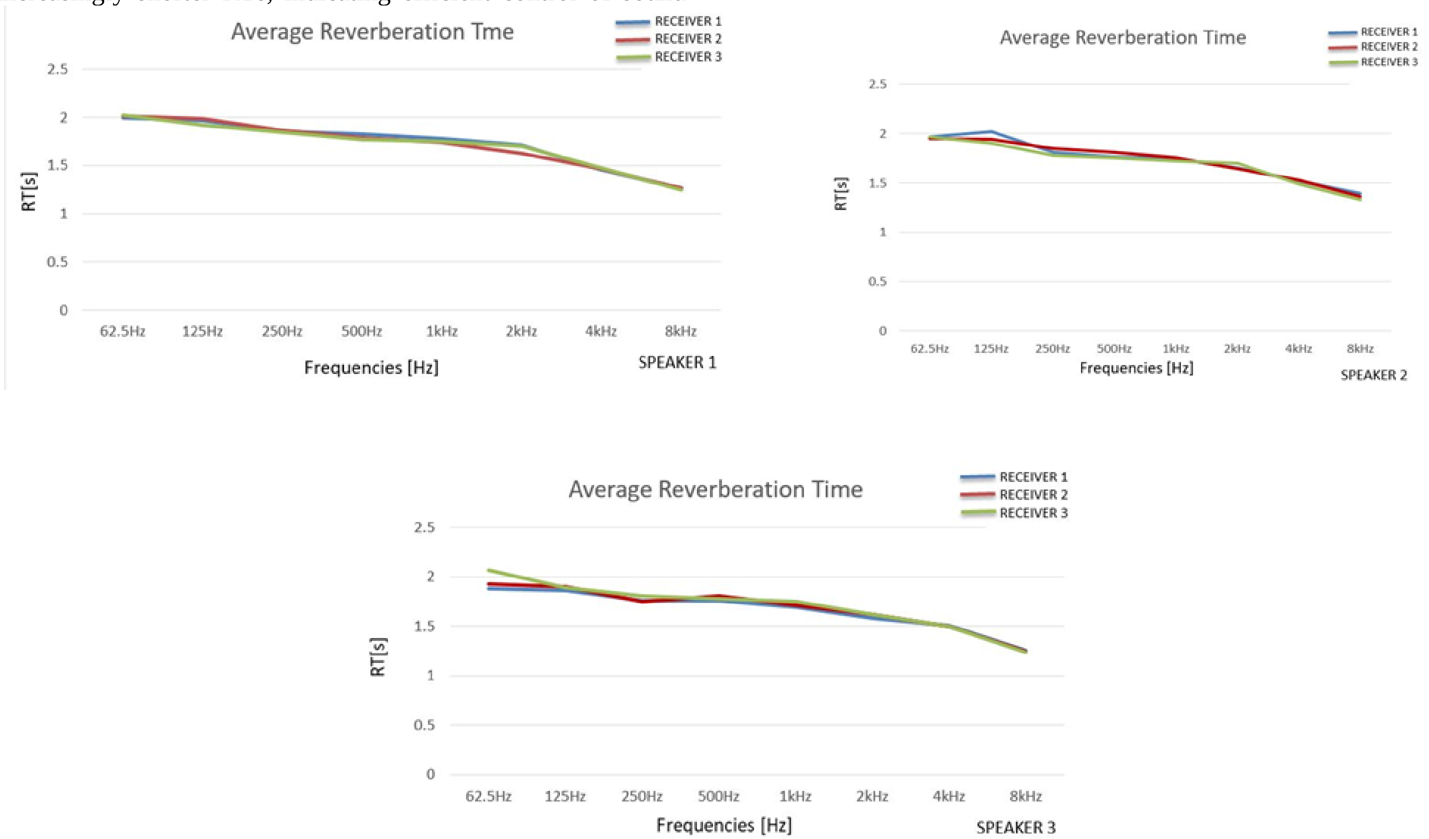


Figure 7: Average reverberation.

Red reflection indicators' absence in some areas indicates effective incorporation of sound-absorbing materials that decrease the reverberation time (RT) but can create an acoustically dry environment, potentially unfavorable for musical performances. On the other hand, zones of abundant red reflection indicators point towards high surface reflectivity, thereby high RT values. Quick decay of red indicators is associated with low RT values, indicating reflecting efficient sound absorption, as shown in "Figure 8".

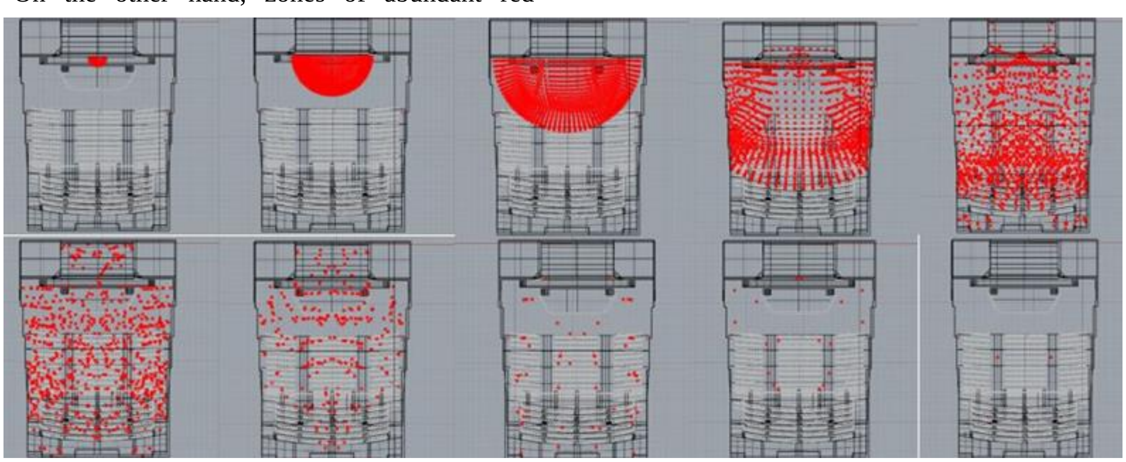


Figure 8: Sound distribution.

4. 4 Acoustic Enhancements in the Media Hall through Proposed Material Interventions

4. 4 Acoustic Performance Criteria and Standards for Multipurpose Auditoria

In order to assess the effectiveness of the suggested acoustic improvements, the results should be checked against standard acoustic performance criteria for multipurpose auditoriums. In general, internationally accepted criteria are based on ISO standards, national guidelines, and standard acoustic design criteria. Based on ISO 3382-1, which describes the measurement and evaluation criteria for the performance of spaces, Reverberation Time (RT) is one of the most important factors in judging the acoustic quality of spaces. The design criteria presented by Kuttruff and Everest suggest that the ideal Reverberation Times in the mid-range frequency region (500-2000 Hz) should lie between 0.8-1.2 s and 1.0-1.5 s, respectively, for spaces where speech predominates and multipurpose spaces where both speech and music are presented. The British acoustic criteria and standards, including those presented by the Institute of Acoustics (IOA) and the former BB93, also highlight the importance of controlling mid-range Reverberation Times in the 500-2000 Hz frequency region in spaces where speech needs to be intelligible, suggesting RT values close to 1.0 s.

According to German acoustic practice, as per DIN 18041, acoustic comfort criteria are set for speech and music in rooms, and reverberation time should be within 0.9 to 1.3 seconds in medium-sized halls. This is in line with ISO-based acoustic criteria and emphasizes the significance of mid-frequency reverberation time, allowing a slightly longer time for musical purposes. In the context of Iraq, national acoustic criteria for auditoriums are not available or are not explicitly mentioned. Therefore, acoustic design criteria in Iraq generally follow internationally accepted criteria like ISO, British, and German criteria, which are suitable to local building practices and functional needs. For Media Hall, which is meant for conferences, events, and musical purposes, these criteria are appropriate and valid to be used as evaluation criteria. If these criteria are evaluated, it is evident that the proposed acoustic enhancement meets the criteria in terms of reverberation time within the range of mid-frequency bands. Although low-frequency reverberation time is on the higher side, it is generally accepted that this is common in large volume auditoriums, and it does not compromise compliance with accepted international criteria.

4. 4. 1 Impact of Material Modifications on Sound Absorption Coefficient

The simulation results after the application of the proposed material interventions showed significant enhancements in the acoustic performance of space across all frequency ranges. In the low-frequency band from 62.5 to 250 Hz, the inclusion of membrane absorbers tuned to 63–125 Hz with deep porous corner traps greatly improved absorption to coefficients of up to 0.9 at 63 Hz and approximately 0.6 in the 125 to 250 Hz range. For the mid-frequency range of 500–2000 Hz, absorption coefficients vary between 0.7 and 0.85 with the implementation of perforated wood panels lined with wool and heavy acoustic curtains, with ceiling clouds. Such an intervention provided a better balance of the acoustic response by aligning the resulting reverberation characteristics with recommended design criteria for speech and multipurpose auditoria, particularly within the mid-frequency range critical to human perception. At the higher frequency range of 4000–8000 Hz, the combined use of ceiling clouds and curtains-maintained absorption values within the range of 0.7 to 0.85, by successfully minimizing harsh reflections without excessive damping of the sound field and thus preserving clarity and overall acoustic quality as shown in "Table 3".

Table 3: Influence of Material Changes on Acoustic Absorption Performance – Media Hall.

Element	Material	62.5 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Floor	Carpet (existing)	0.05	0.06	0.06	0.06	0.06	0.06	0.15	0.2
Floor	Terrazzo tile (existing)	0.01	0.02	0.02	0.02	0.02	0.04	0.05	0.05
Stage Floor	Carpet (existing)	0.05	0.06	0.07	0.08	0.08	0.1	0.15	0.2
Seating	Upholstered seats (existing)	0.15	0.18	0.4	0.59	0.65	0.68	0.7	0.7
Ceiling	Ceiling clouds (mineral wool, 100 mm, fabric-faced)	0.2	0.4	0.7	0.85	0.85	0.85	0.85	0.85
Walls (side/rear)	Perforated wood panel + 40–80 mm cavity + wool backer	0.15	0.35	0.6	0.75	0.75	0.75	0.75	0.7
Walls / Stage	Heavy acoustic curtains (deployable)	0.1	0.2	0.4	0.7	0.7	0.7	0.7	0.7
Low frequency	Membrane absorbers (tuned to 63–125 Hz)	0.9	0.8	0.6	0.2	0.1	0.05	0.05	0.05
Corners	Deep porous corner traps (200–400 mm)	0.6	0.6	0.6	0.4	0.3	0.2	0.1	0.05

The effectiveness of the proposed material interventions as presented in Table 3 was assessed against internationally accepted standards on room acoustics. According to ISO 3382, which provides definitions for acoustic parameters to be satisfied in performance spaces, and literature on auditorium design, optimal reverberation time values lie between 0.8 to 1.2 seconds for speech-oriented rooms, while small to medium-sized multipurpose auditoria intended for both speech and music presentations demand reverberation times ranging from 1.0 to 1.5 seconds, depending on hall volume and functional use [1,18].

The absorption coefficient values obtained post-intervention lie within acceptable ranges for reverberation time values, which are 0.8 to 1.2 seconds and 1.0 to 1.5 seconds, respectively, across critical mid-frequencies (500 to 2000 Hz). Hence, it can be inferred that the proposed material changes are acceptable based on acoustical performance criteria for multipurpose auditoria and are deemed suitable based on functional requirements for the Media Hall.

4. 5 Discussion of Acoustic Performance Relative to Design Standards.

From the critical analysis of the results obtained from the data provided in Table 3, it is evident that the proposed intervention strategies are effective in enhancing the overall acoustic balance of the Media Hall. However, some limitations have also been observed. The mean absorption values obtained are in the range of 0.75–0.85, covering the mid-frequency range of 500–2000 Hz, which is critical for the intelligibility of the sound produced. This range is perfectly aligned with the internationally accepted guidelines for the acoustic design of auditoria intended for speech-oriented and multipurpose halls, where the overall clarity and intelligibility of the sound produced are of primary importance. The low-frequency range of 62.5–125 Hz, although enhanced with the incorporation of membrane absorbers and corner traps, shows comparatively poor mean absorption performance. This is because, as per the guidelines of architectural acoustics, the control of low-frequency range is always difficult in large-volume halls, where the overall surface area is limited for the implementation of tuned absorption systems. The reverberation decay is therefore longer in the low-frequency range than the mid-frequency range, indicating that the bass control is the weakest acoustic domain of the proposed design.

From a standards-based perspective, the resulting reverberation characteristics derived from these absorption values correspond to recommended ranges for multipurpose auditoria, where optimal mid-frequency reverberation times are typically between 0.8–1.2 s for speech and 1.0–1.5 s for mixed-use halls, as indicated in international acoustic design guidelines and auditorium design literature. Therefore, while the proposed interventions achieve compliance with accepted performance criteria for speech and general multipurpose use, the results also indicate the need for more specialized or larger-scale low-frequency treatments if enhanced musical warmth and bass control are prioritized. This demonstrates that the proposed design achieves functional optimization rather than absolute acoustic uniformity across all frequency bands.

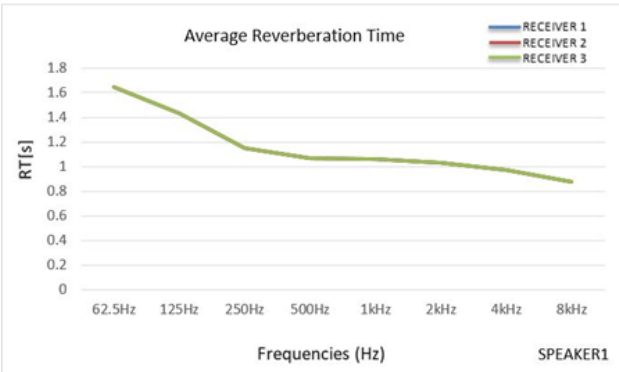
4. 6 Validation of the Acoustic Simulation Method

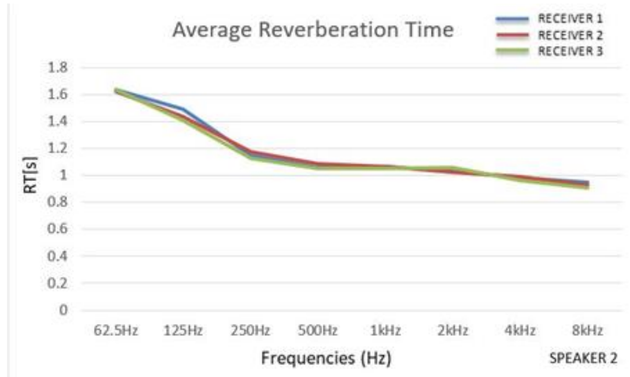
In order to guarantee the reliability and effectiveness of the methodology employed, the acoustic simulation methodology was based on a validated model of the existing condition of the Media Hall. No standardized in-situ acoustic measurements were taken as part of this research project; therefore, it was necessary to validate the acoustic model based on literature-derived material properties, geometric accuracy, internal consistency of results among receiver locations, and comparison with internationally accepted acoustic behavior in auditoriums. A detailed 3D acoustic model was created based on architectural surveys, including accurate room geometry, seating arrangement, and material properties based on manufacturer specifications and literature-derived absorption coefficients. The acoustic parameters simulated, sound pressure level (SPL) and reverberation time (RT) in octave bands, demonstrate characteristics that are consistent with the expected acoustic behavior of a hall of similar volume, surface materials, and seating density, as reported in international acoustic design literature. For instance, the longer reverberation time in low frequency and shorter reverberation time in mid- to high-frequency octave bands are consistent with material properties.The internal consistency of the simulation results for various receiver locations and their conformity to common acoustic principles in multipurpose auditoriums provide confidence in the simulation model as a reference condition. The validated reference condition was then employed to carry out comparative studies between the existing condition and the post-intervention condition, facilitating a before-and-after evaluation of the effectiveness of the proposed acoustic treatments.

In the absence of in-situ acoustic measurements, this research is intentionally positioned as a simulation-based comparative evaluation rather than absolute validation. The simulation model shows strong internal consistency in receiver position and frequency-dependent acoustic behavior consistent with established auditorium acoustics literature, thus providing confidence in the model's use for before and after comparative evaluation.

4. 4. 2 Reverberation time response across frequency bands after acoustic treatment

Reverberation time demonstrates a steady decrease with an increase in frequency because of increased absorption capabilities of the room surface in mid-to-high-frequency ranges. In low-frequency ranges (62.5–250 Hz), RTs remain higher, ranging from 1.6 to 1.85 seconds, which depicts low absorption capabilities and low-frequency energy an acoustic characteristic often represented in an enclosed environment. For mid-frequencies (500–2000 Hz), RTs become steady at 1.0 to 1.2 seconds, contributing to an acoustical balance that enhances both speech intelligibility and musical clarity. In higher frequency ranges (4000–8000 Hz), reverberation time decreases further to approximately 0.8–1.0 seconds, thus minimizing sharp reflections while maintaining brightness and definition. Overall uniformity of data across all receivers indicates uniform acoustic performance throughout the space of the setting without distinguishing across listener positions. Overall, it is clear that all these findings indicate that space is capable of creating a well-controlled and balanced sound, making it favored for speech and multi-purpose events, as well as smaller musical performances as shown in "Figure 9".





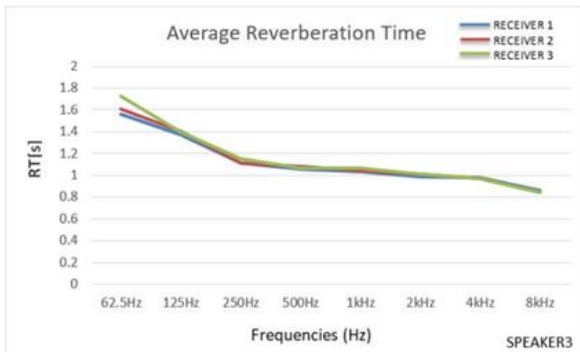


Figure 9: Average reverberation time after acoustic treatment.

The comparison shows that the upgraded acoustic treatments greatly enhanced the absorption performance of the Media Hall, mainly within the low-frequency range below 250 Hz where the original design was weakest, as seen in figure 3 and table 4. The most impressive achievement refers to mid-to-high-frequency bands of 2–8 kHz, which had reverberation times reduced by up to 40–45%, bringing the acoustic response much closer to the recommended range for speech intelligibility. This is credited to the installation of broadband ceiling clouds, fabric-faced wall panels, and heavy curtains that act as highly effective absorbers in these frequency ranges. At the same time, the reverberation time reduction was more modest at low frequencies between 63 and 125 Hz. Despite the additional use of membrane absorbers and corner traps, the presence of longer decay in these bands reflects the inherent difficulty to control low-frequency energy in large volume spaces and also that there was a limited surface area available for tuned low frequency treatments. Overall, in developing an intervention strategy with clarity and speech transmission optimization, strong results have been realized in the most important frequency ranges for human communication, while realizing the need for more extensive or specialized low-frequency treatments in order to achieve equivalent improvements in the bass region as illustrated in "Figure 10," "Table 4".

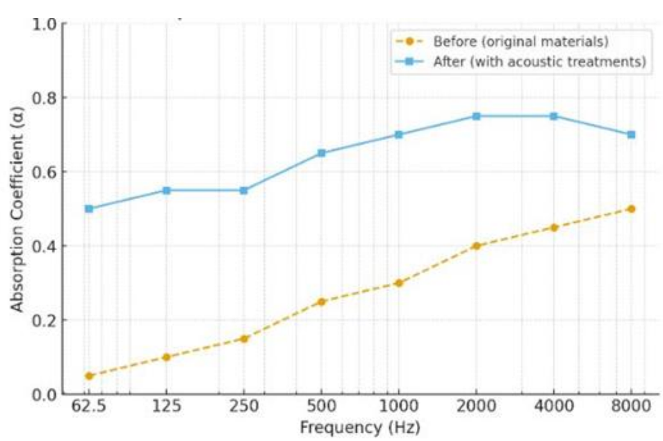


Figure 10: Media Hall Absorption Coefficients before vs after Material change.

Table 4: Comparison of Reverberation Time (RT) between (Existing and Proposed).

Frequency Range	Proposed	Existing	Implication
Low Frequencies (62.5–250 Hz)	RT ~1.6–1.85 s	RT ~2.0–2.2 s	Existing set shows weaker low-frequency absorption, leading to stronger bass resonance.
Mid Frequencies (500 Hz–2 kHz)	RT ~1.0–1.2 s	RT ~1.6–1.8 s	Proposed set provides clearer midrange, better for speech; second set remains more reverberant.
High Frequencies (4–8 kHz)	RT ~0.8–1.0 s	RT ~1.2–1.4 s	First set controls reflections better, enhancing clarity; second set retains more brightness and echo.
Uniformity Across Receivers	Curves overlap closely	Curves overlap closely	Both sets show stable and consistent acoustic behavior throughout the room.
Overall Acoustic Character	Balanced, controlled, optimized for multipurpose use (speech + music)	Semi-live acoustic, good for speech but unbalanced, with weak bass absorption and uneven frequency response	Proposed set = clarity; Existing set = semi-live acoustic.

To further evaluate the effectiveness of the proposed acoustic design enhancements, the post-intervention reverberation time values in Table 4 were compared with the target performance ranges established by successful auditorium designs and internationally recognized acoustic design standards. According to ISO 3382-1, DIN 18041, and auditorium design literature, the internationally recognized reverberation time values for multipurpose auditoriums in the mid-frequency range (500 Hz to 2000 Hz) should range between 1.0 and 1.5 seconds, whereas speech-oriented auditoriums should have slightly lower values ranging from 0.8 to 1.2 seconds. The proposed acoustic design configuration for the Media Hall auditorium resulted in reverberation time values ranging from 1.0 to 1.2 seconds in the mid-frequency range, thus placing the auditorium well within the optimal range for speech and functional multipurpose use. In the high-frequency range (4 kHz to 8 kHz), the reverberation time values were reduced to 0.8 to 1.0 seconds, effectively limiting excessive reverberant sound in the auditorium.

It should be noted that, although low-frequency reverberation times ranging from 62.5 to 250 Hz are still relatively higher, with values ranging from 1.6 to 1.85 seconds, this follows the pattern of acoustic performance that has been seen in many successful medium and large volume spaces and reflects the inherent difficulties associated with controlling low-frequency energy within enclosed spaces. Notably, however, these values do not exceed the upper limits that have been reported in reference designs and therefore do not compromise acoustic acceptability. Based on the above comparison, the acoustic performance of the Media Hall after the treatment can be said to conform with acceptable international benchmarks and reflects successful design solutions similar to those that have been seen in successful multipurpose auditorium spaces. It can therefore be noted that the proposed enhancements can be considered acoustically acceptable and functionally positive when evaluated against acceptable standards and design targets.

5 Conclusion and Findings

The objective of this research was to assess the acoustic performance of the Media Hall auditorium and to evaluate the effectiveness of specific material-based improvements in enhancing the auditorium's suitability for multipurpose use. To fulfill this objective, this research employed an integrated methodology that incorporated architectural field surveys, parametric acoustic simulations, and numerical analysis via Pachyderm for Rhino/Grasshopper and Fluffy Fish. The evaluation methodology was based on specific acoustic performance parameters, including sound absorption coefficients, sound pressure level (SPL) distribution, and reverberation time (RT), which enabled the evaluation of the acoustic condition of the auditorium and the effectiveness of specific improvements.

The results of the initial analysis indicated that the existing hall already has good acoustic performance in the high-frequency range, mainly due to the presence of fabric-covered wall surfaces and upholstered seating. Nevertheless, the high level of high-frequency absorption, coupled with the lack of low-frequency absorption in the range of 250 Hz and below, created an unbalanced acoustic environment in the existing hall. This is evident in the long reverberation times in the low-frequency range, as well as the bright sound field that lacks acoustic warmth, possibly affecting the comfort of the listeners, especially in the case of musical performances. The reverberation time values in the existing hall varied between 1.6 and 1.85 seconds, showing that the hall performed well in terms of music-related activities, but the values were beyond the optimal thresholds for speech-oriented functions such as conferences and lectures, where shorter reverberation times are critical in ensuring the intelligibility of the spoken words.

The simulation results showed that the incorporation of acoustic treatments, including broadband ceiling clouds, perforated wooden panels with backing absorption, and membrane-based absorption, resulted in a considerable improvement in the acoustic performance of the hall. The improvement was particularly notable in the mid-frequency range, i.e., 500-2000 Hz, where a reduction of reverberation time values by 40-45% was achieved, thereby matching international guidelines for multipurpose and speech-based auditoriums. The reflections in the high-frequency range were satisfactorily managed without causing over-damping, thereby ensuring an appropriate level of acoustic liveliness while greatly improving clarity and speech intelligibility. The improved acoustic performance also resulted in a more even SPL distribution, thereby providing a clearer sound field, which was useful in ensuring the functional flexibility of the hall for conference, lecture, and other purposes.

Despite the improvements in low-frequency acoustic response, the presence of extended decay times in low frequencies could still be observed, thereby validating the observation that low frequency control still remains the weakest aspect of the hall's acoustic response. This result illustrates one of the major difficulties encountered in the acoustics of auditorium spaces, where low-frequency absorption is always difficult to achieve because of the long wavelengths and the enclosed spaces. The results, however, do illustrate that low frequencies play a positive role when integrated into a frequency-specific design strategy.

In all, the results have validated that the suggested material-based improvements have successfully addressed the objectives of the research by improving the speech intelligibility, acoustic balance, spatial uniformity, and functional suitability of the Media Hall spaces for speech, music, and multipurpose usage. The research demonstrates the importance of frequency-sensitive material selection and placement in architectural acoustic design and the benefits of simulation-based processes as reliable and effective tools for diagnosing acoustic problems, assessing design solutions, and informing evidence-based design decisions in existing multipurpose auditoria.

Limitations of the modeling approach

The modeling approach used has some limitations. The simulation results use literature- and manufacturer-based absorption coefficients, rather than in-situ measured ones, which might not accurately take into account the aging of materials or possible variations in installations. The simulation of low-frequency sound fields is approximate, and it is generally more difficult to make accurate predictions in large volume spaces. Moreover, sound sources were modeled as omnidirectional, and audience dynamics were not included in the simulation. The method, however, appears to be appropriate for a comparative evaluation of acoustic performance and improvement between existing and proposed conditions.

Authors contribution

The authors contributed to developing and implementing the plan for conducting their research. They also contributed to analyzing their data, incorporating their respective findings into one document to create their manuscript. Their collaborative efforts played an essential role in their research, emphasizing their commitment to its success.

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