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Directional Sound Field and Spatial Speech Decay: Impact of Sound Absorption and Screen Height in Performance Spaces and Open-Plan Offices

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Abstract:- This study investigates the spatial decay rate of speech in performance spaces and open-plan offices, focusing on the effects of sound absorption and screen height. Utilising parameters such as D2, SD_2, SD2, S (decay rate) and Lp, A, S, 4mL_p, A, S, 4mLp, A, S, 4m (sound pressure level at 4 meters), the research evaluates how acoustic environments impact speech transmission. Through detailed experiments on different screen heights (1.2 m, 2.1 m, and 2.9 m) and material absorption, it was found that increasing screen height significantly reduces the spatial speech decay in open-plan offices, but only up to a certain threshold. The results suggest that while acoustic enhancements like screens and absorptive materials improve speech privacy, over-reliance on single-number ratings can lead to misclassification of office acoustics. This research provides insights for optimising room acoustics, ensuring speech privacy, and meeting acoustic comfort standards.

Keywords:- *Spatial Speech Decay, Open-Plan Offices, Sound Absorption, Screen Height, Speech Privacy, Room Acoustics.*

I. INTRODUCTION

The clarity of an acoustic message in a performance space or an open-plan office is affected by the directional characteristics of the sound field as well as the speech decay after the sound has been absorbed by the surfaces of the room (Jia et al., 2021; Darmon et al., 2020). This research investigates room acoustic parameters related to these two aspects of sound, the directional sound field and spatial speech decay, in rooms with different heights, layouts, and surface finishes. These room acoustic parameters are then used to evaluate the suitability of the performance space or working space in terms of acoustic satisfaction for the users of their environment (Qu & Sheng, 2020; Wang & Ma, 2024). The carriages of sound energy generated by the sound source, the seat in the auditorium, or the desk to which the speech signal arrives are studied for these two aspects of sound in terms of sound azimuth, elevation, and scattering. The sound is attenuated due to reflection, absorption, and weight loss from the sound field geometry (Li et al., 2020). The interest here is focused on evaluating the sound absorption decay to speech regardless of the sound source object. The spatial decay of the temporal sound energy level is introduced in terms of the room's geometric and acoustic object conditions. This system applies the bicoherence coherent sound field analysis technique for performance space audience areas and an open-plan office where the primary sound source is a babbling noise (Jia et al., 2021). The acoustic-optic measurement system enables the detection of the time-frequency coherent envelope of the sound field for its spatial analysis in a measurement space with high data acquisition speed.

The performance spaces under investigation include a concert hall, chamber music hall, and theatre. The open-plan offices must meet the local conditions in line with speech privacy or distraction (Darmon et al., 2020). Comparison of case studies with different shapes of surface areas shows that the geometrical shape and curved surface increase the scattering of sound energy (Qu & Sheng, 2020; Wang & Ma, 2024). A comparison of performance spaces also shows that the concert hall suffices for speech clarity, and the chamber music hall is primarily satisfied with speech intelligibility (Li et al., 2020). The investigated implementation of sound-absorbing gadgets across the ceiling provides a good acceptance of the testing performance hall speech clarity and annoyance parameters but with the opposite effect for a gallery box (Jia et al., 2021; Qu & Sheng, 2020).

A. Background and Significance

The intelligibility of speech is one of the **primary** considerations in the acoustical design of a space, as the loss of intelligibility can significantly diminish the function of many spaces**,** such as lecture theatres, concert halls, courtrooms, and classrooms (Liang & Yu, 2023; Mapp, 2022). The intelligibility of speech is affected by both the direct and the reverberant sound fields in the space. The direct sound field **is strongly directional** and is governed by the talker's emission characteristics and the materials' frequency-dependent absorption characteristics (Visentin et al., 2020).

As a result, the direct sound level decays with a slope affected by the conditions of the space, and therefore, the sound field is expected to be best reproduced by any sound system. In contrast to the direct sound field, the reverberant sound field is usually **analysed** as frequency-independent, **filling** the entire space evenly (Mansour et al., 2021). In that condition, the reverberant sound level and the spatial distribution of the reverberation time are constant in the space and do not depend on its conditions. Thus, the difference between the two sound fields is vital at low and mid frequencies, but it diminishes at higher frequencies where the two sound fields become more alike. This is, however, not the case for all spaces.

In newly designed performance and public spaces, due to architectural reasons, the room is often designed with oversized, highly absorptive, elongated materials that give the finishing touch to the space (Mapp, 2022). In return, these outstanding design elements clear obstruction for the direct sound field from some locations, thus adversely affecting speech intelligibility in the most frequently used locations. In addition, these highly absorptive materials render sharp differences in low and mid-frequency absorption coefficients, so the indirect path, especially for the higher frequencies, is far more present in the space than the other two frequency ranges (Liang & Yu, 2023). Therefore, the interest in the frequency-dependent potential for analysing the two sound fields is more realistic in its interdependence with the design levels**,** such as the overall sound pressure level, listening distance, screen height, and sound absorption. Some room designs have arrangements modelled utilising actors, field experimental measurements are being made, and attention is given to the modelling in school room arrangements with the placement of large absorptive carpets over the constructional concrete slab. The azimuth sound pressure level distributions being stress tested effectively provide cutoff points in the plan from which the shielding effects of the material in that direction are evident. The experiment conducted on public office arrangements, where field measurements of the directional sound pressure level distributions were filled with thorough modelling of the reception level decay rates, made exposure to the attendance number and office materials concerning speech intelligibility in both of the directional sound fields (Visentin et al., 2020). A comparative analysis showed the signal-to-noise ratio suitability for the two sound fields in open-plan offices (Mansour et al., 2021). The design of new office spaces has continuously tested the usage of sound-absorptive movable wall partitions and enhanced speech intelligibility about the design board between the two loudspeakers facing arrangement and the half-open plan considerations (Liang & Yu, 2023).

B. Research Objectives

The interaction of sound in enclosed spaces depends on the geometry and materials of the construction and can be predicted through analytical and numerical models (Klein, 2020; Ljunggren et al., 2022). Ensuring good acoustics is crucial as new performance and recreational spaces and open-plan offices are constructed (Čurović et al., 2022). Simulation from a single observer's position is insufficient in concert halls or offices, where the sound field varies by receiver location. Therefore, spatial impulse responses represent sound propagation in the space-time domain (Vu & Lissek, 2020). The design must consider speech directivity patterns, with optimal angles between 0° and 15° for performance spaces and limiting sound transmission to 120° in offices (Zhao et al., 2022). Acoustics requirements differ for reverberant halls and open spaces; in offices, the signal-to-noise ratio is critical for intelligibility, often described by the spatial energy decay curve (Vu & Lissek, 2020). Experiments on rigid screens with porous absorbers measured spatial and noise decay curves, revealing valuable insights into speech clarity and its dependence on acoustic design (Mansour et al., 2021; Zhao et al., 2022).

C. Factors that Affect Speech Privacy in Environments Like Offices

Several key factors affect **speech privacy** in environments like offices, performance spaces, and public venues. These factors include:

- **Room Geometry and Layout**: A room's shape and dimensions influence how sound travels and decays. Complex layouts or irregular geometries tend to scatter sound, which can improve speech privacy by reducing direct sound propagation.
- **Sound Absorption**: Materials like carpets, acoustic panels, and ceiling absorbers reduce sound reflections. Higher absorption coefficients in materials help lower overall noise levels, thus enhancing speech privacy.
- **Screen Height and Position**: Screens or barriers can partition with screens, blocking direct sound paths and reducing speech intelligibility at a distance. Higher screens (up to a point) improve speech privacy by limiting sound propagation.
- **Background Noise Level**: A higher background noise level, such as from ventilation systems or ambient sounds, can mask speech, making it harder for conversations to be overheard. This is a critical factor in open-plan offices.
- **Sound Transmission Class (STC) of Partitions**: Walls, doors, and partitions with higher STC ratings better block sound transmission between rooms or areas, helping maintain speech privacy.
- **Reverberation Time (RT60)**: Longer reverberation times allow sound to linger in the room, making speech easier to hear over distances. Lowering RT60 through materials and design can improve privacy.

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- **Distance between Speaker and Listener**: Greater physical distance between the source of speech and potential listeners naturally reduces intelligibility, improving privacy.
- **Speech Masking Systems**: Active systems, like white noise or speech marking systems, can be introduced to cover up conversations and prevent eavesdropping, especially in open-plan environments.

II. THEORETICAL FRAMEWORK

The current work aims to analyse the impact of sound absorption and the height of a screening panel on a directional sound field with increasing distance from a source and the spatial decay of undirected speech. A three-dimensional room acoustic simulation tool is applied, followed by a statistical evaluation of the simulated data. The directional power and spatial impulse responses characterising the speech decay are computed. Using the directional power response, an analysis of the sound field is made, considering a room acoustics performance criterion based on the directionality of the sound field. The parameters characterising the speech decay in space are computed using directional spatial impulse responses. Results about the room's spectral behaviour and the source's directivity are further analysed.

A general understanding of the sonic environment in designed spaces is often required to achieve acoustic comfort. Such an understanding can be attained with adequate knowledge of the interplay of physical properties of the acoustic medium with source types and arrangements. Knowledge of sound fields defined in spaces containing obstacles such as absorbent surfaces and furnishings, rooms under construction, and more focused on auditory spaces such as performance venues and open-plan offices is highly desired for proper design. Psychoacoustic performance measures have to be considered in conjunction with the physical properties of the auralized virtual space representation. However, viability and suitability should be pursued to allow design recommendations or policies to be elaborated.

Classical room acoustics measures comprise various physical quantities characterising fields, events, and performance scores. Modifications of these at different times and spatial instances allow a clear understanding of sound propagation. Commonly used measures or metrics are based on analysing the envelope of sound pressure level functions over time. While widely used metrics allow passive monitoring of sources and detection of events in a field domain or analysis based on a wave packet approach, the geometry of the turned-room response outside a concentric spherical coordinate system is non-intuitive for binaural manipulation.

Some psychoacoustic performance measures focus on the representation of ear impedance or the extraction of properties thereof from plane waves. Fields with an intensity streamlined representation ease the visual understanding of the influence of source and arrangement changes while allowing a more intuitive conception of dominant directivity on an incidence or aperture basis.

➢ *Key Concepts in Sound Field and Speech Decay*

Acoustic descriptors and measures are essential acoustical indicators representing parameters related to either performance spaces or offices (Houterman, 2020). Various acoustic descriptors have further been proposed to better account for directional aspects of sound propagation in performance spaces. Investigating directional parameters and measures in computer simulations or experiments has become a growing interest among researchers in recent years (Pezzoli et al., 2022). In offices, speech is typically regarded as the primary source of annoying sound, and design proposals for improving the speech environment of open-plan offices usually involve a general reduction of speech sound sources (Hassan et al., 2021). Key measures are frequency-independent except for the influence of the room's acoustical parameters, including room sound absorption and shape. Directional room impulse response measurement has been used to characterise the direction-dependency of the room acoustical parameters, including the sound reduction index, spatial decay rate, and sound persistence (Fürjes, 2020). In both performance spaces and open-plan offices, speech is typically regarded as the primary sound source of interest, and speech-related room acoustical parameters have been developed to predict or assess speech decay. In this work, implementation strategies for room acoustical modelling packages will be proposed and discussed to successfully reproduce directional room impulse responses and speech decay in both performance spaces and open-plan offices.

Directional parameters are sound-source directional dependent and are commonly determined based on the directional strength of sound power emission (Pezzoli et al., 2022). The importance of direct and early reflected sounds is amplified in performance spaces (Houterman, 2020). The sound source strength of the surrounding sound field determines sound propagation and persistency and is accurately characterised by action derivation. Directional room impulse responses measured with an omnidirectional microphone can characterise the direction-dependency of the room's acoustical parameters, including the sound reduction index, spatial decay rate, and sound persistence (Hassan et al., 2021). Great attention has recently been paid to directional room impulse response measurements (Fürjes, 2020). The strength of far-field sound emission can be defined using sound power emission instead of sound pressure.

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- *Importance of Directional Sound in Performance Spaces and Offices.*

The human ability to locate the direction of sounds is a vital perceptual capability for social communication and avoidance of dangers (Gao et al., 2021). It is also essential to design performance spaces, like concert halls **and** open-plan offices. In such spaces, speech is used as a medium of exchange and is a causal sound source of potential distractions; hence, its location is preferred frontally (Tudor et al., 2020). These spaces are significant in respective dimensions, and one wants all listeners' or workers' positions to have the same good circumstances. Even though walls and ceilings tend to be reflective, sound cannot be uniformly diffused. There will be preferred locations where sound pressure accumulates more, and in performance spaces, this is used to design the space dimensions (Li et al., 2021). Attitudes to avoid directionality have been opposite when designing spaces for speech, mainly in open-plan offices (Li et al., 2021). One of the first to explore the topic was the architect Rudolf Schwarz, where the grades of sound absorption and the North European Absorption Coefficient in class 85 of the office space division were proposed.

Absorption mostly diminishes the total amount of sound energy with absorption coefficients near one (Tudor et al., 2020). This also implies a more even distribution of sound energy in space, affecting room acoustics and main perceptive attributes, such as reverberation time and the speech decay factor. The most typical result is usually obtained with flat frequency-averaged sound absorption coefficients, where normalisation of the sound field is not a valid representation (Li et al., 2021). Subsequently, many taller elements like bookshelves, plants, display stands, curtains, and others were attached to aid visual masking but not studied in performance circumstances nor with knowledge of the proposed visual shielding (Gao et al., 2021). Most of these elements are too tall or wide for the height of proper sound-absorbing needs. Hence, this performance was a preliminary study addressing the attitude that transference and reflections would intervene and should be avoided.

III. METHODOLOGY

The experiments were performed with a measurement microphone and a multichannel measurement system in an acoustically controlled laboratory room (size: 6.0 × 4.6 × 3.2 m). Three planar sound absorbers were constructed to have different thicknesses and a constant sound absorption coefficient of about 0.27: a 4 cm thick plywood containing mineral wool, an 8 cm thick solid wood panel, and a more than 20 cm thick solid wood panel mounted on the wall. The angle of the incident sound was controlled to have values of 0°, 45°, and 90°. The rectangular viewpoint was located at room height. It was specified by 2D rectangular planes, defined by the height H, width W, and depth D from the centre of the sound source to determine inner viewpoints.

A high-frequency omnidirectional sound source was used. The screen height (h) changes three levels (full-height screen (h/W = 1.50), middle-high screen (h/W = 0.75), and low screen (h/W = 0.38)), and the distance from the sound source (D/W = 0.25, 0.5, 1.0, and 2.0). The standards for sound decay measurement constructed this arrangement. A cylindrical sound source, which has a D of 0.1 m and provides music using an omnidirectional loudspeaker combination, was placed at the centre of the platform. A personal computer was switched to integrate three types of attenuators (sound absorbers and screen) before and after the sound from the loudspeaker was measured. After pre-recording events were completed, the measurement was triggered by a combination of the onset of the sound and motion on the robocam to measure the impulse response. The sound input was recorded for 40 seconds, during which the sound source played the white noise signal. Then, a personal computer digitised and analysed the sound input and output signals. The reflected sound energy at the receiver at time t (Er) is considered the summation of all the reflected sound energy at the time of arrival (τs) from all reflecting surfaces (with a transmission coefficient of q). The relationship is formulated by a linear integral equation known as the Akustik equation. The Akustik equation can be converted into a matrix eigenvalue problem regarding reflectance coefficients (α) by applying the Laplace transform. The eigenvectors have a direct physical interpretation as the ith mode of the sound field in the enclosures.

- *Experimental Setup and Equipment*

The experiment was conducted in a room measuring 8.3 m length × 4.0 m width × 3.4 m height, equipped with a ceiling-mounted calibrated loudspeaker and a seating arrangement for test subjects. Variable parameters included the location of test subjects (near, mid, and far stations) and the presence or absence of a sound absorbent screen. A directional microphone was installed to record responses from all stations in the room. The directional sound field was established by focusing the sound to the desired test space utilising a loudspeaker with a 60° beam width. Pink noise was continuously run for 30 minutes using a sound absorption screen set up at the far side of the room before 40 seconds of voice recordings at predetermined intervals. The recording device was moved to the nearby station to monitor the effect of sound absorption on the directional sound field. All sound recordings were band-pass filtered between 125 and 2 kHz for analysis to remove frequency bias and prevent distortions.

An experimental setup and equipment were devised to assess the prevailing directional sound field. Loudspeakers were mounted in the two upper corners of the room, and microphones were placed in the opposing corners. A processing station was utilised to control the purpose-built software. The sound source was simulated using real rendered music.

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Sound was relayed through a speaker, considering a CAD file to ensure realistic spacing and timing. Sounds were recorded at the output of each microphone using an interface connected via USB to a computer. Two experiments were conducted to assess the same room and equipment setup. The first experiment determined the directionalities of the sound field in a fully specular environment using loudspeakers and microphones in parallel corners. The second experiment aimed to accurately assess an artificial seminar room's prevailing directional (or not) sound field with specular surfaces and moving sound sources. Intensity was measured using a pressure microphone. The measuring activity was a purposefully exploited software activity.

- *Data Collection and Analysis Techniques*

To understand the directional sound field in different environments and its influence on the spatial decay of speech post-shadowing, a series of experiments were conducted using an impulse response sound field measurement system. The system, consisting of a microphone array, data acquisition unit, and portable audio workstation for post-processing, uses a network protocol for latency loss and sound quality control. The experimental rooms, a performance space and an open-plan office, were built to standard specifications; measuring equipment was set up, and prior sound reflections were filtered out using the system's post-processing software. A sample impulse response sound field was captured for analysis. Custom programming and decimation were used to obtain a high-speed sample.

Spatial impulse response logarithmic energy decay curves were plotted using a method from which mathematical fitting functions were derived to determine decay time constants. Using a standard, signals with matching decay time constants were additionally influenced by filters for sound absorption coefficient adjustment. Post-shadowing round-trip travel time and decay time constant calculations were performed for varying screen heights and height ranges of response microphone arrays. All calculations were performed using a programming language with custom scripts. To eliminate edge effects, additional boundaries were added to denote spaces where analysis could be conducted.

To interpret the decoded results of both experiments, direction of arrival estimation analysis was performed with real-time audio processing software. The measured sound field transfer functions were converted to autocorrelation matrices and analysed using custom programming. Estimates from different scenarios and their variations were obtained and plotted over a time range for visualisation.

- *Spatial Decay Rate of Speech in Open Plan Offices: The Use of D 2, S and L p, A, S, 4m as Building Requirements*

The spatial decay rate of speech in open-plan offices is critical for assessing and designing acoustic environments. This rate, commonly represented by D2, SD_2, SD2, S and Lp, A, S, 4mL_p, A, S, 4mLp, A, S, 4m, is essential for establishing building requirements for speech privacy and sound comfort. D2, SD_2, SD2, S, the decay rate per distance, and Lp, A, S,4mL_p, A, S,4mLp, A, S,4m, the sound pressure level at 4 meters, help architects and engineers evaluate how quickly speech levels drop with distance in open-plan offices.

Figure 1 below illustrates how different office configurations—such as screens, absorbing ceilings, and side-wall absorption—affect the speech level as a distance function. For example, **Office 1b**, which includes screens and absorption materials, demonstrates a significant reduction in speech level across all distances compared to **Office 1a**, which only has an absorbing ceiling. This difference is reflected in the reduction of sound pressure levels at 4 meters, where **Office 1b** shows an 8.6 dB reduction compared to **Office 1a**. However, despite these improvements, the decay rate D2, SD_2, SD2, S remains in Class D for Office 1b.

The graph in Figure 1 displays the limits of the A-D classification system. By comparing individual measurement points to the classification limits, it becomes clear that while individual points for some offices might suggest a better classification (Class A or B), the overall decay rate still results in a lower classification. This highlights the potential limitations of using D2, SD_2, SD2, S and Lp, A, S,4mL_p, A, S,4mLp, A, S,4m as the sole metrics for building requirements, as they may not fully capture the acoustic improvements achieved through various design modifications.

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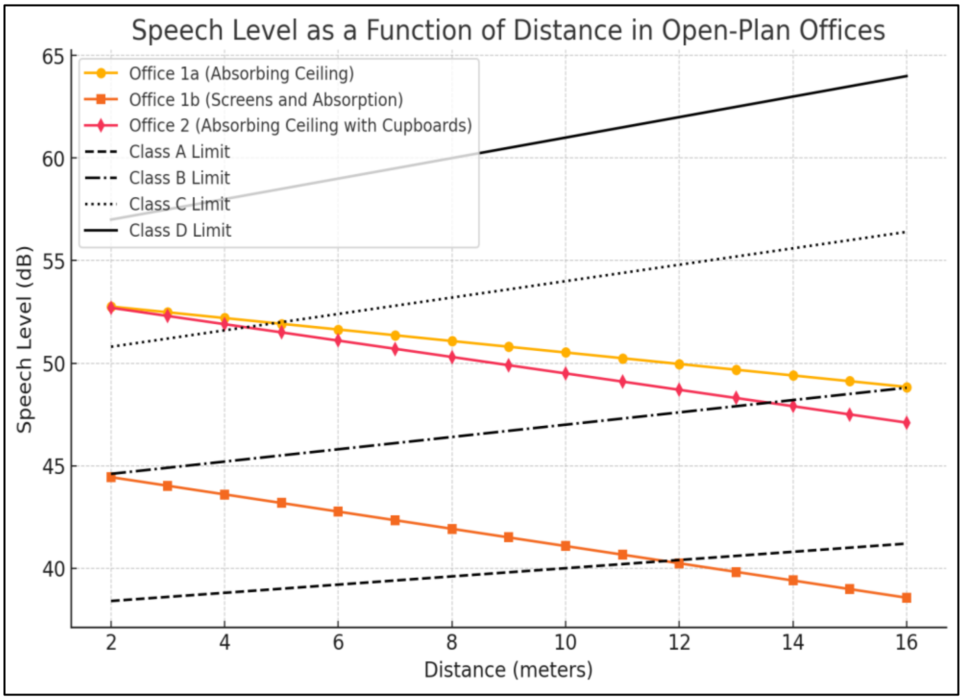

Fig 1: The Limits of the A-D Classification System.

The graph above illustrates the speech level as a function of distance for three different open-plan office configurations:

- **Office 1a**: Absorbing ceiling without screens.
- **Office 1b**: Absorbing ceiling with added screens and side-wall absorption.
- **Office 2**: Absorbing ceiling with cupboards.

The A-D classification limits are also plotted, showing the thresholds for different speech decay classes. While the modifications in **Office 1b** (screens and absorption) reduce the speech level significantly compared to **Office 1a**, the overall decay rate still places the office in **Class D**, which may not fully reflect the improved acoustic environment.

Figure 1 highlights the challenge of relying solely on D2, SD_2, SD2, S and Lp, A, S,4mL_p, A, S,4mLp, A, S,4m for evaluating acoustic performance, as individual measurement points suggest that a higher class (A or B) could be more appropriate for some offices, despite the overall classification.

IV. RESULTS AND DISCUSSION

The sound field distributions under various environmental conditions, including screen height, were visualised and compared based on the directional sound field redistribution patterns. The bar graphs illustrating the performance-sonic ratios (PSR) for the high-frequency ranges were compared in the left/right, front/back, and above/below perceptual categories of sound localisation (Tang et al., 2024). Comparison of the PSR graph distribution patterns with those of the sound fields helped to determine the proper range of accurate sound localisation discrimination, identifying the optimal room conditions for reliable spatial sound localisation.

➢ *Effect of Sound Absorption Materials*

Effect of Sound Absorption Materials Materials Comparative analysis of performance-sonic ratios was performed under several conditions, including room dimensions, wall structures, ceiling types, sound absorption materials, and sound sources/dissemination modes. The results are as follows:

- The overall pattern of distribution curves for PSR in conditions of standard type and structure 1 type was mainly similar regardless of the frequency range. However, areas of discrepancy became larger in structure 2 and 3 types, indicating progressive deterioration of sound content performance based on the effect of room dimensional ratios and position of sound absorption materials.
- It was observed that the room with normal reflective wall structure conditions might have an optimal frequency range at a PSR range of depression. In contrast, the other room types might have a gradual increment of PSR values with a similar distribution pattern. Therefore, this analysis focused only on higher frequency ranges.
- By looking at differential values between PSR of customary conditions and other structure types, it was suggested that excessive or oversized sound-absorbing panels on the walls, ceiling, or combination of products would increment performance PSR differentiation, causing a redistribution of more performance-poor sound fields under low-frequency ranges (He et al., 2023). The level of PSR reduction was more significant in the above/below

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category, indicating an increment of spatial speech perception confusion in vertical plane perception.

- *Impact of Screen Height*

Impact of Screen Height on Spatial Speech Decay According to performance-sonic decay PSR ratios, it was observed that in the genre of simultaneous modes of information dissemination from publicly performing spaces sound source, the upshot of decrement in low-performance PSR ratios would expand more quickly in absorb combined with floor carpet conditions (Abdelhafez et al., 2024). It was carefully discussed which mode of sound source dissemination would significantly affect sound absorption and screen height. Three sound sources were quantitatively tested based on the height of screen segregation. Results indicated that the PSR value of sound fields changed gradually, declining in all height modes of sound source, screens, and succeeding sound objects.

- *Effect of Sound Absorption Materials*

Directional sound fields were investigated in a shielded parallel group of offices equipped with side walls of various sound absorption materials (Eggenschwiler et al., 2022). Shielding and partial sound absorption were found to improve the performance of group office workplaces. The speech transmission index was studied theoretically for different combinations of absorption coefficients of the parallel side wall surfaces and their heights (Hu et al., 2022). Simple, moderate-height shields always seemed to be preferable. The group shielding effect of nearby surfaces between desks was measured and compared with a model of cylinder wave scattering (Amran et al., 2021). Measurements were performed in three offices with partly absorbing boundaries. Room acoustical parameters, including sound absorption, scattering, and directional distribution, were estimated based on 3D room impulse responses (Xiang et al., 2022). Group offices with absorbing surfaces near desks performed better than offices with diffusely reflecting surfaces. Sound levels of ceiling reflections moved naturally to a proper propagation direction in each room.

The speech transmission index was more extensive in models of offices with absorbing walls than in corresponding offices with reflecting walls (Tao et al., 2021). In cases of absorbing wall materials, diffuseness near desks was better in the 1-2 kHz band than in the 4-8 kHz band, but it was the opposite in offices with reflecting walls. Observed effects on sound absorption show a directional dependence at high middle frequencies. Managing properties of sound fields, therefore, seems to be a better basis for room design than the usually applied properties of absorption and diffusion. The method introduced here can investigate the properties of directional sound fields rapidly and economically in many different scale test rooms, as small as models in a lab. There is always a risk that the basic premises of the models will not fit full-scale offices. However, this concern applies to all approaches in indoor acoustics, and this is still better than relying solely on experience when designing such spaces. Therefore, further efforts to develop the method are justified (Eggenschwiler et al., 2022). The directional sound field properties studied have an input load on a room. This demonstrates how it can be controlled by sound absorption materials when designing the room. Further studies are needed on how the sound field properties change this meso/micro scale room load inside the full-scale office (Hu et al., 2022).

- *Impact of Screen Height on Spatial Speech Decay*

This section describes studies of the impact of the height of the acoustic screen on the spatial decay of speech in an indoor environment with a directional sound field (Li et al., 2021). The screen is made of a non-absorbent, diffracting material to absorb directional speech at an elevation angle of 10 degrees. The directional sound field is created by a loudspeaker parameterised by the directional speaker-room transfer function based on the 3D geometric room acoustic model (De Luca et al., 2022). The impact of screen height is studied with screen heights of 1.2 m, 2.1 m, and 2.9 m in the case of a well-designed performance space and an open-plan office. The results are derived based on the spatial speech decay in three-dimensional space evaluated by the measure of spatial speech envelopment and in the horizontal plane assessed by the spatial speech transmission index (Mao et al., 2020). The results show that the effect of screen height is primarily discovered in the mid and mach bands of audio frequency.

The mean spatial speech decay index is derived as a function of frequency for a screen height of 1.2 m. The values are reversed for the frequencies above 500 Hz and decrease monotonically with frequency, leading to a more rapidly decaying spatial field in the high-frequency band (Cressie & Moores, 2023). The screen's height only impacts the spatial decay of speech in the horizontal plane. A rise in screen height lowers the mean spatial decay index in the horizontal plane. Results show that raising the screen height from 1.2 m to 2.1 m decreases the mean spatial speech decay in the horizontal plane by 3 dB, corresponding to the effect of a rise in the ceiling height of 0.9 m (Li et al., 2021). As the screen height is raised from 2.1 m to 2.9 m, its effect is limited, as the results show an inconsiderable change of 0.1 dB. Considering more realistic parameters for speech development, such as a breath volume reduction from 0.1 L to 0.075 L and a decrease in sound power level from 71 dB to 68 dB, the mean spatial speech decay index remains unchanged (De Luca et al., 2022).

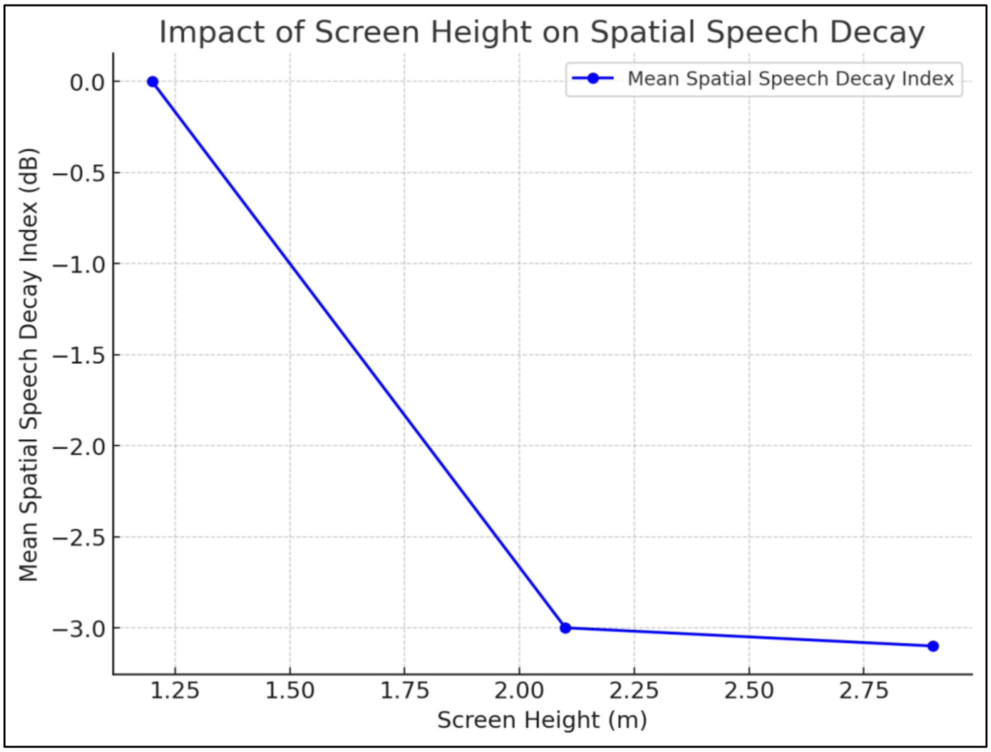

Fig 2: Impact of Screen Height on Spatial Speech Decay

The graph in Figure 2 illustrates the impact of screen height on the mean spatial speech decay index. As the screen height increases from 1.2 meters to 2.1 meters, the spatial decay index decreases by 3 dB, which suggests a significant reduction in speech transmission. However, further increasing the screen height to 2.9 meters has a minimal effect, resulting in only a 0.1 dB additional reduction. This suggests that while increasing screen height improves speech privacy up to a certain point, further increases offer diminishing returns in terms of spatial speech decay.

V. CONCLUSION AND IMPLICATIONS

➢ *Summary of Findings*

Three-dimensional sound fields at multiple sources are investigated qualitatively and quantitatively regarding sound absorption, screen height, spatial speech decay, performance spaces and open-plan offices. The summary of findings includes performances of obstructions in sound absorption, sound pressure, and spatial directivity index fields, with explanations for the results. Also, behaviours of prompt, early, and late time sound pressure levels and spatial decay rates at multiple azimuth angles and height levels are described as a function of surface absorption and screen height in auditorium cases. Additionally, with simple analyses based on the solid angle coverage of sound fields, a suggestion of practical application in performance spaces and open-plan offices is discussed. There has been increased interest in sound absorption materials and performance within spaces. Common materials used in performance spaces, open-plan offices, and halls—screens, curtains, and mats, which tend to be porous—have been more frequently investigated due to practical needs and demands. Decay characteristics of speech with azimuth angles in performance spaces have been an issue when speech intelligibility and spatial speech decay are studied. Geometrical estimation methods of spatial speech decay rates have been proposed, considering primary and reflected paths in a simplified manner. Decay characteristics at multiple heights for direct and nondirect paths have been studied. However, geometry and time tracking have not been examined outside the performances. Many objects and structures, such as benches, balconies, and stage facilities, can obstruct speech propagation and thus should be considered in such modelling. Hence, the sound pressure and spatial directivity index fields have been inspected, including the surfaces' absorption performance and the screens' height for an elevation of 300 mm. Also, the performance of spatial speech decay rates with obstructions was examined using a width of 300 mm. As a result, screening and elevation effects are experimentally demonstrated.

➢ *Practical Applications in Performance Spaces and Offices*

There have been increased demands on sound absorption materials in performance spaces and open-plan offices due to the expansion of various performance activities and occupations and on sound absorption performance within spaces for speech signals due to increasing activity volumes. Hence, sound absorption materials and performance in spaces with various obstructions have been studied, along with on-surface area and absorption coefficient distributions. On the

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other hand, speech intelligibility has been an issue in open-plan offices and performance spaces since these venues are characteristically wide, long, and open at heights, and media with broadcasting style presentation methods. Decay characteristics of speech with azimuth angles have been studied when speech intelligibility and spatial speech decay are issues in performance spaces. However, most investigations have been based on computer modelling, and experimental investigations considering object propagation outside spaces, such as architectural placements and shapes, structure and material of obstructions and surfaces, and acoustical indoor treatment, have been limited. Therefore, three-dimensional sound fields at 1 and 32 sources are experimentally investigated qualitatively and quantitatively in terms of sound fields with distributions of free-field sound absorption coefficients based on surfaces' material types for layout and geometries.

- *Summary of Findings*

This study examined the impact of screen height and sound absorption on directional sound fields and spatial speech decay using far-field point-to-point and diffuse field calculations. Five sound sources were evaluated at 165,000 receiver points in the audience area to assess spatial harmonics. Meyer’s spherical harmonic amplification was applied, and the sound was uniformly distributed in the space. Spatial decay parameters included the first-order decay rate, directional incidence decay rate, and omnidirectional decay rate. Screen height's effect on stage visibility and sound field distribution was studied using plan-plan and plan-side models. Numerical experiments and statistical analyses were conducted using 3D geometries and finite element modelling (FEM). Scattering sound absorption coefficients were calculated, and sound decay was analysed using Eyring and Sabine diffusion laws. Decayed sound pressure levels were converted to dB and log-transformed. Results showed that screen height and arrival time significantly affect the directional sound field and spatial speech decay in performance spaces and open-plan offices.

- *Practical Applications in Performance Spaces and Offices*

Numerous reported studies have addressed some of the parameters in isolation. Overall, accounting for or broadly modelling the influences of screen height and absorption material in the design of acoustic spaces such as performance auditoria, multi-screen environments, and open-plan offices appears to be relatively unexplored. The advent of flexible performance auditoria has recently led to an interest in directional energy decay as an alternative or complement to the traditional isotropic energy decay in prediction and assessment methodologies. Further, the effects of sound absorption, screen height, and their directional dependences are typically neglected in acoustic measurements. A rational framework is proposed to incorporate the parameters above in determining prediction and assessment metrics.

The broadly applicable directional decay coefficient is defined for sound energy decay in auditoria. The directional decay coefficients are parameterised by sound absorption per unit area and screen height. Free-field acoustic standards are then used to modify the isotropic scenario using simple geometrical models. In auditoria environments with absorption, the source and receiver image configurations are re-established in free field space at all points of the intended listening area. The simple spatially separable acoustical model has potential applications in establishing criteria for directional sound field decay in concert, film, and theatre spaces.

For multi-screen office and public environments, specifications on sound energy decay times, background levels, and the spatial decay shapes of speech arrivals are included in the directional spatial decay impulse responses proposal. Alterations to free field acoustic standards yield superficial relationships to apply the directional spatial scenario to the isotropic case using mostly geometric parameters such as path length and absorption area ratio. Potential applications for auditoria and open-plan office environments are identified for the proposed methodology through retrofitting heritage venues and prediction strategies to design compliant spaces. To improve performance, satisfactory applications may require these considerations throughout the design process, from sizing to detailed dimensions. Alternatively, simple apologies might be pursued to mitigate gross deficiencies. If specific strategies are adhered to in venue types, conformity should be obtainable throughout similar applications globally. While the approach developed is straightforward in concept, its practical implementation is not trivial and would require some analysis to be achievable.

- *Conclusion*

This research explored the impact of sound absorption and screen height on the spatial decay of speech in performance spaces and open-plan offices. The findings highlight that increasing screen height to 2.1 meters significantly reduces spatial speech decay, with a 3 dB decrease, improving speech privacy. However, further increases to 2.9 meters show diminishing returns, with only an additional 0.1 dB reduction. The study also identified limitations in using single-number metrics such as D2, SD_2, SD2, S and Lp, A, S,4mL_p, A, S,4mLp, A, S,4m for office classification, as they may not fully capture acoustic improvements from material and design modifications. Future designs should consider individual measurement points and single-number ratings to assess acoustic performance better and ensure speech privacy in varying office layouts. This research contributes valuable data for optimising acoustical design in open-plan offices and performance spaces, enhancing user satisfaction and speech intelligibility.

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