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LABYRINTHS OF SOUND: ADAPTIVE ACOUSTIC SOLUTIONS FOR PUBLIC BUILDINGS

LABIRYNTY DŹWIĘKU: ADAPTACYJNE ROZWIĄZANIA AKUSTYCZNE W OBIEKTACH UŻYTECZNOŚCI PUBLICZNEJ

Abstract

The article presents a concept of adaptive acoustic systems for public utility buildings, integrating architectural acoustics, materials engineering and user-centred design. Contemporary users increasingly experience sensory overload generated by the environments in which they function. Insufficient acoustic comfort in work and learning spaces can significantly impair information processing, concentration, attentional selectivity and reaction speed. Reducing unwanted noise sources, optimising reverberation time and improving speech intelligibility not only reduces sensory strain but also supports cognitive processes, communication and psychological well-being. Adaptive architectural acoustic solutions and multisensory design strategies enhance users' spatial orientation, support concentration and foster inclusive environments, particularly for neurodivergent individuals.

Keywords: *acoustics, adaptive architecture, public utility buildings*

Streszczenie

Artykuł przedstawia koncepcję adaptacyjnych systemów akustycznych dla przestrzeni obiektów użyteczności publicznej, łączących akustykę, inżynierię materiałową i projektowanie skoncentrowane na użytkowniku. Współczesny odbiorca zmaga się z przeciążeniem sensorycznym wywołanym przez środowisko, w którym funkcjonuje. Brak komfortu akustycznego w strefach pracy i nauki może znacząco wpływać na efektywność przetwarzania informacji, poziom skupienia, selektywność uwagi i szybkość reakcji użytkownika. Redukcja niepożądanych źródeł hałasu, optymalizacja czasu pogłosu i poprawa zrozumiałości mowy nie tylko minimalizuje obciążenie sensoryczne, lecz także wspiera procesy poznawcze, komunikację i dobrostan psychiczny użytkowników. Adaptacyjne rozwiązania architektoniczno-akustyczne i wielozmysłowe strategie projektowe mogą poprawić orientację użytkowników w budynkach, zwiększyć ich poziom koncentracji i tworzyć środowiska inkluzywne, zwłaszcza dla osób neuroróżnorodnych.

Słowa kluczowe: *akustyka, architektura adaptacyjna, budynki użyteczności publicznej*

1. INTRODUCTION

Contemporary living and working environments place an increasing sensory load on occupants. Inadequate acoustic comfort within the spaces where people live and work adversely affects information processing, concentration, attentional selectivity and reaction speed. Chronic exposure to noise undermines learning outcomes, reduces work efficiency and impedes social interaction. Noise reduction, optimisation of reverberant conditions and enhancement of speech intelligibility mitigate these negative effects and support cognitive processes as well as users' well-being. Acoustic comfort in public building spaces should therefore be treated as a fundamental design objective.

Adaptive architectural-acoustic solutions and multisensory design strategies can improve users' spatial orientation, increase their capacity for sustained attention and foster more inclusive environments, particularly for neurodivergent individuals. The aim of the solutions presented here is to improve the quality of existing public-use facilities and to adapt them to current and future challenges. Although numerous acoustic technologies are available on the market, the crucial task is to relate objective acoustic parameters to users' lived experience of space.

Educational spaces constitute a distinct category of public interiors, characterised by multifunctionality and variability of use. Using lecture rooms at the Faculty of Architecture, Wrocław University of Science and Technology, as an example, one can identify multiple modes of operation within the same physical space: individual consultations, lectures with a single centralised sound source, lectures with distributed sound sources, small-group work generating local sound clusters, and simultaneous teaching by two lecturers with two concurrent student groups. Such functional variability imposes specific acoustic and organisational requirements and justifies the need for flexible acoustic design solutions tailored to diverse usage scenarios.

Within the research programme of the Laboratory of Architecture and Sound (LAiD) at the Faculty of Architecture, Wrocław University of Science and Technology, hybrid, lightweight and mobile modules have been developed to modulate reverberation time (RT) and improve speech transmission index (STI), thereby enhancing learning conditions in higher-education teaching spaces. These interventions are intended to improve users' orientation and well-being. The laboratory has also conducted student workshops in which the designed mobile forms were empirically validated through acoustic measurements.

2. HARMFUL EFFECTS OF NOISE: ROOM ACOUSTICS AND ABSORPTIVE ELEMENTS

Noise pollution is a significant environmental factor that adversely affects health, well-being and the effectiveness of work and learning. Its impact depends on the physical characteristics of the source and the duration of exposure, as well as on individual psychophysiological resilience and the nature of the tasks performed. Empirical studies indicate that prolonged exposure to noise disrupts the functioning of the nervous, cardiovascular and digestive systems, increases the risk of psychosomatic disorders and reduces work performance by impairing concentration, memory and reaction speed. In public and industrial environments, excessive noise further impedes communication, degrades speech intelligibility and may contribute to

accidents. Therefore, in cultural, educational and occupational settings, noise mitigation is a prerequisite for acoustic comfort and user well-being.[1]

Sadowski defines room acoustics in buildings as the shaping of appropriate acoustic conditions necessary for the transmission and reception of music and speech within rooms, achieved through the selection of suitable volumes, geometric proportions and forms, and through the arrangement of elements that direct, diffuse and absorb sound according to functional requirements. One of the principal acoustic parameters of a room is reverberation time, which is the interval over which sound decays after the source is switched off. Reverberation time influences speech intelligibility and the character of musical timbre; excessively long reverberation distorts speech and raises the perceived noise level through reflections.[2]

In public-use interiors, the perception of sound is governed by room characteristics including internal and external noise sources, distance from the source and the propagation of waves within the space. The acoustic contact between a performer (or speaker) and a listener depends on the ratio of the direct sound to the room reflections. The proportion of direct sound determines the clarity of the message, and its degradation rapidly diminishes perceptual quality.[3]

Acoustic adaptations within such rooms are critical to their functional value because they determine the quality of spoken-sound reception. Design solutions should ensure low levels of external and internal disturbance, high speech and music intelligibility, uniform sound coverage, absence of discrete echoes and appropriate sonic qualities. In large halls a compromise is often required between a short reverberation time that favours intelligibility and a longer reverberation that supports a full musical sound. High disturbance levels cause masking and distortion, thereby degrading perceptual quality.[4]

Absorptive materials and constructions are classified into two groups: (I) sound-absorbing materials and products, and (II) sound-absorbing systems. The first category includes materials used as infill for acoustic systems (e.g. textile products, mineral wool, porous boards) as well as factory-formed panels or mats with decorative surfaces that can be mounted directly on walls and ceilings. The second group comprises absorptive constructions: panel, membrane, perforated or spatial systems designed with attention to both acoustic performance and aesthetic requirements.[5]

In designing adaptive acoustic solutions, the selection of absorptive materials and elements is essential. Their purpose is to reduce noise levels in enclosed spaces by limiting the energy of reflected waves. The assessment of absorption properties is conducted in accordance with European standards that specify measurement methods and laboratory conditions to ensure comparability of results. Absorption characteristics depend on material structure, porosity, thickness and mounting method. Appropriate combinations of components allow the designer to shape a frequency-dependent absorption profile that meets the functional

[1] J. Sadowski, *Akustyka architektoniczna*, Państwowe Wydawnictwo Naukowe, Warszawa–Poznań 1976, p. 68.

[2] *Ibidem*, pp. 13, 38.

[3] J. Kulowski, *Akustyka sal. Zalecenia projektowe dla architektów* (2nd ed.), Wydawnictwo Politechniki Gdańskiej, Gdańsk 2011, p. 81.

[4] T. Zakrzewski, R. Żuchowski, *Kompendium akustyki architektonicznej wraz z przykładami metod obliczeniowych*, Wydawnictwo Politechniki Śląskiej, Gliwice 2009, pp. 148–149.

[5] J. Sadowski, *op. cit.*, p. 137.

requirements of the interior, forming the basis for systems that enable dynamic regulation of acoustic conditions.

2.1. SOUND-ABSORBING MATERIALS AND SYSTEMS

A wide range of solutions supporting the acoustic performance of building interiors is available on the market. These include sound-absorbing materials and absorptive systems. Materials whose dominant property is absorption typically exhibit a porous or fibrous structure; this group comprises textile fabrics, mineral and natural wools, mats and fibreboards, cellular concretes and porous plasters.[6]

Textile absorbers and textile acoustic products such as carpets, runners, curtains, felts and nonwovens are effective primarily in the mid-to-high frequency range but show limited absorption at low frequencies. Consequently, they are principally used as supplementary elements to regulate reverberation time within those frequency bands. Absorptive systems enable deliberate shaping of an interior's absorption characteristics because their acoustic behaviour can be predicted and calculated, allowing the construction to be tailored to the room's acoustic requirements. Such systems are manufactured both from intrinsically absorptive materials and from non-absorptive building materials (e.g. perforated metal or plywood) that acquire absorptive properties only when integrated into a properly designed system. A spatial absorber is an absorptive system formed as a three-dimensional body shaped to meet specified acoustic requirements, thereby achieving the desired absorption characteristics.[7]

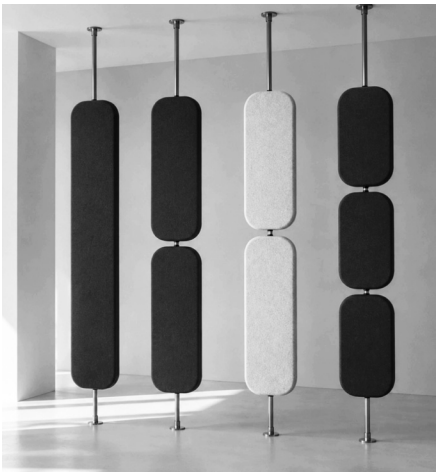
Acoustic screens, functioning as combined insulating and absorptive barriers, are introduced between a source and a receiver to interrupt the propagation path of sound waves. In public buildings, fixed or mobile screens constructed from panels or segments are commonly used. Although their effectiveness is lower than that of full enclosures, screens are useful where complete enclosure of a noise source is impractical. Their principal advantages are flexibility of placement and a wide variety of available shapes and sizes; however, their performance is generally more limited than that of other absorptive systems, and they are typically effective for sound level reductions of approximately 10 dB.[8]

Commercial developments include as well environmentally friendly acoustic systems made from PET felt, designed for diverse interior applications. These product ranges commonly comprise wall panels, acoustic ceilings, islands, screens and movable acoustic panels that permit flexible reconfiguration of interior layouts without erecting permanent partitions.[9]

There are also solutions such as soundproof booths, which are designed to provide acoustic separation from the surrounding environment and to control the internal acoustic conditions. They can be employed to protect speech privacy, to isolate noise sources and to create a controlled acoustic space. Depending on user needs and spatial constraints, booths may be semi-open or fully enclosed. Their degree of isolation depends, inter alia, on the materials used and their thickness. A practical example is the modular system

[6] S. Będkowski, *Akustyka budowli. Ochrona przeciwdźwiękowa*, Wydawnictwo Politechniki Wrocławskiej, Wrocław 1974, p. 68.
[7] J. Sadowski, *op. cit*., pp. 141, 147–148, 174.
[8] T. Zakrzewski, *op. cit*., pp. 248–250.
[9] Filzbee, *Nasza produkcja*, "Flizbee", https://filzbee.com/nasza-produkcja/ (access: 15.06.2026).

developed by the Portuguese company BUBLIING, which addresses the need for improved acoustic comfort in work and educational environments. These products are predominantly mobile modules (variants: S, Stwin and M) that create privacy and concentration zones by combining absorptive and diffusive materials, and are equipped with assisted, adjustable ventilation and integrated lighting for user comfort. In teaching rooms their use is, however, constrained by spatial, functional and logistical limitations, whereas in circulation areas (corridors, lobbies, atria) such modules can serve effectively as flexible acoustic support points.[10]





Ill. 1, 2. Acoustic screens made of recycled PET felt from the Polish company Filzbee, source: https://filzbee.com/przegrody/ (access: 15.06.2026)





Ill. 3, 4. BUBLIING soundproof booth in a multifunctional space at the University of Lisbon, photo by A. Dobrzyńska-Jarosz

[10] Bubliing, *A space for everyone*, "Bubliing", https://bubliing.com/imagens/downloads/Cat%C3%A1logoBB03_EN.pdf (access: 15.06.2026).

The application of absorptive materials and systems is particularly effective in spaces with low intrinsic absorption, where a measurable reduction in sound level can be achieved. In practice, this reduction rarely exceeds about 10 dB. The greatest efficacy is observed in relatively small rooms (up to approximately 3000 m³) and in low spaces (up to about 5m); in very large or tall interiors the attenuation effect is smaller, although overall acoustic quality and occupant comfort are still improved.[11]

2.2. THE ARCHITECTURE AND SOUND LABORATORY (LAID)

At the Laboratory of Architecture and Sound (LAiD) at the Faculty of Architecture, Wrocław University of Science and Technology, bespoke prototypes composed of sustainable absorptive materials are developed on the basis of in-situ measurements conducted in two teaching rooms. These lightweight, hybrid and mobile modules are tested under real-world conditions and are designed to enable effective modulation of acoustic field parameters and reduction of reverberant noise in the spaces under investigation. For pedagogical and research purposes, the final designs were preceded by initial mobile solutions developed during interdisciplinary student workshops in architectural acoustics. Laboratory measurements in controlled conditions assessed the sound absorption and damping properties of the constructed systems. The results demonstrate a significant reduction in reverberation time for the proposed interventions.





Ill. 5, 6. Photos from the student acoustic workshops, task: mobile adaptive acoustic prototype, on the left – the phase of preliminary measurements, on the right – workshop work, photos by A. Dobrzyńska-Jarosz, J. Gronostajska-Kadecka

3. SUMMARY

Flexible, mobile acoustic solutions, by regulating the intensity of auditory stimuli, enable the adaptation of spaces to multifunctional requirements and accommodate the natural diversity of neurotypes and fluctuations in users' psychophysiological states, thereby fostering environments with controlled sensory comfort. They also empower occupants to modify the

[11] T. Zakrzewski, *op. cit.*, p. 208.

available acoustic system autonomously according to individual needs. Appropriate selection and combination of materials permit the tailoring of frequency-dependent absorption profiles to the functional demands of an interior, which is particularly important in multipurpose spaces such as teaching rooms. In these contexts, adaptive acoustic strategies encompassing deliberate material choice, geometric shaping and control of sound propagation allow designers to create environments that support auditory perception, effective communication and user well-being. Acoustic design should integrate criteria for airborne insulation, reverberation-time control and uniform sound-field distribution, account for room function and user expectations, and enable flexible reconfiguration to meet changing operational requirements. Integrating these parameters allows public interiors to be understood as "labyrinths of sound" in which adaptive acoustic solutions based on the considered selection of systems, materials and geometries promote communication, perception and acoustic comfort.

References

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[2] Bubliing, *A space for everyone*, "Bubliing", https://bubliing.com/imagens/downloads/Cat%C3%A1logoBB03_EN.pdf (access: 15.06.2026).

[3] Filzbee, *Nasza produkcja*, "Flizbee", https://filzbee.com/nasza-produkcja/ (access: 15.06.2026).

[4] Kulowski J., *Akustyka sal. Zalecenia projektowe dla architektów* (2nd ed.), Wydawnictwo Politechniki Gdańskiej, Gdańsk 2011.

[5] Sadowski J., *Akustyka architektoniczna*, Państwowe Wydawnictwo Naukowe, Warszawa–Poznań 1976.

[6] Zakrzewski T., *Akustyka budowlana*, Wydawnictwo Politechniki Śląskiej, Gliwice 1997.

[7] Zakrzewski T., Żuchowski R., *Kompendium akustyki architektonicznej wraz z przykładami metod obliczeniowych*, Wydawnictwo Politechniki Śląskiej, Gliwice 2009.

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