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THE ROLE OF ACOUSTICS IN ARCHITECTURAL DESIGN

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INTRODUCTION

Cédric Van hoorickx, Associate Professor at Eindhoven University of Technology (TU/e) in the Netherlands, immerses himself in the realm of building acoustics with fervor. His daily pursuits revolve around both instructing and delving into research concerning the propagation of noise and vibration within constructed environments. Central to his endeavors is the refinement of sophisticated numerical simulation models, meticulously crafted to dissect and enhance the intricate interplay between structures and spaces.

Bram Botterman, an acoustic consultant and researcher affiliated with Eindhoven University of Technology (TU/e), specializes in the domain of sound-absorbing materials. As the founder of Matude, he maintains a steadfast commitment to the Building Acoustics Group at TU/e, his alma mater. Engaging in educational initiatives, Bram ardently endeavors to ignite students' passion for the nuances of acoustics within built environments. Through his research, he actively contributes to pioneering innovations, driven by a zealous desire to translate newfound knowledge into tangible applications.

Maarten Hornikx, Professor of Building Acoustics at Eindhoven University of Technology (TU/e) in the Netherlands, stands as an authority in utilizing computer simulations to render acoustics perceptible within both enclosed spaces and urban landscapes. His primary objective revolves around crafting software aimed at unraveling and enhancing the impact of acoustics on various environments. With an unwavering commitment to bridging theory with practical application, Maarten actively disseminates developed software and promotes citizen science initiatives. At TU/e, he leads the Building Acoustics Group, spearheading endeavors to advance understanding and implementation in the field.

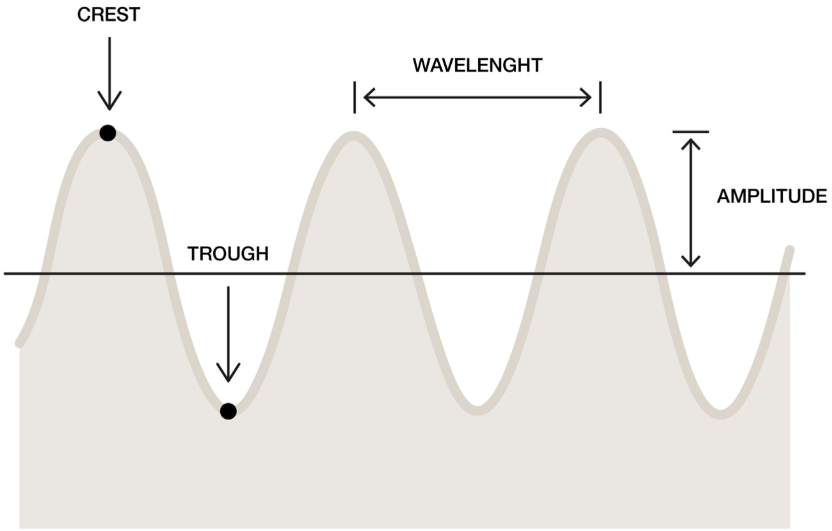
THE IMPACT OF SOUND ON ARCHITECTURAL SPACES

This white paper begins with a simple yet revealing exercise. Take a moment wherever you are, close your eyes, and listen intently to the sounds around you for just one minute.

Chances are high that you've noticed multiple sounds, as sound is everywhere. From the bustling atmosphere of a train station to the tranquil serenity of a quiet living room. Sound permeates our environment, and for good reason. Humans rely on sound as a means of communication. Whether it's the blare of a fire alarm signaling danger or the subtle hum of a brewing coffee pot, sound serves as a vital source of information in our daily lives. Moreover, it holds the power to sway our emotions, with music being a prime example.

Yet amidst the desired sounds lie a plethora of undesired noises — road traffic noise, the whirring of air conditioning units, or a colleague's lengthy phone conversation. While these noises may seem merely bothersome, they can disrupt functional sounds, impede communication, or even mask critical warning signals. Moreover, they have the potential to disrupt activities, interrupt sleep, and diminish work performance. Extensive WHO (World Health Organisation) research has unveiled the detrimental health effects associated with noise.

Consider now the sounds within the room you currently occupy. These sounds are influenced by the architectural properties of the space - a realm known as room acoustics or architectural acoustics. As sound waves traverse the room, they interact with its various elements and boundaries, such as walls, floors, and ceilings. Consequently, the acoustics of a space must align with its intended function. Meeting rooms should facilitate clear speech communication, restaurants should foster comfortable conversation levels, and concert halls should enhance the auditory experience for both audience and performers alike. Additionally, it's important to consider that in countries like the Netherlands, where over 10% of the population suffers from hearing disorders, the necessity for excellent acoustics is further underscored. Thus, the role of acoustics in building design is paramount, ensuring our daily activities are supported and mitigating adverse health effects. This white paper delves into the key aspects related to this crucial discipline.



GENERAL INFORMATION AND TERMINOLOGY

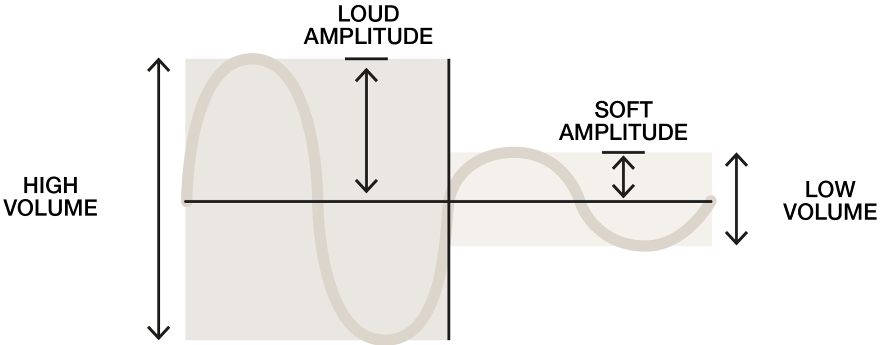
Room acoustics deals with the intricate dynamics of sound within enclosed spaces, ranging from small rooms to grand concert halls. It probes the interplay of sound waves with their environment, exploring phenomena like reflection, absorption, and diffusion. These phenomena have a profound influence over the auditory landscape within a space, shaping the perceived quality of audio or speech. This section elucidates the foundational principles and terminology that underpin the realm of room acoustics.

1. Sound Pressure Level

The sound pressure level is the primary concept to describe the loudness of sound emitted by a source. In the absence of sound, the atmosphere maintains a steady, unyielding pressure, averaging around 1013 hectopascals (hPa). However, in the presence of sound, this tranquillity is disrupted by oscillations in pressure, both above and below the atmospheric baseline. These oscillations, known as sound pressure, encapsulate the temporal flux of pressure variations induced by sound waves. The perception of sound is linked to the root mean square (RMS) of these pressure fluctuations over time, or, more precisely, to the logarithm of the RMS of the sound pressure. A logarithm measure, termed the sound pressure level, is therefore defined:

$$L_\mathrm{p} = 10\log_{10}\frac{p_\mathrm{RMS}^2}{p_0^2}$$

with p_0 (equal to 20 µPa) the reference sound pressure. The sound pressure level L_p is quantified in decibels (dB). The greater the sound pressure level, the more pronounced the auditory experience, leading to a perception of increased loudness.



2. Background Level

Excessive background noise levels can significantly disrupt various activities. For instance, understanding spoken communication may become challenging, resulting in information loss. Moreover, heightened noise levels can impede concentration, leading to frustration and irritation.

To mitigate such disturbances, criteria are established based on the necessary differentials between the emitted sound level (signal) and the interference level (noise). These criteria, often rooted in installation technology, dictate the maximum allowable noise level for specific activities. Furthermore, beyond the sounds generated by technical equipment, environmental noise from sources such as traffic, aircraft, or subway operations presents additional challenges.

Efforts to maintain an environment supporting concentration and productivity entail implementing effective sound insulation measures. These measures aim to restrict sound levels within a designated space below specified thresholds. The permissible noise level is contingent upon factors such as the power and nature of the sound source, as well as the intended activities within the space in question.

3. Absorption

When sound waves, such as those emitted by a loudspeaker, encounter the boundaries of a room – comprising walls, floors, and ceilings – they undergo several interactions. A portion of the sound energy is reflected back into the room, another portion is transmitted through the boundaries, while the remaining portion dissipates within the room boundaries. Sound absorption encompasses all sound that is not reflected and therefore includes both dissipated and transmitted sound through the absorbing material.

The absorption coefficient, typically represented by the Greek letter α, quantifies a material's capacity to absorb sound energy. For instance, an open window exhibits a high absorption coefficient, approaching unity, as nearly all incident sound escapes the room. Conversely, a highly reflective surface manifests a low absorption coefficient, nearing zero. In practice, the absorption coefficients of various materials and constructions are measured, often exhibiting frequency dependence. A table with common materials is displayed in section 9.

The total absorption, denoted as A (in m²), of a room is mathematically defined as the summation across all room surfaces, represented by index i, each having a surface area denoted as S_i and an associated absorption coefficient denoted as α_i. This summation encapsulates the combined absorption contributions from all surfaces within the room. Mathematically, it can be expressed as:

$$A = \sum_i \alpha_i S_i$$

Indeed, the total absorption serves as a crucial metric indicating the quantity of absorption present within a room.

4. Reverberation Time

The reverberation time stands as a fundamental characteristic of a room, delineating the duration between stopping a sound source – be it a stationary emission or an impulsive burst – and the moment when the sound pressure level diminishes by 60 dB. This parameter holds significant import within the realm of room acoustics, serving as a yardstick for evaluating the suitability of a room's acoustical properties for its intended function.

Essentially, the reverberation time gauges the extent to which sound lingers within a space after its source ceases. A shorter reverberation time indicates rapid sound decay, suitable for environments where clarity and precision in audio reproduction are paramount, such as recording studios or lecture halls. Conversely, longer reverberation times are favoured in spaces like concert halls or cathedrals, where the lingering sound contributes to a sense of spaciousness and richness in auditory experience.

The reverberation time of an interior space is intricately linked to its dimensions, specifically how many surfaces a sound wave encounters during a certain period of time. Furthermore, the reverberation time is intimately tied to the extent of sound absorption present within the space. This relationship aligns seamlessly with our perceptual experiences: larger rooms with solid, reflective surfaces often exhibit prolonged reverberation times, whereas smaller spaces adorned with soft furnishings like curtains, rugs, and furniture tend to exhibit minimal reverberation. Through empirical investigations, the American physicist Wallace Clement Sabine established a quantitative relationship between the room's dimensions (expressed as its volume V), the total sound absorption A within the space, and the resulting reverberation time T. This Sabine formula is:

$$T = \frac{0.16V}{A}$$

Sabine's groundbreaking work laid the foundation for understanding and predicting reverberation characteristics in architectural acoustics, facilitating the design and optimization of spaces for diverse purposes. Refinements of this formula consider the influence of air damping (contingent upon the air humidity) and have expanded the application range to highly damped rooms (known as Eyring's formula).

5. Room Acoustic Quantities

Next to the reverberation time, other room acoustic quantities also exist:

- Early decay time (EDT) measures the time taken for the sound level to decrease by 10 dB after the sound ends. It provides insight into the early reflections' contribution to the overall reverberation characteristics of a room.
- Sound strength G measures the perceived loudness of sound sources within a room relative to their distance from the listener.
- Clarity parameters describe the balance between early and late sound energy. This category contains clarity C_{80}, definition D_{50} and center time T_S. The first two quantify the ratio of early to late reflections, offering an indication of speech intelligibility and overall sound quality. The center time represents the center of gravity of the squared sound pressure after an impulse.
- Early lateral energy, a measure for the apparent source width, describes the ratio of the sound energy of the lateral reflections to the total sound energy received by a listener. This parameter looks at the sound pressure levels within the first 80 ms after the arrival of the direct sound.
- Late lateral energy is, similarly to the early lateral energy, a measure of the spatial impression of the sound, but this time for late lateral reflections, i.e. after the first 80 ms after the arrival of the direct sound. Late lateral energy contributes to the perception of spaciousness, envelopment, and naturalness in the auditory experience.

6. Direct and Diffuse Sound Field

When you're near a sound source inside a room, what you're experiencing is largely governed by what is called the "free field" of that source. Think of it as the kind of sound environment you'd encounter in a wide-open space without any surfaces to reflect sound waves, much like standing in an open field or inside a specially designed room called an anechoic chamber. In this scenario, the level of sound pressure you perceive is directly tied to how much power the source emits and the direction in which it sends out sound. As you move away from the source, the sound pressure level gradually decreases. This happens because sound waves spread out in all directions, gradually losing intensity the farther they travel. So, if you're close to the source, you'll hear it louder and clearer compared to when you're farther away.

In rooms, sound waves bounce off surfaces creating a complex wave pattern. As you move away from the source, what you hear is influenced by the energy leftover from these reflected waves bouncing off walls and other boundaries. In a room with a diffuse sound field – where sound bounces around randomly due to numerous reflections – the sound pressure level remains fairly constant. It is determined by the power of the sound source and how much sound is absorbed by the room overall. This means that regardless of where you are in the room, the perceived loudness stays relatively consistent, thanks to the evenly distributed sound reflections and absorption.

The previous discussion reveals that at a specific distance from the sound source, the sound level of the direct sound equals that of the indirect, reflected sound. At this point, the direct sound field transitions into what is known as the reverberant field. The balance between direct and reflected sound is crucial and depends on the intended function of the space. This balance has implications for directional hearing. In environments where speech communication is paramount, it is crucial for listeners to accurately locate the source, such as a speaker. In contrast, for musical settings, the emphasis often shifts to creating a sense of spaciousness, which is achieved through an abundance of reflected sound. Therefore, depending on whether the space is used for speech or music, the balance between direct and indirect sound must be carefully considered to optimize the listening experience.

DESIGN PRINCIPLES

In the previous chapter, we dived into the complex world of architectural acoustics, describing terms that can overwhelm even the most seasoned designers and architects. But don't be scared. In this chapter, we'll break down these technical jargons into practical design guidelines that anyone can understand and apply. These guidelines are like a general recipe for creating indoor spaces with acoustics suiting the functioning of the space.

1. Understand the User and the Function of the Room

First things first: before we start sketching or hammering nails, let's get to know our users and the room's purpose inside out. Are we designing a buzzing office where clear communication is king? Or maybe a cozy restaurant where ambiance is of highest importance? Understanding the needs of the people using the space is key.

2. Optimize the Dimensions of the Room

Getting the room dimensions just right is important in architectural acoustics. The room volume is directly related to multiple room acoustic quantities, and the reverberation time increases with an increasing volume. And when designing the intended function in the rooms, natural choices like privacy-sensitive activities will usually end up in separate rooms. When architects tweak the dimensions just so, they can do all sorts of finetuning afterwards, like making sure certain sound frequencies don’t get too loud and keeping those annoying standing waves to a minimum.

3. Control the Reverberation in the Room

No one likes a room that echoes like a cave, right? By strategically incorporating sound-absorbing materials into the architectural design, architects can exert precise control over the reverberation characteristics of a space. This not only helps minimize the negative effects of excessive reverberation but also enhances speech intelligibility, making it easier for occupants to communicate effectively and engage in meaningful interactions within the environment.

4. Find the Balance Between Reflective and Absorptive Surfaces

But there is more. It’s about finding the right balance between surfaces that bounce sound around and the ones that absorb it. For lecture halls, reflective surfaces are typically designed in the front of the room, such that speech of the lecturer is supported by early reflections to enhance its perception in the room. Vice-versa, absorptive materials are applied at the side walls. It’s like a dance between reflection and absorption, each playing its part in shaping the room’s acoustic landscape.

5. Incorporate Variable Acoustic Solutions

Different activities and events within an interior space may require varying acoustic environments. For example, a conference room may need to accommodate both large presentations and intimate discussions. In spaces where sound quality is critical, such as concert halls, theaters, and recording studios, variable acoustic solutions can enhance performance by optimizing the acoustics for different types of events and performances. This can be achieved by making use of curtains, moveable partitions or adjustable acoustic panels. Good references are TivoliVredenburg in Utrecht and Amare in The Hague.

ACOUSTIC SOLUTIONS

By implementing the acoustic solutions described in this chapter, designers and architects can effectively solve acoustic issues and create interior spaces characterized by improved sound quality, comfort, and functionality.

1. Integrate Sound Absorbing Surfaces

Sound absorbing materials are essential components of interior design, providing a range of functional benefits. They reduce the reverberation time, minimize echoes, lower the background noise level and last but not least they improve the speech transmission by improving the signal-to-noise ratio.

2. Install Sound Reflecting Materials

Sound reflecting materials can be strategically placed to direct sound waves towards a desired listening area, improving the projection and clarity of sound. This is particularly important in performance venues such as concert halls, theaters, and lecture halls, where clear and articulate sound reproduction is essential for audience engagement and comprehension.

3. Make Use of Diffusive Elements

Diffuse acoustic elements scatter sound waves in multiple directions rather than reflecting them back in a single direction. This helps to achieve a more uniform distribution of sound throughout a space.

4. Optimize Room Layout

Arrange furniture and room layout to strategically distribute sound-absorbing and diffusive elements, minimize sound reflections, and optimize acoustic performance. For example, placing bookshelves, plants, and soft furnishings strategically can help break up sound waves and create a more pleasant acoustic environment.

5. Implement Sound Masking Systems

Sound masking systems are like the secret sauce of architectural acoustics. These clever setups emit a gentle background noise, kind of like the soft hum of a fan or the rustle of leaves in a quiet forest. This background noise helps to mask those unwanted sounds, making them less noticeable and creating a more peaceful environment overall.

Sound masking systems don’t just cover up noise, they actually help to improve speech privacy too. By adding a consistent background noise, they make it harder for conversations to be overheard, creating a more confidential and comfortable space for everyone.

SUSTAINABILITY AND ACOUSTICS

Sustainable acoustic solutions for interior spaces involve implementing practices and materials that minimize environmental impact while effectively addressing acoustic challenges. These solutions aim to improve room acoustics without compromising the long-term health of the planet. Here are some examples of sustainable acoustic solutions:

1. Recycled Materials

Recycled materials in acoustic solutions involves repurposing existing materials, such as recycled glass, plastics, or textiles, to create sound-absorbing panels, baffles, and other acoustic treatments. By diverting waste from landfills and reducing the demand for virgin materials, recycled acoustic products contribute to a more circular economy and minimize environmental footprint.

2. Biodegradable Materials

These are made from natural, organic material like wool, cork, or hemp that can break down over time. So when it’s time to say goodbye to your acoustic panels, they won’t end up sitting in a landfill for centuries. They’ll decompose naturally, leaving behind a smaller environmental footprint.

3. Low-Impact and Local Manufactering Processes

Sustainable acoustic solutions prioritize manufacturing processes that minimize energy consumption, emissions, and resource depletion. Choosing manufacturers with low-impact production methods and sourcing materials locally reduces transportation-related carbon emissions and supports regional economies. Additionally, selecting manufacturers with eco-friendly certifications and practices ensures that acoustic products meet rigorous environmental standards.

4. Modular and Demountable Constructions

Modular acoustic solutions consist of prefabricated components that can be easily assembled, disassembled, and reconfigured as needed. This flexibility not only accommodates changing acoustic requirements but also reduces construction waste and facilitates efficient reuse and recycling of materials. Demountable acoustic partitions, screens, and panels offer customizable solutions for optimizing room acoustics while minimizing environmental impact.

5. Natural Acoustic Elements

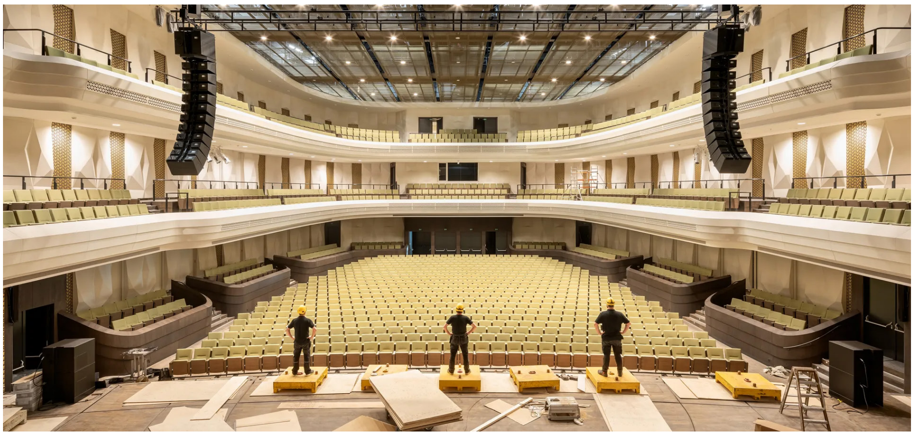
Integrating natural acoustic elements into interior spaces involves incorporating biophilic design principles and organic materials to enhance sound quality and aesthetic appeal. Examples include acoustic panels made from sustainable wood sources, moss walls that act as sound absorbers, and living greenery that improves indoor air quality while providing acoustic benefits. Natural acoustic elements create harmonious and healthy environments that connect occupants with nature while promoting sustainable practices in interior design.

CASE STUDIES

Check out these amazing architectural acoustic wonders!

1. Amare, The Hague (The Netherlands)

Direct link: https://noahh.nl/portfolio_page/amare-the-hague/
Amare is not just your average cultural complex. It's a hub of creativity, housing theaters, concert halls, and more. But what sets it apart is its commitment to perfect sound environments for all sorts of performances. From plays to musical concerts, Amare's acoustic design ensures every note is heard just right.



2. Elbphilharmonie, Hamburg (Germany)

Direct link: https://www.herzogdemeuron.com/projects/230-elbphilharmonie-hamburg/
The Elbphilharmonie stands tall as a marvel of architectural and engineering brilliance. But what really makes it shine is its acoustic design. From its unique shape to its state-of-the-art materials and technology, the Elbphilharmonie creates an auditory experience like no other. Whether you're a performer or an audience member, you're in for a treat at this iconic concert hall.

3. Booking.com City Campus, Amsterdam (The Netherlands)

Direct link: https://www.unstudio.com/en/page/11733/booking.com-city-campus
Behind the captivating architecture lies meticulous attention to detail in every aspect of this ultra-modern building, from materials and floor finishes to ventilation and acoustics. The BREAAM-certified office prioritizes the user's work environment which resulted in an almost entirely silent working environment including natural elements.

CHALLENGES & CONSIDERATIONS

While advances in the science of room acoustics and the availability of materials and solutions on the market have greatly improved the ability to design spaces with optimal acoustics, challenges still remain in achieving proper acoustic design. Although not exhaustive, key challenges and considerations include:

1. Initial Acoustic Insufficiency

Many newly built or renovated spaces may initially lack sufficient acoustics. It’s crucial to prioritize acoustics during the design phase of a building or room. While this paper primarily addresses architectural acoustics, effective acoustic design should also consider external sound sources, such as neighboring noise or noise from aircrafts. Design principles, as discussed earlier, must be integrated alongside other design elements like aesthetics and lighting, and having an acoustic expert in the design team is key. However, often these considerations boil down to budget constraints, impacting decisions regarding hiring an acoustic consultant and investing in materials or room elements tailored to achieve desired acoustics.

2. Large Open Spaces

Large open spaces such as atria, airport terminals, or large indoor shopping malls, present challenges due to their inherent volume and the potential for high volumes of sound from numerous occupants. Special attention is required to address

3. Rooms with Parallel Hard Walls

Spaces featuring parallel hard walls, such as sport halls or squash courts, can suffer from reduced speech intelligibility and the presence of annoying flutter echoes. Mitigating these acoustic issues requires careful design considerations to minimize their impact on occupants.

4. Reduction of Low-Frequency Sound

Low-frequency sounds pose particular challenges in absorption and damping compared to high-frequency counterparts. They are also more easily transmitted from external sources into interior spaces. Furthermore, the prevalence of low-frequency noise is on the rise, stemming from sources like heat pumps and wind turbines. Addressing this issue demands innovative solutions to effectively attenuate low-frequency noise and maintain optimal acoustic environments.

In addressing these challenges, advancements in acoustic science and strategic design approaches play a pivotal role in optimizing the acoustic performance of various spaces, supporting comfort, health and functionality.

FUTURE AND INNOVATIONS

The future landscape of architectural acoustics is shaped by several key pillars, including advancements in techniques, technology, and materials, as well as evolving legislation pertaining to sound production and cultural shifts surrounding sound perception. A glimpse into the future of architectural acoustics reveals several developments:

1. Noise, the New Smoking

There's a growing awareness of the detrimental health effects of noise pollution, akin to the recognition of the health risks associated with smoking. Society increasingly demands proper environments for education, work, and leisure with reduced noise levels, driven by a desire for social justice. This heightened attention to the sound environment, including acoustics, is expected to drive the demand for properly designed spaces. Initiatives like soundprint.co, which curate lists of restaurants with acceptable noise levels, represent just the beginning of citizen-led efforts to promote quieter environments.

2. New Acoustic Materials

The demand for materials that enhance the acoustic qualities of spaces is on the rise, with numerous companies offering products for both private and industrial applications. The emergence of meta-materials, artificially engineered and often 3D-printed materials with unique acoustic properties not found in natural substances, holds promise for more effective sound absorption and blocking with lighter or thinner materials. Expectations are high for these innovative products to enter the market in the near future.

3. Mixed Reality Applications

Imagine experiencing the acoustic ambiance of a concert hall before it's even built or simulating the sound of an aircraft flyover in your own home without the actual aircraft present. Such possibilities are within reach through the use of sound in virtual reality environments. Acoustic consultants are rapidly embracing these tools, and it's anticipated that future developments will extend to augmented reality applications, and making such immersive experiences accessible to a wider audience.

4. Active Noise Control

Active noise control, a technique familiar to many through noise-cancelling headphones, holds promise for mitigating unwanted sound in various contexts. In aircraft cabins, efforts to reduce noise levels through active noise control are underway, while in architectural acoustics, innovations like active control of low-frequency sound through windows are already hitting the market. These solutions may play a crucial role in safeguarding against noise pollution in the future.

5. Dynamic Sound Environments

Soundscapes within indoor spaces are subject to constant change, influenced by evolving technologies and societal trends. As new sound sources emerge, such as the increasing prevalence of heat pumps, the sonic landscape continues to evolve. Looking ahead, one thing remains certain: the soundscape of our environment will always be in flux, necessitating ongoing adaptation and innovation in architectural acoustics.

SOUND ABSORPTION COEFFICIENTS OF SOME COMMON MATERIALS AND STRUCTURES

Table 1 - Indicative values for the diffuse sound absorption coefficient of some common materials and structures.

Material	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Ref.
Rough concrete	0,02	0,03	0,03	0,03	0,04	0,07	[1]
Brick, unglazed	0,03	0,03	0,03	0,04	0,05	0,07	[2]
Breeze block	0,2	0,3	0,6	0,6	0,5	0,5	[3]
Plaster, gypsum, or lime, on brick	0,01	0,02	0,02	0,03	0,04	0,05	[4]
Plaster, on laths/studs, air space	0,3	0,1	0,1	0,05	0,04	0,05	[3]
Plasterboard on frame, 9.5 mm boards, 10 cm cavity filled with mineral wool	0,28	0,14	0,09	0,06	0,05	0,05	[5]
Slightly vibrating walls (suspended ceilings, etc.)	0,1	0,07	0,05	0,04	0,04	0,05	[6]
Single pane of glass, 3–4 mm	0,2	0,15	0,1	0,07	0,05	0,05	[3]
Double glazing, 2–3 mm glass, 1 cm gap	0,1	0,07	0,05	0,03	0,02	0,02	[7]
Wood, 50 mm thick	0,01	0,05	0,05	0,04	0,04	0,04	[8]
Plywood/hardwood, air space	0,32	0,43	0,12	0,07	0,07	0,11	[3]
Wood on solid floor	0,04	0,04	0,03	0,03	0,03	0,02	[9]
Floor boards on joist floor	0,15	0,2	0,1	0,1	0,1	0,1	[3]
Solid wooden door	0,14	0,1	0,06	0,08	0,1	0,1	[10]
Curtains hung straight	0,04	0,16	0,19	0,17	0,2	0,25	[2]
Curtains in folds against wall	0,05	0,15	0,35	0,4	0,5	0,5	[10]
Carpet, 5 mm thick, on solid floor	0,02	0,03	0,05	0,1	0,3	0,5	[6]
16 mm wool pile with underlay	0,2	0,25	0,35	0,4	0,5	0,75	[9]
Layer of rubber, cork, linoleum and underlay, or vinyl and underlay, stuck to concrete	0,02	0,02	0,04	0,05	0,05	0,1	[10]
Marble or glazed tile	0,01	0,01	0,01	0,01	0,02	0,02	[2]
Terrazzo floor	0,01	0,01	0,02	0,02	0,02	0,02	[12]
5 cm mineral wool (40 kg/m3), glued to wall, untreated surface	0,15	0,7	0,6	0,6	0,85	0,9	[7]
Water surface in swimming pool	0,01	0,01	0,01	0,01	0,02	0,02	[13]
Ventilation grille	0,6	0,6	0,6	0,6	0,6	0,6	[7]
Medium upholstered seats, unoccupied	0,54	0,62	0,68	0,7	0,68	0,66	[14]
Medium upholstered seats, occupied	0,62	0,72	0,8	0,83	0,84	0,85	[14]

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