THE BOOK OF ACOUSTICS

Making people happy at work

BAUX

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This is a handbook for architects and interior designers who want to create acoustically beautiful spaces that make people feel happier, healthier and more productive.

Here, you'll learn the fundamentals of sound control and everything you need to know to start feeling more confident working with acoustic treatments in your design projects. When it comes down to it, it really is as simple as making people happy — whether they're at work, school or conversing with friends over dinner.

This handbook was made possible thanks to the keen insights and guidance of experts, researchers and practitioners within the fields of acoustics, design and neuroscience.

Dan Bosnyak

Dan Bosnyak is a neuroscientist and Technical Director of LIVE Lab at McMaster University, in Hamilton, Canada. He specialises in psychology and the human auditory system. Dan is also a member of the McMaster Institute for Music & the Mind (MIMM), an interdisciplinary group of researchers including psychologists, neuroscientists, music theorists, musicians, dancers, media artists, mathematicians, kinesiologists, health scientists, and engineers.

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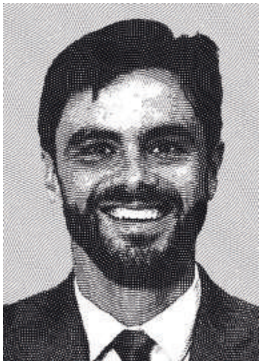
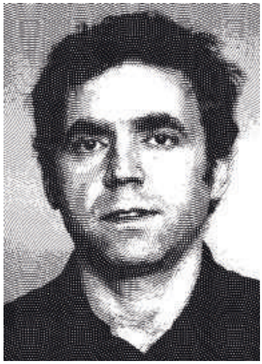
Tine Wagenmann is the founder of Studio Llots, an architecture and interior design agency based in Dusseldorf, Germany. She is also an expert on mindfulness and wellbeing and holds workshops on these subjects. Tine specialises in the development and design of flexible living and working spaces.



Andrew Carballeira

Andrew Carballeira is a Principal Consultant at Acentech, a leading acoustics consultancy based in Cambridge, Massachusetts. He is a member of the Acoustical Society of America (ASA) and the Audio Engineering Society (AES), and a board certified member of the Institute of Noise Control Engineering (INCE). Alongside acoustic engineering, Andrew is a professional musician and avid outdoorsman.



Dr Luis Gomez-Agustina

Dr Luis Gomez-Agustina is the course director of the UK Institute of Acoustics (IOA) Postgraduate Diploma at the London South Bank University (LSBU), UK. He is a Senior Fellow of the UK Higher Education Academy and is also leading the development of the new Acoustic Apprenticeship at LSBU. Luis has authored and co-authored over 30 publications in journals and conference proceedings on acoustics topics and is a reviewer of four acoustics journals.

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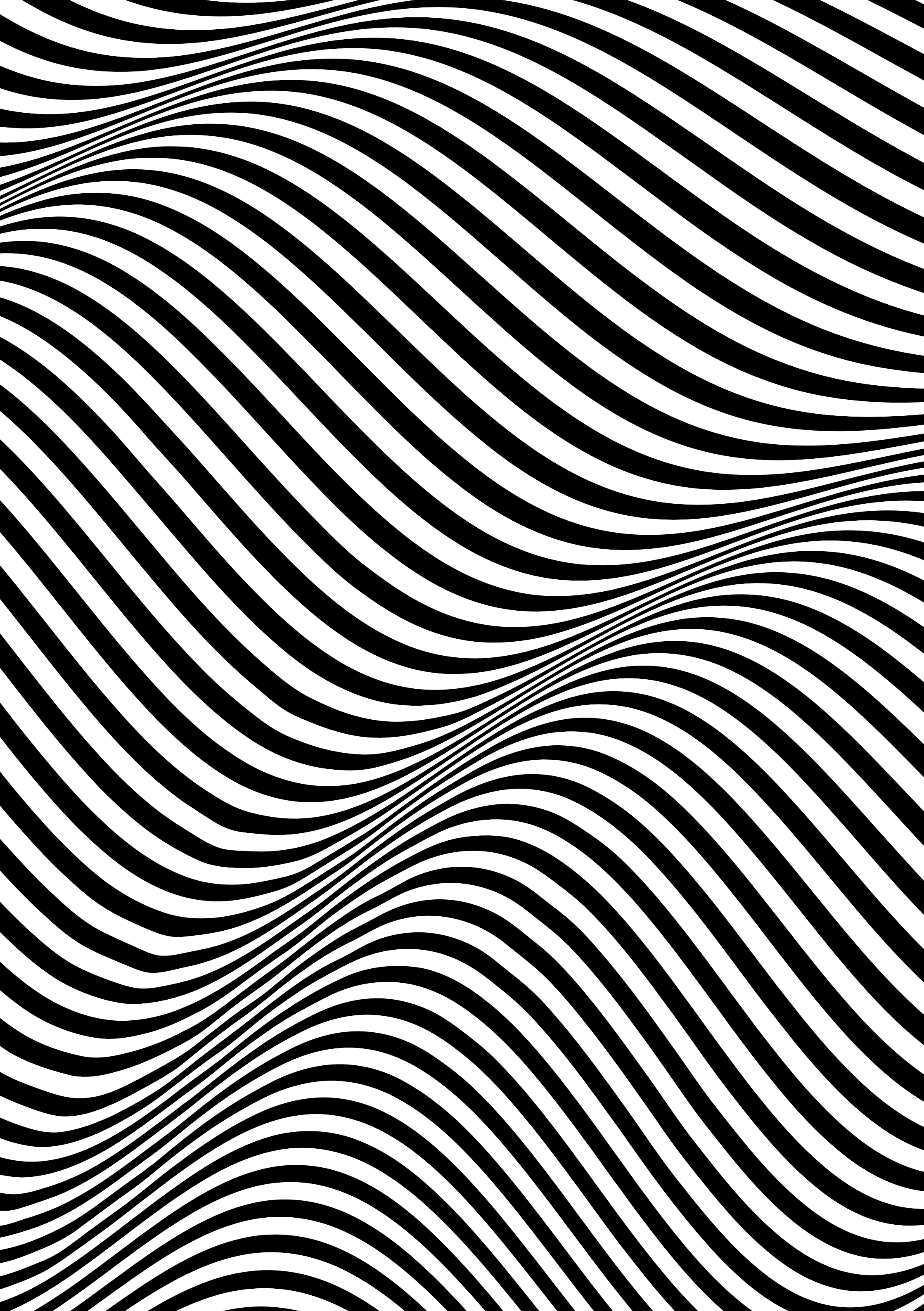


THE FUNDAMENTALS OF SOUND CONTROL

WHAT IS SOUND?

When designing a shared space, it is important to construct an acoustic environment that serves its intended function while meeting the collective needs of its inhabitants. But before getting started, it's important to understand some fundamentals — like, what is sound?

Sound is produced when something vibrates. The vibrating sound source sets particles in the air or other surrounding medium into vibrational motion. According to physics, these audible vibrations are transmitted as sound waves which consist of areas of both high and low air pressure.

When sound waves reach the human ear, they travel down the ear canal and vibrate the eardrums at an equal resonance. The bones of the inner ear convert the vibrations into nerve impulses, which are then carried to the brain for interpretation. The two most influential factors on how humans experience exposure to sound are **frequency** and **sound pressure**.

Frequency

Sound travels as waves of compressed air. A single wavelength is calculated by measuring the distance between one crest and the next. The wavelength determines the frequency of the sound. A sound frequency, measured in Hertz (Hz) likewise represents the speed at which a sound vibrates. It's this vibrational speed that determines the pitch of the sound. Sound that vibrates quickly has shorter wavelengths and a higher frequency, while sound vibrating more slowly has longer wavelengths and a lower frequency.

The generally accepted standard hearing range for humans is 20 to 20,000 Hz, and most human speech occurs at frequencies between 500 and 2000 Hz. Frequencies below 20 Hz are felt rather than heard. Low frequency sounds include bass notes, while high frequency sounds include bells and cymbals. When humans experience hearing loss, typically due to ageing, high frequency sounds especially become harder to hear.

Sound pressure

The other key aspect of sound is sound pressure. The sound pressure level is commonly measured in decibels (dB), which represent the effective pressure of a sound relative to a reference value. Most human speech occurs at around 60 dB. Regular and prolonged exposure to sounds above 85 dB is considered hazardous to human health and wellbeing. Decibels are expressed on a non-linear logarithmic scale. In other words, making the sound pressure level 10 times higher corresponds to an increase in 10 dB. Do not confuse sound pressure with loudness, which is a subjective measure of sound.

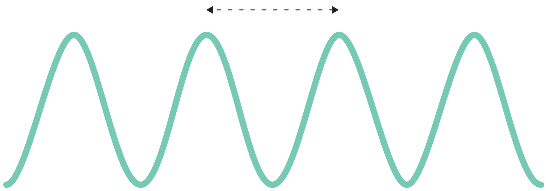
When sound becomes noise

The main difference between a sound and a noise is how the vibration is perceived by the individual. Whether the source is a piece of music, a conversation between coworkers or an active construction site outside the window—what one person considers to be tolerable may be considered disruptive or annoying to the next.

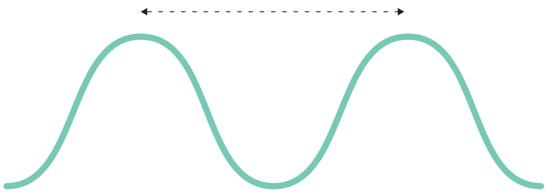
”Acoustical design is about material quality and material position. Treatment should be selected first for the acoustics, and second for the aesthetics.”

Dr Naglaa Sami Adbel Aziz Mahmoud

High frequency
(Shorter wavelength)



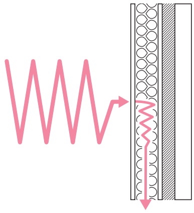
Low frequency
(Longer wavelength)



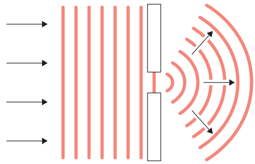
COMMON SOUND WAVE BEHAVIOUR IN INDOOR SPACES

Controlling sound in an indoor space isn't just about addressing the source. After all, sometimes a sound is inevitable or necessary—such as a conversation in a workplace or an espresso machine in a cafe. Controlling sound is also about manipulating the way it behaves once it has been set into motion. Outdoors, a sound wave travels freely in a straight line. In an enclosed space, however, a sound wave behaves and reacts differently based on the kinds of obstacles it encounters, such as walls, furniture and people. A sound wave can bounce off an obstacle, move around it or change directions as it passes from one to the next.

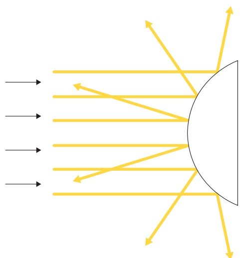
Here are some of the most common types of sound wave behaviours in indoor spaces. A sound wave will typically exhibit a combination of these behaviours over the course of its lifetime.



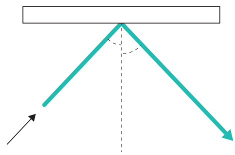
Absorption



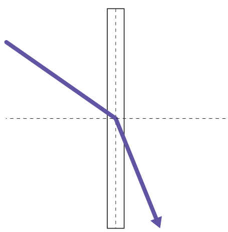
Diffraction



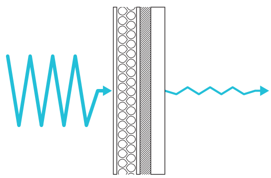
Diffusion



Reflection



Refraction

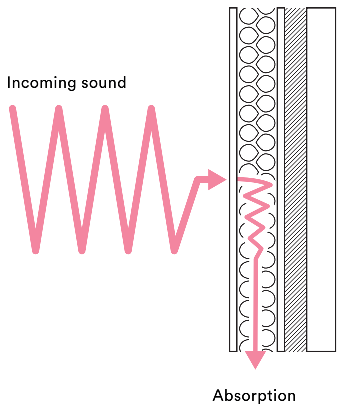


Transmission

ABSORPTION

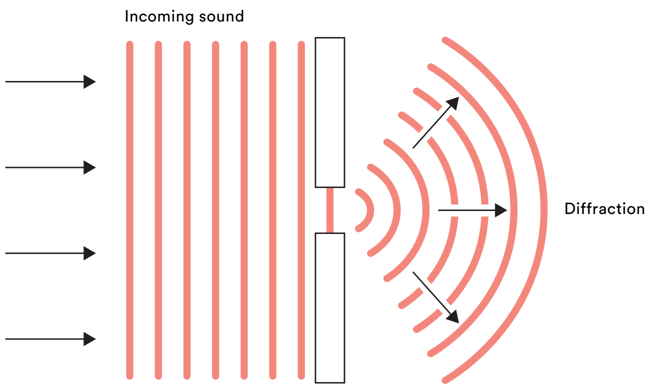
Absorption occurs when a sound wave is absorbed by the object or material it encounters. A sound wave that is absorbed transforms into heat energy inside the object or material absorbing it.

How much energy gets absorbed or continues to travel onward depends on the thickness and nature of the material. Too little absorption causes sound to reflect.



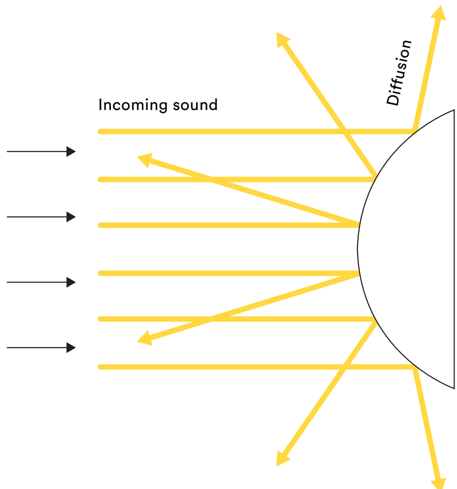
DIFFRACTION

Diffraction is when a sound wave either bends around the edge of the object it encounters, or passes through a narrow opening, such as a doorway, and then spreads out. Diffraction can lead to privacy issues and disruptions, especially in shared, mixed use spaces. It's the reason why someone speaking in a room with an open door can be heard by the people sitting outside.



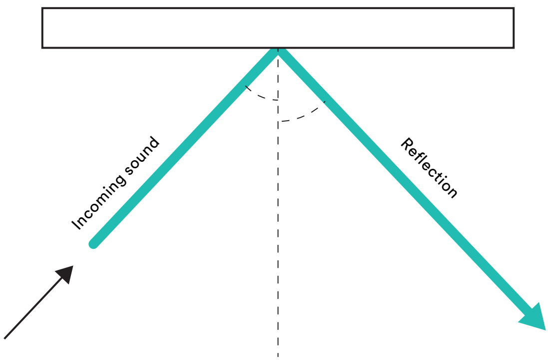
DIFFUSION

Diffusion typically occurs when the texture and hardness of the object or material is similar to the sound's wavelength. Exactly how the sound diffuses depends on the nature of the surface texture. Too much diffusion can make it difficult to localise where a sound is coming from. Diffusion occurs when a sound wave diffuses or scatters in different directions upon encountering an object or material.



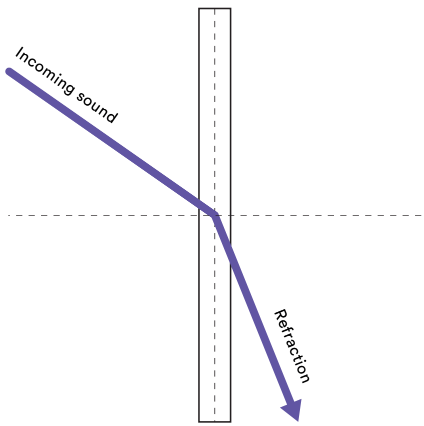
REFLECTION

Reflection happens when a sound wave hits an object or surface, such as a wall, and reflects or bounces back. Reflection is most pronounced in rooms with smooth and hard materials like marble or glass. Reflection can result in sound amplification, echos or reverberation. Too much reflection can make a room feel loud and irritating.



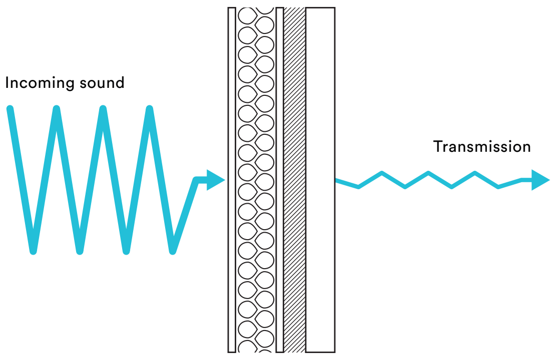
REFRACTION

Refraction occurs when a sound wave bends as it travels from one object or material to another. Both the direction of the sound wave and the speed at which it travels changes depending on the properties of the object or material as well as temperature. Refraction can result in so-called 'shadow zones,' where sound cannot be heard even when the source is within the listener's view.



TRANSMISSION

Transmission takes place when a sound wave transfers from one material or medium to another, and then continues to travel out through the other side. How much transmission occurs depends on how well the acoustical impedances of the two materials match. Transmission becomes problematic when a sound originating from one room travels through the wall to be heard by the people next door.

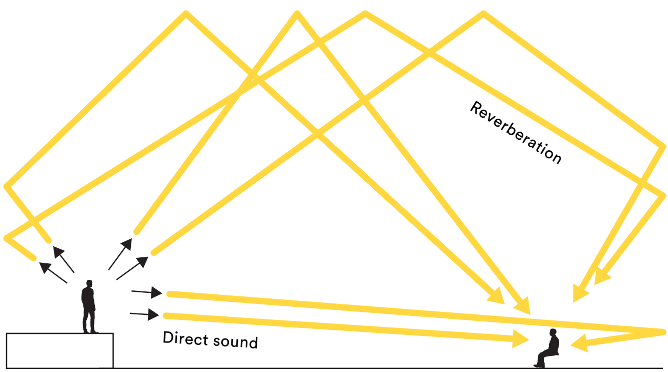


SOUND THAT LINGERS

REVERBERATION

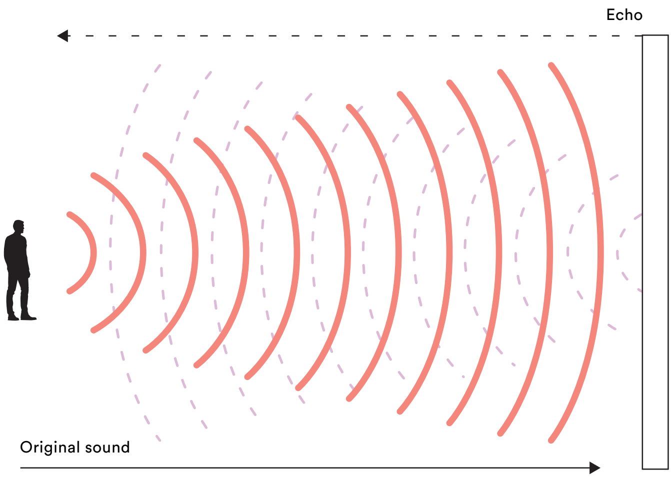
A room with a long reverberation time can be perceived as more spacious and optimise the experience of listening to live music. Reverberation is less optimal for speech, however. When it is too long, it can cause the sounds of individual words spoken consecutively to reverberate simultaneously.

Reverberation is the lifetime or persistence of a sound wave in an enclosed space, measured from the time it first appears to the time it is no longer audible. As a sound wave travels around a space, interacting with different obstacles, it is reflected back and forth between surfaces with some of its energy being absorbed upon each impact until it completely 'dies out'. The more absorbent the room, the more quickly the sound diminishes.



ECHOS

Echoing indoors can make conversation difficult, and amplify distracting sounds. When reverberation time is long enough, an echo can occur. An echo is the distinct repetition of an original sound produced through the reflection of sound waves, which arrives at the listener following a delay. The length of the delay depends on the distances between the reflecting sound surface, the sound source, and the listener. One type of echo that is particularly problematic is a flutter echo. A flutter echo is the phenomenon of sound energy becoming trapped and reflecting repeatedly between two parallel surfaces, such as in a hallway.



THE ABCDs OF SOUND CONTROL

When setting out to manage sound behaviour and acoustical issues in an indoor space, there are four basic approaches you can take: Absorb, Block, Cover or Diffuse.

Absorb

Sound can be absorbed or captured by porous treatment materials to diminish the amount of reflection in a space. These materials can be installed on ceilings, floors, walls or be integrated in furnishings and other objects in a space. The goal is not always to add as many absorbers as possible. Rather, the optimal amount of absorbent materials used should be determined by calculating the optimal reverberation time of the specific type of space.

Block

Sound can be blocked, or stopped from traveling, through the introduction of barriers between the sound source and the listeners in a space. A blocker can take the form of a wall, partition, a tall piece of furniture or extra layers of drywall. Blocking can involve sealing off or isolating a sound source, such as a machine, by building a separate room or isolation chamber. Appropriate ceiling material may also be necessary to block unwanted sound transmission.

Cover

Sound can be covered or masked by introducing additional sounds to a space. The aim is to make it more difficult for the brain to detect intelligible fragments of sound or conversation so that focus can be maintained on the intended activity like work tasks, for example. These active solutions are either natural or artificial in nature. Natural solutions might be, for example, an indoor water feature. Artificial solutions typically involve the use of randomly generated electrical signals that are introduced to a space via a loudspeaker.

Diffuse

Sound can be diffused, or scattered in different directions through the introduction of objects or materials with textured or uneven surfaces. Rather than diminish the sound, the idea is to improve its quality by reflecting and spreading it out more evenly. For example, diffusers can be used to address disturbing sound focusing or to make a dull space feel more alive. Diffusers come in different shapes and sizes, from curved panels to quadratic diffusers and custom designs. Different depths of the diffusing surface address specific frequencies.

WHAT YOU JUST READ

Key Lessons

1.
The aim of acoustic design is to serve the function of a space and the collective needs of the people using it.

2.
Sound is a vibration that travels through air or another elastic medium as a series of mechanical waves.

3.
The way sound behaves in an indoor space depends on the acoustic characteristics of surface materials and the location of boundaries and objects.

4.
There are four main strategies for managing acoustical issues: Absorb, Block, Cover and Diffuse.

Terms & Concepts

Acoustic environment
Sound wave
Frequency
Decibel
Absorption
Reflection
Diffusion
Diffraction

Refraction
Transmission
Reverberation
Echos
Absorb
Block
Cover
Diffuse

Major insight:

Managing sound in indoor spaces isn’t just about addressing the source. It’s about manipulating how sound behaves once it has been set into motion.

ESSENTIAL MEASUREMENTS

START HERE

Every space has a unique set of acoustic properties, and there are various tools and methods that can be used to assess and measure them. However, before you can introduce the right acoustic treatments it's essential to understand your design goals and identify any issues that might need to be addressed.

Some acoustic treatment suppliers offer calculators that estimate treatment needs based on space dimensions and other measurable variables. Advanced prediction technology can also be used to predict acoustic values—for example, by using techniques such as room acoustic modelling, auralisation, ray tracing, and absorption performance prediction. Collaborating with a professional acoustician to carry out such measurements is highly recommended.

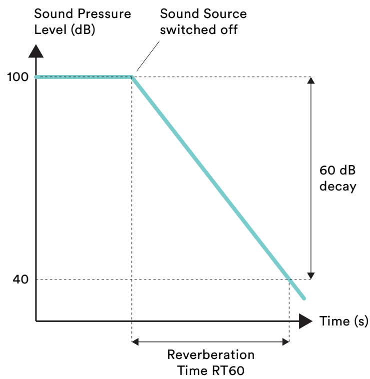
If you are designing a space that is already in use, valuable insights can also be gathered by surveying the needs and complaints of current inhabitants, as well as by experiencing the acoustic environment for yourself.

WHAT TO MEASURE

REVERBERATION TIME

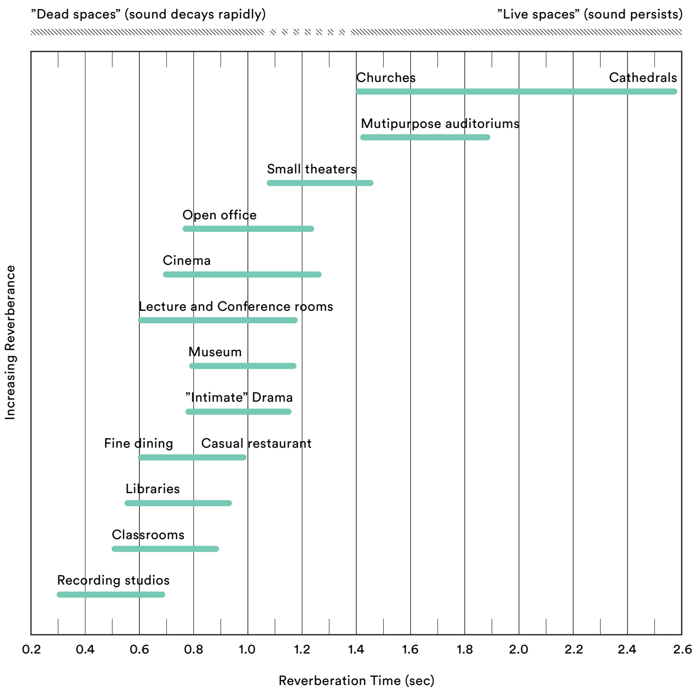
Reverberation time (RT60) is the lifetime of a sound in a space, or the amount of time it takes for the sound to decrease by 60 decibels (dB) once the source of the emission has stopped. Reverberation time is measured in time (seconds) and sound pressure (dB). Spaces with an RT60 less than 0.3 seconds are considered to be acoustically 'dead', while spaces with an RT60 more than 2 seconds are considered to be 'echoic'.

A long reverberation time may make a room sound echoey, live, and full. A short reverberation time may make a room sound dull or dry. Generally, a large room will have a longer reverberation time than a small room. While a room equipped with many sound-absorbing materials, like carpets and textiles, will have a shorter reverberation time than a room with fewer sound-absorbing materials. Likewise, a room with many reflective materials will have a higher reverberation time than a room that does not. The ideal reverberation time depends on the intended use of the space.



A simplified calculation of reverberation time (T) can be conducted using the volume of the room (V) and absorption surface area (A), according to Sabine's formula: $T = 0.16 \times (V/A)$

Ideal reverberation times for different kinds of spaces



The clap test

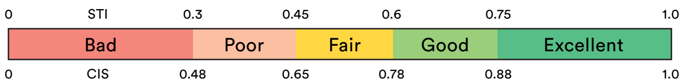
Anyone can use the simple ‘clap test’ to quickly get a sense of the reverberation of a space. Start by doing a single clap outdoors away from buildings to give your ears some context (there should be no echo). Then return indoors and do a single clap in different parts of the space you are assessing. If there is a lot of reverberation the sound will echo back loudly, and continue resonating for some time. If there is little reverberation, the sound will die out quickly. Perhaps there are other acoustic qualities you notice? Practice, observe and learn.

SPEECH INTELLIGIBILITY

Speech intelligibility is a measure of the quality of the transmission of speech. Speech intelligibility is particularly important in public spaces where occupants need to be able to clearly hear and understand instructions, whether the instructions are coming from a person in the same room or via an electronic public address or voice alarm system. For instance, this could apply to classrooms, auditoriums, churches, conference rooms, concert halls, airports, trains stations and shopping centres.

Speech intelligibility is calculated according to a standard index using acoustical measurements of speech and noise. A number of factors influence speech intelligibility, including ambient noise level, reverberation time, the frequency response of a room, psychoacoustic masking effects, as well as the quality of any sound reproduction equipment being used to transmit sound in the space.

The Speech intelligibility index (SII) is represented on a numeric scale called the Common Intelligibility Scale (CIS). The value ranges from 0 to 1, or bad to excellent, and indicates the degree to which a space, aka transmission channel, degrades speech intelligibility.



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The Speech Intelligibility Index (SII)

Category	Nominal STI value	Type of message information	Examples of typical usage	Comment
A+	>0,76		Recording studios	Excellent intelligibility but rarely achievable in most environments
A	0,74	Complex messages, unfamiliar words	Theatres, Speech auditoria, parlaments, courts, Assistive Hearing Systems (AHS)	High speech intelligibility
B	0,7	Complex messages, unfamiliar words		
C	0,66	Complex messages, unfamiliar words	Theatres, Speech auditoria, teleconferencing, parlaments, courts	High speech intelligibility
D	0,62	Complex messages, familiar words	Lecture theatres, classrooms, concert halls	Good speech intelligibility
E	0,58	Complex messages, familiar context	Concert halls, modern churches	High quality PA systems
F	0,54	Complex messages, familiar context	PA systems in shopping malls, public building offices, VA systems, cathedrals	Good quality PA systems
G	0,5	Complex messages, familiar context	Shopping malls, public building offices, VA systems	Target value for VA systems
H	0,46	Simple messages, familiar words	VA and PA systems in difficult acoustic environments	Normal lower limit for VA systems
I	0,42	Simple messages, familiar context	VA and PA systems in very difficult spaces	
J	0,38		Not suitable for PA systems	
U	<0,36		Not suitable for PA systems	

Note 1: These values should be regarded as minimum target values.
Note 2: Perceieved intelligibility relating to each category will also depend on the frequency response at each listening position.
Note 3: The SII values refer to measured values in sample listening positions or as required by specific apllication standards.

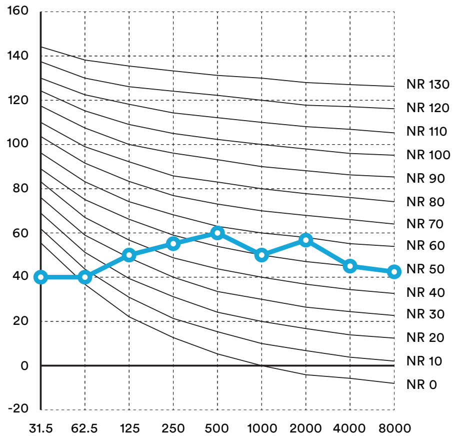
SOUND LEVELS

It is important to understand what sound levels are acceptable in a given space. Excessive background noise can originate within or outside a space and impact inhabitants in a myriad of ways ranging from annoyance and distraction to aggressive behaviour and hearing impairment. Sound level is measured in sound pressure (decibels (dB)) at different frequency levels (Hertz (Hz)).

The International Organization for Standardisation (ISO 1973), the American National Standards Institute (ANSI 1995), and other international organisations, set standards for acceptable sound levels in indoor environments to preserve hearing, clear speech communication and minimise annoyance. The ISO Noise rating (NR) curves, for example, indicate the maximum allowable sound pressure level at different frequencies, varying according to different types of spaces and their intended use. Each maximum rating level is indicated by a NR value.

To determine a NR value for a given space, the sound frequency spectrum of the noise in an unoccupied room is measured. The obtained spectrum of values are then plotted on a graph and compared against the noise rating curves to determine a rating (see calculation example).

Calculating a noise rating



Maximum Noise Rating Level	Application
NR 25	Concert halls, broadcasting and recording studios, churches
NR 30	Private dwellings, hospitals, theaters, cinemas, conference rooms
NR 35	Libraries, museums, court rooms, schools, hospitals, operating theaters and wards, flats, hotels, executive offices
NR 40	Halls, corridors, cloakrooms, restaurants, night clubs, offices, shops
NR 45	Department stores, supermarkets, canteens, general offices
NR 50	Typing pools, offices with business machines
NR 60	Light engineering works
NR 70	Foundries, heavy engineering works

SOUND ABSORPTION

All objects and materials have acoustic properties. They either absorb, reflect or transmit the sound waves they come into contact with. And the degree to which they do these things is dependent on frequency. To understand the acoustic characteristics of a space it is important to consider how existing or planned objects, materials—and even people—might impact the interior acoustic environment. Generally, soft and porous materials and objects are more absorbent than hard and reflective materials. While light materials and objects transmit sound better than dense and heavy materials.

Absorption coefficients help us understand how absorbent or reflective a given object, material or surface is. A coefficient of absorption measures how absorptive or reflective a material is on average, when exposed to different sound frequencies. For example, a material that has a coefficient of 0.3 at a given frequency absorbs 30% of the sound energy it comes into contact with. At the same time, this tells us that the remaining 0.7 or 70% of sound energy, which is not absorbed, is reflected back into the room. Generally, a sound absorption coefficient of 0.20 and higher is considered to be absorptive, and a coefficient of 0.19 and lower is considered to be reflective.

More absorbent	**More reflective**
Carpet	Brick
People	Dense concrete
Foam	Glass
Furniture	Marble
Insulation	Metal
Textiles	Hardwood

Sound absorption coefficients for common materials

Material	Coefficient (a) 500HZ	1000HZ	2000HZ	Material	Coefficient (a) 500HZ	1000HZ	2000HZ
Walls				**Floor**			
Brick, unglazed	.03	.04	.05	Concrete or Terrazzo	.015	.02	.02
Brick, unglazed, painted	.02	.02	.02	Linoleum, asphalt, rubber, or cork tile on concrete	.03	.03	.03
Plaster, gypsum, or lime, smooth finish on tile or brick	.02	.03	.04	Wood	.10	.07	.06
Plaster, gypsum, or lime, rough or smooth finish on lath	.06	.05	.04	Wood parquet in asphalt on concrete	.07	.06	.06
Concrete block, light, porous	.31	.29	.39	Carpet, heavy, on concrete	.14	.37	.60
Concrete block, dense, painted	.06	.07	.09	Same, on 40 oz hairfelt or foam rubber	.57	.69	.71
Gypsum boards. 1/2-inch nailed to 2×4s, 16 inches o.c.	.05	.04	.07	Same, with impermeable latex backing on 40 oz hairfelt or foam rubber	.39	.34	.48
Plywood paneling, 3/8-inch thick	.17	.09	.10	Marble or glaze tile	.01	.01	.02
Large panes of heavy plate glass	.04	.03	.02	**Fabrics**			
Ordinary window glass	.18	.12	.07	Light velour, 10 oz per sq yd, hung straight, in contact with wall	.11	.17	.24
Misc				Medium velour, 14 oz per sq yd, draped to half area	.49	.75	.70
Chairs, metal or wood seats, each, unoccupied	.22	.39	.38	Heavy velour, 18 oz per sq yd, draped to half area	.55	.72	.70

Occupancy rate

People absorb sound too. Make sure you factor in the number of people that will occupy a space before approaching acoustic treatment.

Average sound Absorption per person at Octave Band Frequencies

Frequency (Hz)	Average Sound Absorption per person
125	0.29
250	0.43
500	0.51
1000	0.68
2000	0.71
4000	0.73

Volume of air

Air has a natural ability to absorb sound. The amount of sound absorbed by air in an indoor space depends on the level of humidity and the distance the sound wave travels.

WHAT YOU JUST READ

Key Lessons

1.
Understand the purpose of the space before taking measurements.

2.
Tools for measurement range from simple calculators to more advanced software used by professional acousticians.

3.
Valuable clues about acoustic issues can be gathered by asking the people currently using the space.

4.
Four of the most common interior acoustic measurements are reverberation time, speech intelligibility, sound level, and sound absorption.

5.
All objects, materials and people have acoustic properties which should be accounted for when assessing an acoustic environment.

Terms & Concepts

Acoustic treatment
Reverberation time
Sabine's formula
Sound pressure (dB)
Frequency level (Hz)
Speech Intelligibility
Noise rating (NR)
Sound absorption
Absorption coefficient

Major insight:

Before you can select a suitable treatment, you need to identify the acoustic properties of the space as well as any acoustic issues detracting from its function.

TYPES OF ACOUSTIC TREATMENTS

THE ART OF SHAPING THE ACOUSTIC ENVIRONMENT

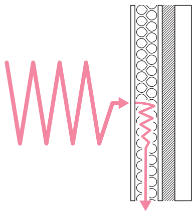
The goal of acoustic solutions is to correct or enhance the acoustics of a space in order to support its intended function and goals. There are two categories of acoustic solutions: Soundproofing and treatment. Soundproofing aims to prevent sound from traveling outside or arriving into the space, i.e. sound isolation. To achieve soundproofing you need mass; this is the only way to fully isolate sound from bleeding through walls. By contrast, an acoustic treatment seeks to improve or optimise the sound. Interior acoustic solutions range from simple to complex, depending on the application and project budget. Acoustic treatment is about changing the sound inside the room for clarity; transforming the dynamics of how sound waves move within a space. Most acoustic treatments absorb sound waves which improves the sound within a space, giving the listener a better sonic experience. Acoustic treatment's primary focus is to reduce naturally occurring reverberation that occurs in a room, standing waves and other issues.

”An acoustic treatment is like the essential dressing that a naked, acoustically incomplete space needs to wear in order to function.”

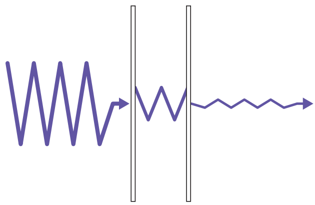
Dr Luis Gomez-Agustina

TREATMENT OPTIONS

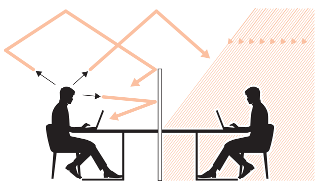
Besides taking into account the innate acoustic properties of an interior's materials and surfaces, there are several acoustic treatments that can be introduced to help construct the desired acoustic environment. These treatments can be used to mitigate any problematic sound behaviours and optimise the overall acoustic experience. There are four main treatment types, corresponding with the ABCDs of sound control which were summarised earlier.



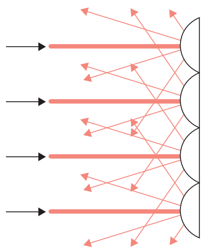
Sound absorbers



Sound blockers



Sound maskers ('coverers')



Sound diffusers

SOUND ABSORBERS

Sound absorbers are designed to trap sound energy and prevent some of it from being reflected back into the room. The traditional absorber is generally made from porous and fibrous materials such as foam, mineral wool, and textiles. But absorbers can even include materials made of metal or wood. The absorptive abilities of such materials vary significantly depending on sound frequency. For this reason, a variety of shapes, styles and thicknesses are available to meet different absorption requirements.

Three types of absorbers

1. Porous absorbers:
Thick and porous materials that trap sound energy in a cellular structure. The trapped sound energy turns into heat as oscillation is dampened by friction. Examples: carpets, textiles, aerated plaster, mineral wool and open-cell foam.

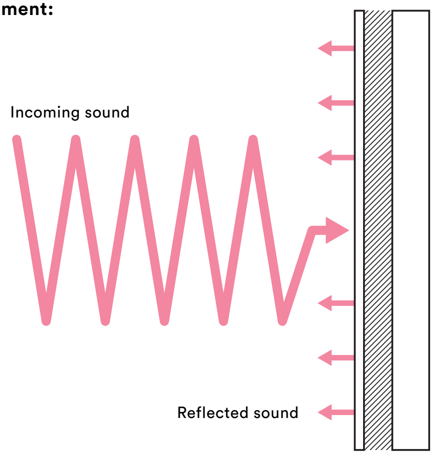
2. Panel Absorbers:
Flexible and non-porous materials that bend and vibrate as they trap sound energy in their enclosed interiors filled with air volume. Examples: flat panels made of wood, metal, gypsum and plastic with interiors filled with mineral wool or foam.

3. Resonators:
Perforated materials that trap sound energy in holes or slots of different depths where it is then converted into oscillation energy. Resonators can be customised to reduce a specific set of frequencies. Examples: perforated wood, metal and gypsum board.

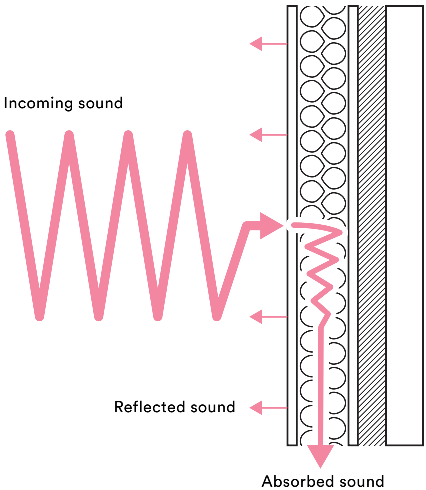
Use to:

» Dampen sounds within a space
» Reduce sound reflections and echos
» Shorten reverberation time
» Improve speech intelligibility

Before treatment:



After treatment:



SOUND BLOCKERS

Sound blockers prevent sound from entering or leaving a space. Blocking sound can involve introducing dense or heavy structural components during construction like concrete blocks or gypsum boards that increase the structural mass of walls, floors or ceilings. It can also mean introducing vertical ceiling panels or room dividers, sealing gaps between doors or windows, or filling other openings letting noise in with materials like insulation or acoustical sealant. The extent of the measures that need to be taken depends on the amount of noise you wish to block.

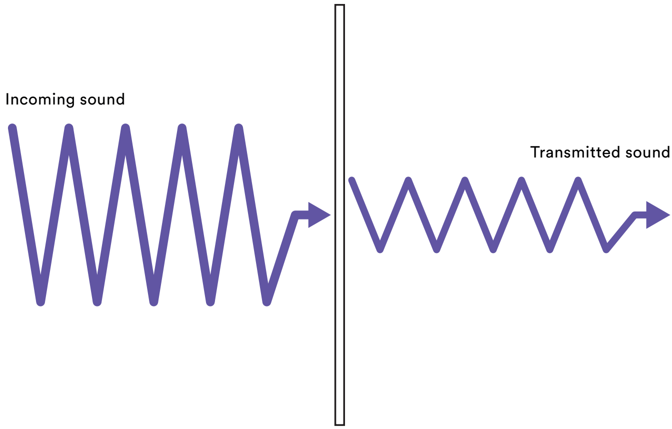
Types of sound blockers

- Mass-loaded vinyl barrier
- Mineral wool insulation
- Resilient channels for decoupling drywall from internal building structure
- Soundproof drywall
- Acoustic caulk or sealant
- Acoustic quilt
- Double-pane windows
- Door sweeps or seals
- Floor underlayment
- Soundproof partitions

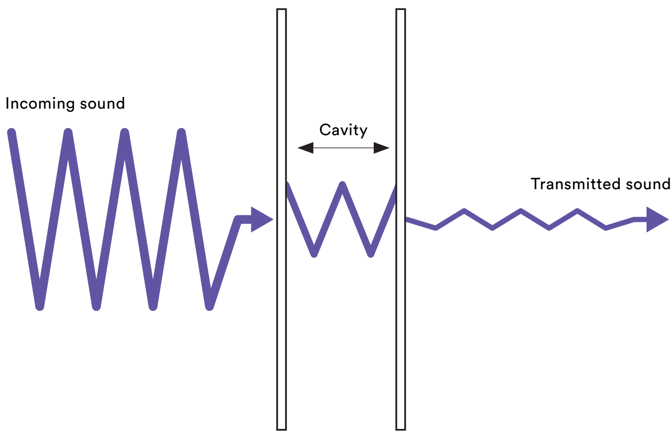
Use to:

- Reduce amount of sound entering from outside
- Isolate noise from noisy appliances
- Soundproof for extra privacy
- Prevent sound inside a space from disturbing others outside

Before treatment:



After treatment:



SOUND MASKERS

Sound masking systems do not eliminate noise, but instead make it more difficult to perceive the noise by introducing additional sounds to a space. The sound emitted from such systems is random and ambient, and professionally tuned to a specific frequency and level to cover unwanted sound and achieve acoustic comfort. When such systems are working properly, the sound is barely perceptible and evenly distributed. Most systems include a sound source, amplifier, equaliser and speaker. Speakers are placed either at or above ceiling height, or beneath the floor. The number of speakers used depends on the amount of coverage desired. The introduction of a water feature can also be considered to be a sound masking or covering solution, as the natural sound of dripping water distracts listeners from disturbing noises.

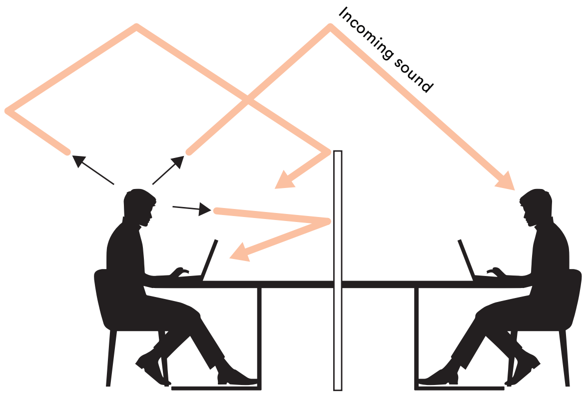
Types of sound masking solutions

» Direct-field sound masking systems
» Indirect-field sound masking systems
» Water feature or fountain

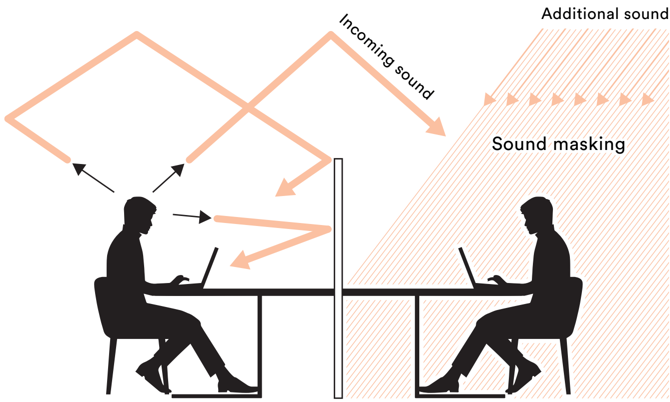
Use to:

» Cover distracting noises that are otherwise difficult to remove
» Create greater speech privacy
» Increase the feeling of comfort
» Create restful or private zones in a multi-use space

Before treatment:



After treatment:



SOUND DIFFUSERS

Sound diffusers reflect and evenly scatter sound energy back into a space. Instead of removing or minimising sound, the goal of the diffuser is to improve the quality of existing sound in a space. When a sound wave comes into contact with a diffuser, interference occurs as it encounters uneven surfaces of varying depths. So when the sound reflects and re-enters the room it doesn't bounce back in the same direction it came from but spreads out in multiple directions over an expanded area. Diffusers come in different shapes and textures, and can even be custom designed to create a special effect for critical listening applications.

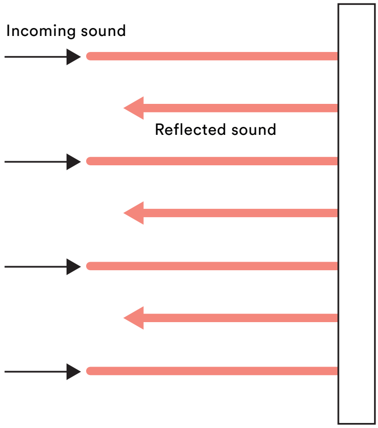
Types

» Curved panels
» Quadra pyramid diffusers
» Pyramidal diffusers
» Polycylindrical diffusers
» Quadratic diffusers
» Custom designed diffusers

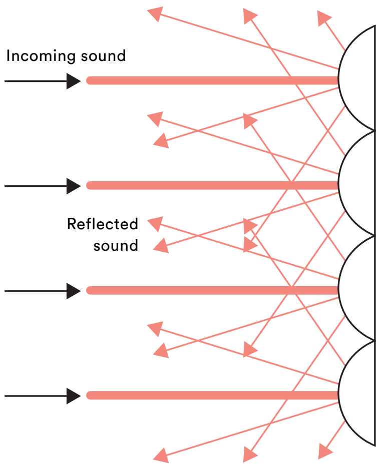
Use to:

» Reduce echos and reflections
» Reduce sound focusing
» Prevent standing waves
» Enhance richness of sound in a space
» Create a feeling of spaciousness
» Make a dull space feel more alive
» Provide wider sound coverage for speech or music
» Improve speech intelligibility and clarity

Before treatment:



After treatment:



IMPORTANT ACOUSTICAL TREATMENT RATINGS

Acoustical rating systems provide guidance when it comes to understanding the efficacy of different treatment solutions. Here are some of the most important ones to familiarise yourself with.

Sound Transmission Class (STC)

Sound Transmission Class (STC) is a numerical rating used to indicate how effectively a given building material blocks sound from transmitting through it. STC is used to rate partitions or dividers, as well as floors, ceilings, doors and windows. Generally, a low performance rating is less or equal to 35, while a high performance rating is greater or equal to 55.

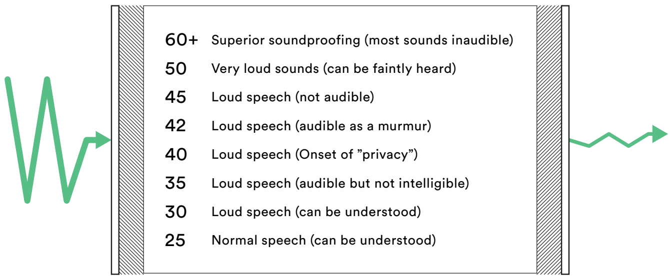
Noise Reduction Coefficient (NRC)

A Noise Reduction Coefficient (NRC) is a single number index rating that indicates the ability of a given material to absorb sound. Based on an average of individual sound absorption coefficients in the mid-frequency range, an NRC of 0 indicates perfect reflection while an NRC of 1 indicates perfect absorption. NRC is commonly used to rate acoustic wall panels, ceiling tiles, baffles, banners and office screens.

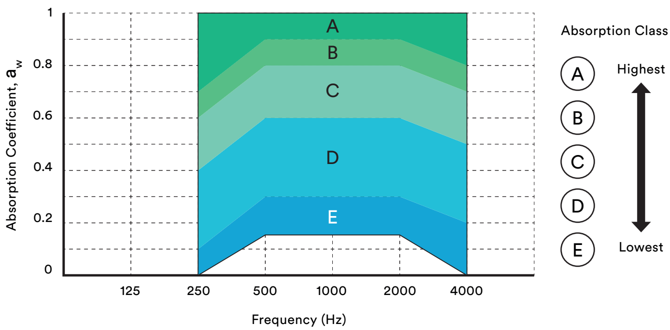
Sound Absorption Class

Sound Absorption Class ratings are used to enable comparison of the absorption performance of different acoustic products. The classes are classified with letters ranging from A-E. The class ratings are obtained by measuring a product's absorption coefficient values over a range of frequencies. These values are then compared against a reference curve to obtain a weighted sound absorption coefficient. An acoustic product with an A rating has the highest sound absorption performance. However, an A rating is not necessarily better than a B rating in certain cases. The absorption class you select ultimately depends on which frequencies you need to absorb.

Sound Transmission Class (STC)



Sound Absorption Class



WHAT YOU JUST READ

Key Lessons

1.
The goal of acoustic treatment is to correct or enhance the acoustics of a space in order to support its intended function and the comfort of its inhabitants.

2.
Designing for acoustics early in the design process can minimise costly treatments and compromises later.

3.
There are four main types of acoustic treatments: absorbers, blockers, maskers and diffusers.

4.
Acoustical rating systems define and rate the efficacy of different treatment materials.

Terms & Concepts

Acoustic treatment
Sound absorbers
Sound blockers
Sound maskers
Sound diffusers
Sound Transmission Class
Noise Reduction Coefficient
Sound Absorption Class

Major insight:

Acoustic treatments enable you to correct unwanted sound behaviours and shape the acoustic environment to serve your design goals.

TREATMENT PLACEMENT

TREATMENT PLACEMENT

Once you've identified the types and combination of treatments a given space needs, it's time to install them. But where exactly should they be placed?

Ideally, placement decisions are made in consultation with a professional acoustician. Proper placement is critical to achieving desired performance. The ideal positioning depends on a variety of factors including room type and shape, activities, problem areas, as well as the location of objects, materials and furniture.

Visualise the path the sound wave travels

Imagine you're holding a bouncy ball in your hand, and let this ball represent a sound wave. Now, look at the space in front of you. If you were to throw this ball from the direction of a sound source—such as a voice—what path would it travel? What obstacles would it encounter? Would it get trapped bouncing (reflecting) back and forth between parallel walls? Would it escape out the window? This exercise may provide some initial clues about what spots might require treatment.

Basic principles

1. Spread them out
Acoustic panels grouped together in one area of the room usually don't achieve the desired effect. Consider the path sound travels and place the panels accordingly.

2. Address parallel surfaces
Parallel surfaces can cause excessive reflection and echoing. Be sure to spot these trouble areas and treat them.

3. Place them level with the noise source
Consider the location of the noise you wish to mitigate and add treatment close to that source. For instance, to absorb some of the sound of talking voices add treatment at the eye level of people in both seated and standing positions.

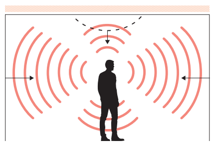
4. Treat corners
Sound can easily build up in corners of rooms and ceilings. Spot these areas and add treatment.

TREATMENT PLACEMENT BY ROOM SHAPE

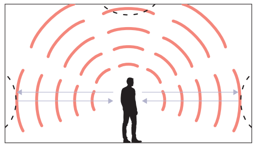
The geometry of a room shapes the acoustic environment

The shapes created by the location of constructed walls and barriers also form the acoustic character of a space. As these diagrams illustrate, convex and elaborate surfaces cause sound to scatter, flat surfaces cause sound to reflect, and concave surfaces tend to focus sound waves as they reflect away. Collectively, the surfaces of a given space not only influence how sound will behave but also the path that it will take.

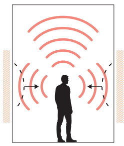
If you are in the position to influence the architectural layout of a space, you can make decisions early on that lead to optimal acoustics instead of having to fix problems later. Generally, domes and round shapes should be avoided when possible as they cause sound focusing issues. Parallel surfaces are also problematic, leading to excessive reflection issues such as flutter echos.



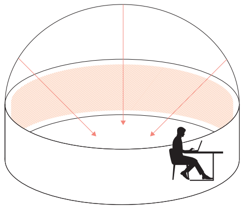
Small spaces



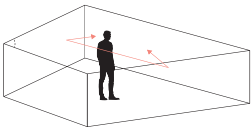
Large spaces



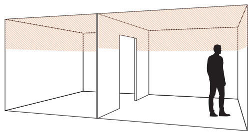
Hallways



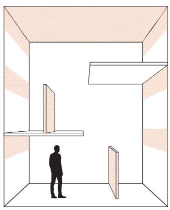
Circular spaces



Slanted surfaces



Connecting rooms

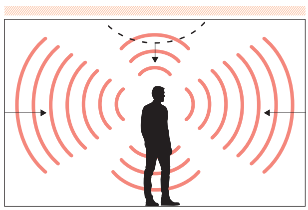


Multi-storey spaces

SMALL SPACES

Short wall-to-wall distances in smaller rooms cause echos as sound bounces back and forth between parallel surfaces.

Strategy:
Place sound absorbers at reflection points on walls and ceiling



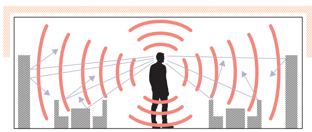
Small rooms

Sound absorbers with a low-frequency profile should be used and placed on the ceiling surface.

LARGE SPACES

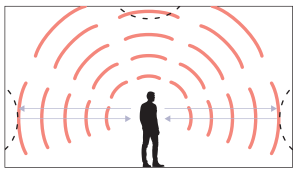
In larger spaces, reverberation time increases and sounds can be heard over long distances.

Strategy:
Use wall and ceiling treatments and barriers that diffuse and absorb sound.



With low ceiling

Sound absorbing and sound diffusing materials should be used, and sound barriers should be applied to the ceiling. The sound regulation from the floor is secured by furniture and the use of sound barriers.



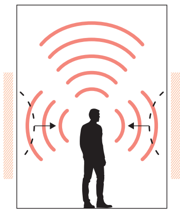
With high ceiling

The sound level should be reduced in such a way that some of the sound masking effect from the relevant noise is still present. Furthermore, the spreading of sound should be limited.

HALLWAYS

Hallways have narrow, parallel surfaces that cause echos due to sound bouncing back and forth. The fact that hallways are often high traffic areas can make noise especially problematic.

Strategy:
Add sound absorbers on the walls at shoulder height or higher. Add rugs or carpeting to the floor.



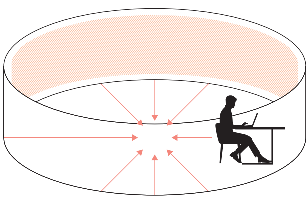
Hallways

Sound absorbers must be placed as close to the sound source as possible. Therefore, the absorbing materials must primarily be placed on the walls.

CIRCULAR SPACES

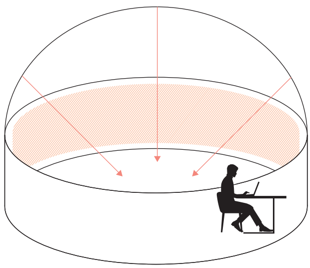
Round or domed spaces cause sound to move towards the centre of the room, causing excessive focusing and echos.

Strategy:
Place sound diffusers along the curved surfaces of the space.



Round rooms

The sound diffusing elements should be placed on the curved surfaces in order for the sound to be dispersed in many directions. The working stations should not be placed in the centre of the construction. In stead, furniture with sound diffusing properties should be placed in the centre.



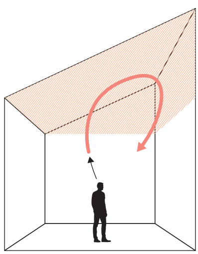
Domes

The sound diffusing elements should be placed on the curved surfaces in order for the sound to be dispersed in many directions. The working stations should not be placed in the centre of the construction. In stead, furniture with sound diffusing properties should be placed in the centre.

SLANTED SURFACES

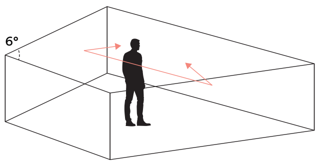
Slanted or inclined surfaces like ceilings or walls cause sound to both spread and become overly concentrated in one area.

Strategy:
Add sound absorbing materials to the surface directly opposite to the inclined wall or ceiling.



Inclined ceilings

The wall area opposite the inclined ceiling should also be equipped with sound absorbing materials. As a principal rule, all surfaces above the normal ceiling height (2.60 m) including the end walls should be equipped with sound absorbers.



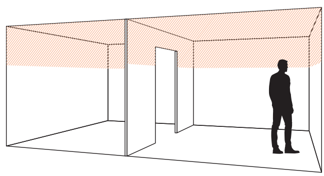
Inclined walls

The sound spreading effect is achieved by inclining the wall in proportion to other walls and the ceiling. In general, the walls inclined by more than 6 degrees ensure an excellent sound diffusion. The most effective diffusion is obtained by applying several angles.

CONNECTING ROOMS

Sound travels from one room to the next and spreads out, causing disruption, diminished speech privacy and a potential echo chamber effect.

Strategy:
Add sound absorbers to the upper walls and ceilings of both rooms.



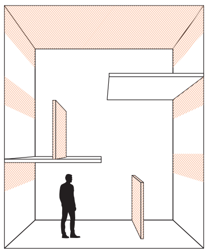
Connected rooms

Both rooms must be equipped with sound absorbers. If the distance between the opening and the opposite walls is short (5-6 m), the walls much be covered with sound absorbers or diffusers.

MULTI-STOREY ROOMS

In multi-storey spaces, sound travels between areas causing excess noise and diminished speech privacy.

Strategy:
Cover all surfaces in sound absorbing or diffusing materials, possibly including vertical absorbing or blocking barriers.



Multi storey rooms

Both rooms must be equipped with sound absorbers. If the distance between the opening and the opposite walls is short (5-6 m), the walls much be covered with sound absorbers or diffusers.

HOW MUCH MATERIAL SHOULD YOU USE?

The amount of treatment material a space requires varies from case to case. Too little treatment material can undermine your acoustic performance goals. Too much can mean unnecessary expenses and space usage.

Calculating the reverberation time of a space can give you an idea of how much treatment material is needed. Additionally, most treatment suppliers offer calculators that allow you to estimate treatment needs based on space dimensions and other variables. Consulting with a professional acoustician is also highly advisable.

WHAT YOU JUST READ

Key Lessons

1.
Correct treatment placement is critical to achieving the desired acoustic performance.

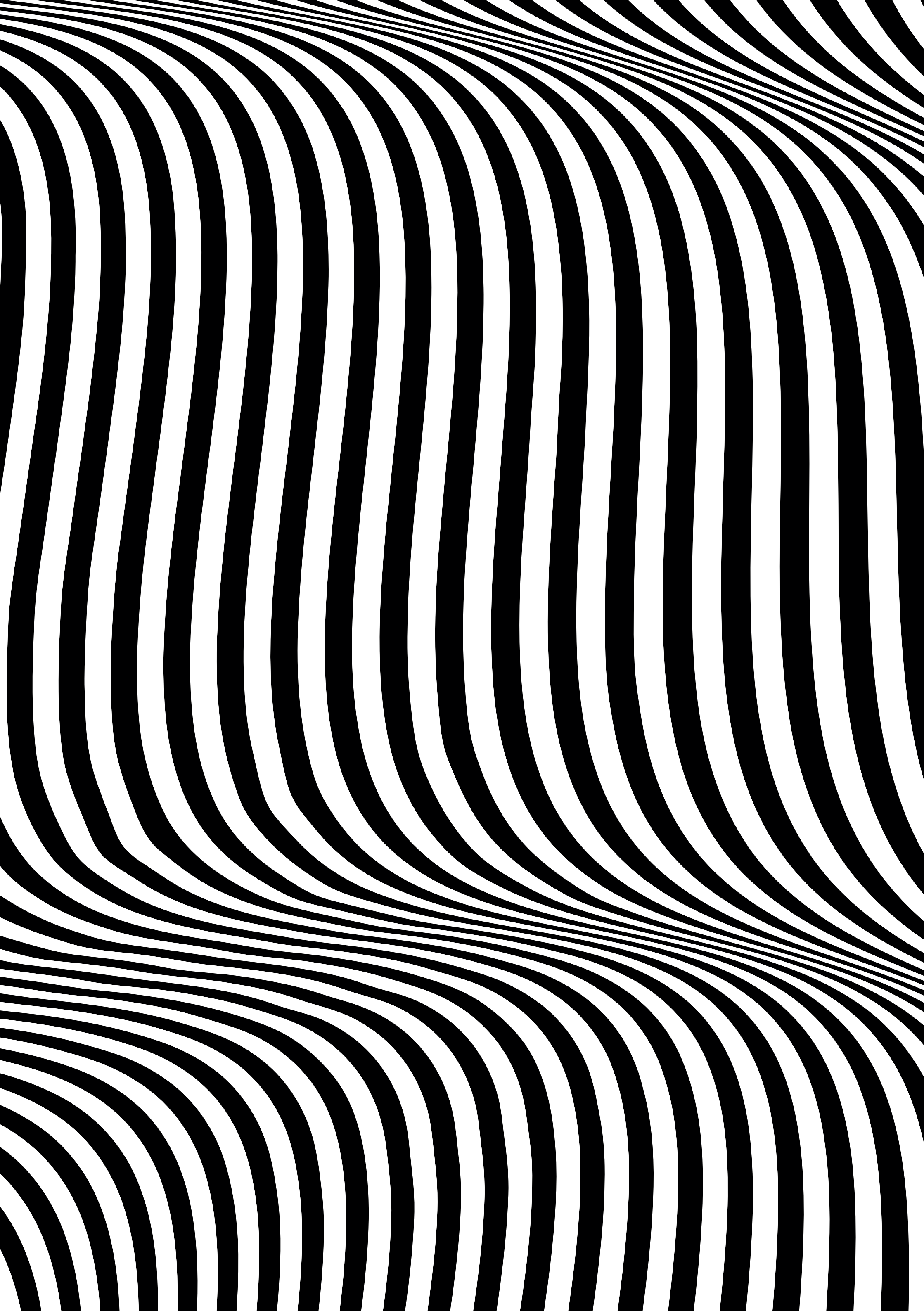
2.
A variety of factors influence where a treatment should be placed, including room shape, obstacles and planned activities.

3.
The geometry of a space influences how sound behaves and where it travels.

4.
How much treatment material is needed depends on variables like target reverberation time and room dimensions.

Major insight:

Acoustic treatments should be placed at constructive points along the path sound travels and in a quantity in-line with the target acoustic performance.



BENEFITS OF GOOD ACOUSTIC DESIGN

WHY SHOULD PEOPLE CARE ABOUT THEIR ACOUSTIC ENVIRONMENT?

Whether we're conscious of it or not, we are always listening to the environment around us. The sounds we take in impact us on a physiological and psychological level, and affect our ability to perform, interact and thrive. For this reason, designers should aim to create an acoustic environment that is as inhabitable as possible.

Top 8 benefits of acoustic treatment

1. Facilitate greater speech clarity and higher quality interactions
2. Improve speech privacy in shared spaces
3. Increase safety and security through greater speech intelligibility and awareness of surroundings
4. Boost the performance and productivity levels of occupants
5. Maintain or increase the health and wellbeing of occupants
6. Enhance learning and concentration through better listening
7. Support the specific function of the space
8. Create an aurally pleasing soundscape that enhances mood and aesthetics

HEALTH & WELLBEING

Excessive noise exposure has consequences for our health and wellbeing that extend far beyond hearing damage. Noise triggers the brain's acute fight-or-flight stress response and with it, the release of stress hormones like adrenaline and cortisol. With prolonged exposure, the body begins to show signs of suffering. Research links noise to harmful physiological effects ranging from anxiety and depression to an increased risk of cardiovascular disease.

Conversely, less noisy acoustic environments that are designed to support health and wellbeing have been proven to yield positive outcomes. A growing body of research indicates that spending time in quiet environments helps to lower stress and blood pressure levels, decrease fatigue, enable brain restoration, and promote healing. One study in the United States found that reducing environmental noise exposure by just five decibels would reduce the prevalence of hypertension by 1.4% and coronary heart disease by 1.8%, while saving $3.9 billion a year in healthcare costs.

A well designed acoustic environment leads to:

- » Less tension and more relaxed states
- » Reduced blood pressure levels
- » Lower cortisol and adrenaline levels
- » Greater capacity for brain cell regeneration
- » Better immune system function
- » More sustained energy
- » Better sleep quality
- » Accelerated healing and recovery
- » Greater feeing of calm and tranquility
- » Enhanced self awareness and ability to self-reflect on mental and emotional states

FOCUS & PRODUCTIVITY

In most modern workspaces the ability to focus is critical to productivity. Studies show that when people become distracted it can take up to 25 minutes to regain concentration.

Everything from the sound of ringing phone and nearby conversations to closing doors and the buzz of appliances can affect peoples' ability to concentrate and perform. Long-term exposure to distracting noises have consequences that not only affect production and learning outcomes, but also the quality of social interactions and the degree to which inhabitants feel satisfied and comfortable in their environment.

On the other hand, acoustic environments designed to support focus and productivity have a clearly positive impact. For example, studies show that an improvement of acoustic conditions in office environments yielded the following results:

» 48% improvement of workers' ability to focus on tasks
» 51% decrease of conversational distractions
» 10% improvement of error-rates
» 27% decrease of office-related stress symptoms

A well designed acoustic environment leads to:

» Better decision making
» Fewer work errors
» Improved behaviour and interactions
» Greater willingness to engage with others
» Better workplace satisfaction
» Greater attraction and retention of talent

LISTENING & LEARNING

The ability to sit still for extended periods of time while listening, especially crucial for students of all ages, is directly influenced by environmental factors such as distracting or irritating sound. Being able to hear a lecturer or teacher clearly without distraction is a prerequisite for effective learning, and yet educational environments commonly face the same challenges as workspaces; namely, excessive noise and poorly designed acoustics. Teachers also risk damaging their vocal chords and hearing when regularly exposed to high levels of sound. A large-scale study by the Institute for Interdisciplinary School Research in Germany found that more than 80% of teachers surveyed reported experiencing stress from noise generated by students. Students with special needs and learning disorders such as autism are particularly susceptible to poor acoustics. Many countries mandate the provision of specialised learning environments for students with learning disorders, but fail to take into account the impact of sound, which can contribute to anxiety, stress and antisocial tendencies.

In a recent study, the reduction of acoustic reverberation in UK classrooms led to improved behaviour, information retention and engagement by all pupils, as well as less stress among teachers.

A well designed acoustic environment leads to:

- » Improved ability to focus
- » Lower cognitive stress
- » Fewer distractions and interruptions
- » Better information retention
- » Improved reading comprehension
- » Better short term memory
- » Reduced risk of hearing loss
- » Minimised vocal strain
- » Reduced stress for those with special needs

SAFETY & SECURITY

In some shared or public spaces, noise levels have a direct impact on safety and security. Excessive noise can negatively affect speech intelligibility, which is a problem when it comes to understanding the content of public announcements made over the public address or voice alarm Systems in schools and train stations, for example. Poor speech intelligibility is particularly detrimental in public emergencies, where announcements contain instructions intended to lead people to safety.

Noise exposure can even lead to a higher occurrence of human errors and inappropriate aggressive social behaviour among predisposed individuals. It has been shown that 'helping behaviour' declines in environments where noise levels rise above 80 dBA. It has also been shown that schoolchildren exposed to high levels of noise may be more susceptible to helplessness.

A well designed acoustic environment supports public safety and security by enhancing speech intelligibility and creating a less agitating and more peaceful soundscape where people can think clearly and maintain awareness of their surroundings.

A well designed acoustic environment leads to:

» Better speech intelligibility
» Less annoyance and irritation
» Less stress
» Fewer behavioural problems
» Improved ability to focus
» Better decision making
» Enhanced self awareness and ability to self-reflect on mental and emotional states
» More compassion and empathy for others

WHAT YOU JUST READ

Key Lessons

1.
Acoustic environments impact people on a physiological and psychological level.

2.
In healthcare spaces, well designed acoustics can help lower stress and promote healing.

3.
In work spaces, well designed acoustics can help reduce distractions and improve performance.

4.
In learning environments, well designed acoustics can help improve student engagement and information retention.

5.
In public spaces, well designed acoustics can help minimise aggressive behaviour and improve the intelligibility of public announcements.

Major insight:

The acoustic environment that surrounds us impacts our wellbeing and performance —whether we're aware of it or not.

THE PAST AND FUTURE OF ACOUSTIC TREATMENTS

Acoustic

/əˈko͞ostik/ /əˈkustɪk/

Derived from the Greek word ἀκουστικός (akoustikos), meaning "pertaining to hearing," or "ready to hear."

The Oxford dictionary defines it as:

1) The properties or qualities of room or building that determine how sound is transmitted in it.
2) The branch of physics concerned with the properties of sound.

While acoustics was not formally recognised as a science until the 20th century, human records show that we have been manipulating our acoustic environments since the beginning of civilisation. The 4th century Greek architects of The Great Theatre at Epidaurus may not have been familiar with sound wave theory, but they knew how to design their arena so that sound could be heard all the way in the back row. Here are some highlights from humankind's string of acoustic feats and discoveries over the past 2.5 million years.

2.5 million years ago to 1,200 BC
Hunters seeking to teach new generations of their tribe about hunting tactics realise that the circular layout is most optimal for enabling everyone to adequately hear their message.

4th century BC
The Greek amphitheater at Epidaurus is built with a sophisticated acoustics filter that can carry voices and instruments with amazing clarity all the way to the back row. The theatre continues to be an acoustic marvel up to this day.

20 BC
Roman architect and engineer Vitruvius writes about interference, echos and reverberation in a treatise on the acoustic properties of theatres.

973-1048 AD
During the Islamic Golden age, scholar and scientist Abū Rayhān al-Bīrūnī postulates that the speed of sound is much slower than the speed of light.

1564-1642
Italian astronomer, physicist and engineer Galileo Galilei and French polymath Marin Mersenne independently discover the complete laws of vibrating strings. Galileo writes, ”Waves are produced by the vibrations of a sonorous body, which spread through the air, bringing to the tympanum of the ear a stimulus which the mind interprets as sound.”

1630-1680
Experimental measurements of the speed of sound moving through air are successfully carried out by Marin Mersenne and others.

1642–1727
English mathematician Sir Issac Newton derives the relationship for wave velocity in solids.

1877
The British scientist Lord Rayleigh publishes The Theory of Sound which examines questions about sound vibrations and the resonance of elastic solids and gases. A monumental work that is still highly revered in the field of acoustics today.

1898
American physicist Wallace Clement Sabine defines reverberation time and develops a formula for calculating the reverberation time of a room. Initially developed for personal use in order to predict and optimise acoustics in the Fogg Lecture Hall at Harvard University, Sabine published his equation for the benefit of the public in October 1898.

1892
The Cabot's Quilt, one of the earliest acoustical tiles, is made out of eelgrass wrapped in paper.

1911
Wallace Clement Sabine develops the Rumford Tile, a mixture of clay, peat, and feldspar which yields a porous clay matrix when baked.

1920s
Development accelerates and a variety of new acoustic materials and systems enter the scene. New materials used for treatment include wood, asbestos fibres, mineral wool, cork, gypsum, sugarcane and cement. New systems are put into use such as felt-and-membrane and board-and-tile systems.

Today

Today in the 21st century, the field of acoustics continues to evolve with increasingly advanced measurement and modelling techniques and an ever expanding variety of treatment types, shapes and materials.

The future of acoustics

Progress in the field of acoustics today is largely shaped by the ongoing digital transformation. In the coming years, we can expect to see everything from more accurate measurement and prediction software to the use of AR and VR in auditory simulation and a new generation of advanced acoustic materials.

WHAT DEVELOPMENTS CAN WE EXPECT TO SEE IN THE FUTURE?

Dr Luis Gomez-Agustina:

”There is a strong drive to develop meta materials designed to provide acoustic properties and benefits that conventionally designed materials cannot offer.”

Tine Wagenmann:

”In the future, acoustics will become even more important because people are becoming more and more aware of how it affects wellbeing.”

Dan Bosnyak:

”I’m excited about variable acoustics... when you think about the potential of taking one room and giving it completely different purposes, or making a room that’s really intended for conferences or presentations also passable for musical performance, then you’ve just created two rooms out of one.”

Andrew Carballeira:

”In the future I think we can expect to see some of the knowledge once explicit to the acoustics trade become devolved into software and AI tools that can guide designers on commonplace everyday questions.”

HOW TO DESIGN WITH ACOUSTICS

FORM VS. FUNCTION

Does achieving the ideal acoustic environment have to mean sacrificing form for function? This is a common concern among designers and architects new to acoustic design. However, the palette of choices is far more diverse than a collection of foam panels in three different colours.

There's a variety of materials, colours, shapes and textures available to choose from on the market today, and the options are expanding every day. Once you understand the fundamentals of sound control and learn about the tools and options available, you will gain more confidence and creative freedom to achieve the acoustic performance goals of a space without sacrificing your aesthetic vision.

”The ideal acoustic environment does no harm, provides for clear communication and — as kinda the icing on the cake—it takes what is and makes it a little bit more beautiful. It has an aesthetic component to it.”

Andrew Carballeira

6 RULES FOR EXCELLENT ACOUSTIC DESIGN

1. **Start early**

   Architectural and design choices made in the early conceptual stages of the design process impact on the amount of acoustic corrections that need to be made later.

2. **Design for function**

   Different spaces have different acoustical goals. Always find out the present and future possible functions of the space, and design accordingly.

3. **Collect feedback**

   To help clarify goals and assess results, collect feedback before and after a project. Take acoustic measurements and survey the people inhabiting the space.

4. **Understand the path sound travels**

   Surface geometry and obstacles affect how sound behaves in a space. Taking time to assess the unique acoustic landscape will help you make wiser acoustic design decisions.

5. **Know your treatment options**

   The more familiar you are with the solutions in your toolkit, the better equipped you will be to shape the acoustic environment according to your wishes.

6. **Make friends with an acoustician**

   You won't always know the answers. Find a professional acoustician you can maintain an ongoing dialogue with and bring in for extra support when needed.

AURAL AESTHETICS

Beyond functional applications, the acoustics of a space as an aesthetic element is just as impactful as the shapes and colours that meet the eye. Aural aesthetics add another sensory layer to the way we experience a constructed environment. And, just like visual design, acoustics influence whether we perceive a space as beautiful or ugly, or something in between.

Of course, just like other aesthetic elements, we all perceive sound a little bit differently and have our own personal preferences. Studies are currently underway to look into links between different cultural backgrounds and aural preferences. One culture might experience a space as chaotic and irritating while another may experience the same soundscape as vibrant and energising. Once again, when designing the acoustics of a space it is important to understand the unique needs and preferences of its inhabitants.

THE STEP BY STEP PROCESS FOR DESIGNING WITH ACOUSTICS

1. Understand

» What is the purpose of this space?
» How many people will use it?
» What are your client's expectations?

2. Identify

» What are the common acoustic complaints?
» What is the reverberation time?
» What are the noise levels?
» What are the primary sources of unwanted sound?
» How is the shape of the room affecting sound dynamics?

3. Set goals

» What is the target reverberation time for this space?
» What specific noises do you want to reduce?
» How do you want people to feel in this space?
» What activities do you want to support in this space?

When should you bring in an expert?

Ideally, as early as possible. An acoustic expert can help steer you in the right direction at the start of an acoustic design project and help you address challenges and discover solutions you might not have spotted yourself. In projects involving critical listening environments, such as a concert hall or theatre, involving an expert is especially essential.

4. Treat

» Do you need to absorb, block, cover, diffuse—or a combination of treatment strategies?
» How much treatment material do you need?
» What is the ideal placement for each material?

5. Evaluate

» Do the measurements (RT, Db, etc) reflect your start goals?
» Are noise sources addressed?
» How do people feel in the space?
» Do the resulting acoustics support the activities taking place in the space?

BUDGET CONSIDERATIONS

In design project budgets, often too little priority is given to acoustics. After all, acoustics is an invisible design element that you feel rather than visually experience. Here are some key considerations when working with a modest budget.

1. Plan for acoustics early
For newly constructed spaces, you have the opportunity to make proactive design decisions that prevent expensive problem-solving later on.

2. Define expectations
Often, achieving the platinum standard of room acoustics is unnecessary. If you aren't designing a concert hall, you may be able to set the bar at least a little bit lower. Prioritise the areas that need treatment most. For example, a room that is rarely used may require less treatment than a popular meeting room or frequently traveled hallway.

3. Don't waste product
Carefully calculating the actual treatment needs of a room can save a lot of money. This can be done with help from an acoustician or a calculation tool provided by a treatment supplier.

4. Mix cheaper materials with more expensive ones
If the space allows, it could be an option to integrate some cheaper materials and hide them out of sight while featuring beautiful and expensive materials where people can actually see them.

5. Consider the return on investment
What you put in, in terms of money and effort, you ultimately get back in the form of happier, healthier and more productive people.

THE ACOUSTIC DESIGN TOOLBOX

Measurement

» Clap test
» Reverberation time
» Sabine's Formula

Treatments

» Absorbers
» Blockers
» Maskers
» Diffusers

Codes and standards

» Sound Transmission Class (STC)
» Noise Reduction Coefficient (NRC)
» Sound Absorption Class (SAC)

Expert assistance

» Acousticians
» Treatment suppliers
» Specialists for specific applications
» Universities - consulting services, student interns

WHAT YOU JUST READ

Key Lessons

1.
Thanks to the variety of options available today, integrating acoustic treatments in a space design does not mean you have to sacrifice form for function.

2.
To achieve excellent acoustic design you should start early, design for function, collect feedback, understand the path sound travels, know your treatment options and make friends with an acoustician.

3.
Acoustics influence to the way people perceive and experience the aesthetics of a space.

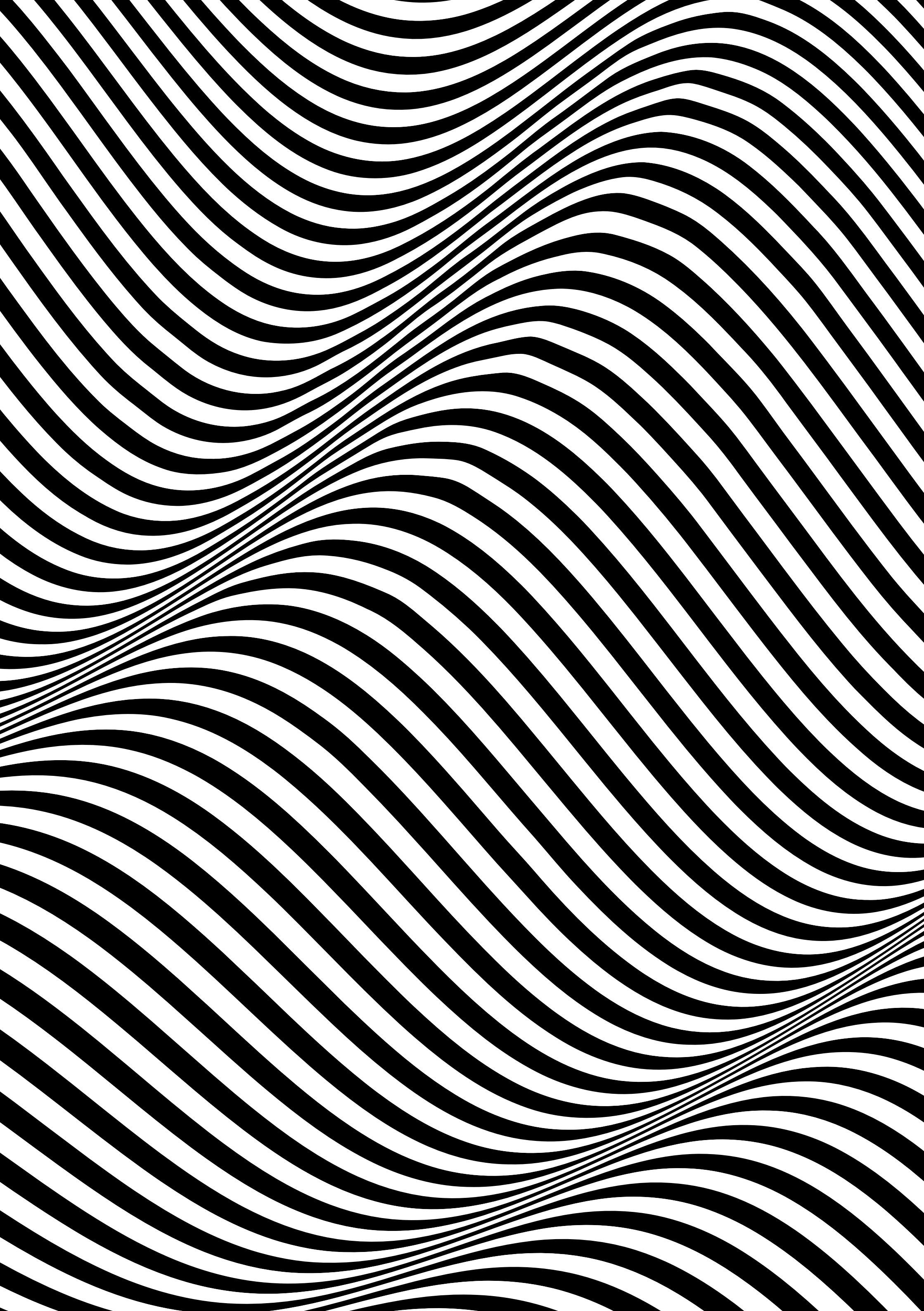
4.
The basic acoustic design process consists of five steps: Understand, identify, set goals, treat and evaluate.

5.
Professional acousticians can provide general guidance, address specific challenges, and help achieve goals in critical listening environments.

6.
If you have a small budget you can keep costs down by planning for acoustics early, defining expectations and priorities, not wasting product, and mixing cheaper materials with more expensive ones.

Major insight:

Acoustics are both an aesthetic and functional element of design that should be integrated into the design process as early as possible.



COMMERCIAL APPLICATIONS

ACOUSTIC DESIGN MUST FOLLOW SPACE FUNCTION

The fundamentals of acoustic treatment can be applied to all interior spaces. However, it's the specific function of a space and the needs of its inhabitants that ultimately informs what a given aural environment should feel like and what the specific design goals should be. When designed correctly, acoustics serve and enhance the purpose, inhabitants an d activities of a space.

"Aural comfort and aural aesthetics in public indoor spaces is mainly dependent on the acoustic characteristics of surface materials on the boundaries of the space and objects."

Dr Luis Gomez-Agustina

WORKPLACES

The primary function of an office or workplace is to serve as a place where employees can both meet and collaborate, and retreat to focus and get things done. In the case of open office layouts, multiple types of acoustic environments need to be able to coexist within the same space.

Everything from chatty coworkers to noisy office appliances can serve as a source of noise and distraction in a workplace environment. Noise from traffic or neighbouring businesses can also pose a challenge.

It has been proven that noisy or disruptive workplaces often lead to diminished productivity, well-being and satisfaction among employees. In a survey of over 350,000 employees across 2,700 workplaces in 69 different countries, it was revealed that 75% of employees consider noise level as an important quality in an effective workplace. At the same time, just 30% reported satisfaction with workplace noise levels.

Taking measures to improve workplace acoustics, however, makes a big difference. In another study, when distractions were reduced, 75% of employees reported greater productivity, 57% experienced increased motivation, and 49% reported feeling happier at work.

Design strategies

» **If possible, during early stages** of building design, add structural buffer zones between noise-sensitive classrooms and areas prone to higher activity and noise levels.

» **Reduce reverberation** in hallways and other adjacent rooms

» **Add soft and sound absorbing materials** to the room such as rugs or carpets, fabric curtains, cork board and ceiling and wall panels.

» **Arrange desks** at an angle around the room, rather than in rows.

» **Insulate doors,** windows and noisy equipment with sound blocking material.

» **Replace noisy light fixtures.**

» **Add soft tips or pads** to the bottom of tables and chairs.

» **Add a speech-reflecting zone** with reflective ceiling tiles above the area where the teacher normally stands to make it easier for their voice to reach all corners of the classroom without strain.

Space function:	**Design goal:**
Focus, productivity and collaboration	Reduce noise distractions and increase speech privacy between different areas of the workplace
Target reverberation time:	**Maximum noise rating level:**
0.5-0.9	NR 35

EDUCATION

The primary function of a classroom is to serve as a learning environment where students can receive instruction from their teacher, collaborate with one another, read, and work independently to complete tests and learning exercises. The ability to hear, understand, and focus is critical to the learning process.

Sounds from other students inside the classroom, building appliances like heating, ventilation or air conditioning systems, as well as sounds coming from outside the building like cars or lawnmowers or playgrounds impede students' ability to hear and concentrate.

One study shows that for a child sitting in the fourth row of an average classroom, speech intelligibility is only 50%. Classrooms with poor acoustics not only have a negative impact on students' ability to comprehend speech, but they also impact their ability to read, pay attention, concentrate and behave appropriately. These challenges amplify for students with learning disabilities or hearing impairments. Teachers suffer from poor acoustics too. Another study showed that 50% of teachers have suffered vocal damage from talking over classroom noise. Longterm noise exposure can also cause hearing damage and consequences from prolonged stress and job burnout.

Good classroom acoustics benefit everyone. Following improvements to classroom acoustics, teachers have reported higher student engagement and improved learning outcomes. In one study, on-task student behaviour in an acoustically treated classroom increased by 17%. In another study, teacher absence decreased from 15% to 2% post treatment.

Design strategies

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Space function:	**Design goal:**
Learning and concentration	Reduce noise levels and increase listener and speaker comfort
Target reverberation time:	**Maximum noise rating level:**
0.5-0.9	NR 35

HEALTHCARE

The primary function of a hospital or healthcare centre is to provide an environment for healing, comfort, recovery, and sleep. It is also a work environment for doctors, nurses and other staff members. In a hospital, the ability to relax and recuperate are just as important as speech confidentiality and the ability to work efficiently. Both restful and optimised working environments are therefore needed to support patients' recovery and enhance communication between staff members.

In a hospital, sources of noise include everything from footsteps in the corridor and conversations between staff members, patients and visitors, to banging doors and beeping medical equipment.

Research conducted on the impacts of noise on hospital patients and staff members shows that noise presents more than a source of annoyance. Noise has also been linked to sleep disturbance, elevated blood pressure, increased heart and respiration rate, higher medication needs post-surgery, and even negative impacts on wound healing.

A good acoustic environment, on the other hand, has been shown to have positive effects on patient healing and care. Following the improvement of hospital room acoustics in one study, pulse amplitudes were lower among intensive coronary care unit patients, incidences of re-hospitalisation decreased, and patients reported greater satisfaction with hospital care.

Design strategies

» **For patient bedrooms,** treatment and examination areas design private rooms with enclosed walls and sound-absorbing materials and acoustic panels

» **Add sound absorption tiles** to the ceiling to increase speech intelligibility and prevent sound from traveling to adjacent areas

» **In rooms shared** by multiple patients, add absorbent room dividers that go from floor to ceiling

» **Eliminate or reduce noise** from medical equipment whenever possible

» **Insulate windows**

» **Design rooms for staff members** and visitors in each unit where private discussions can take place

Space function:	**Design goal:**
Healing and productivity	Reduce noise levels, increase speech privacy and appropriate mix of restful and productive environments
Target reverberation time:	**Maximum noise rating level:**
0.5-0.9	NR 35

DINING ROOMS

The primary function of a restaurant or cafe is to serve as a place where people can meet, socialise and enjoy culinary experiences. While some ambient noise is desirable, a balance needs to achieved where guests can feel immersed in the unique atmospheric buzz of the restaurant while also being able to converse comfortably with the people at their table and enjoy the taste sensations from the food they are served.

In a restaurant, the same characteristic sounds that are desirable become irritating when they are too loud. Conversations from neighbouring tables, activities in the kitchen, music playing from speakers can quickly amplify to intolerable levels if there is too much reflection in a space. And the louder it gets, the higher people raise their voices in order to hear one another.

One survey found that noise is the second most common complaint among restaurant guests. Research demonstrates that background noise and loud music not only make it difficult for diners to communicate with one another. It can actually impair their ability to taste food and drink.

Conversely, a good acoustic environment and the right kinds of sounds have been shown to enhance and complement the dining experience and the taste of food and drink. In fact, restaurants that have excessive absorption can be just as uncomfortable, making the room feel lifeless and boring. Some ambient noise adds to the atmosphere and table privacy.

Design strategies

» **During space planning,** separate high activity areas like the kitchen, bar and bathroom from the dining area.

» **Add absorption materials** to the walls and ceilings of open dining areas

» **Add space between tables and booths**

» **Break up and dampen sound** with physical barriers

» **Keep noisy kitchen appliances away** from guests in the dining area

» **Reconsider open kitchens.** Adding a glass wall can still give the look of an open kitchen without the noise

» **Add soft tips and pads** to the bottom of tables and chairs

» **Use sound absorbing fabrics** and soft furnishings

» **Separate larger groups** of diners from tables for smaller groups

» **Add a sound masking system** that can be adjusted depending on the number of guests

Space function:	**Design goal:**
Socialising and gastronomic pleasure	Create a balance where both intimate table conversation and the atmospheric buzz of the restaurant can coexist
Target reverberation time:	**Maximum noise rating level:**
0.6-1.0 (fine dining to casual restaurant)	NR 40

WHAT YOU JUST READ

Key Lessons

1.
Different types of spaces have different kinds of acoustic design goals.

2.
The acoustics in work spaces should be designed to support focus, productivity and collaboration.

3.
The acoustics in learning environments should be designed to reduce noise levels and increase listener and speaker comfort.

4.
The acoustics in healthcare environments should be designed to support healing and recovery.

5.
The acoustics in restaurants should be designed to support socialising and gastronomic pleasure.

Major insight:

Acoustic design should always be adapted to the specific use and function of a space and the unique needs of its inhabitants.

TROUBLESHOOTING

ACOUSTIC DESIGN DO'S AND DONT'S

Do

» Plan for acoustics as early as possible during the conceptual design stages

» Bring in the competence you need to do the job properly

» Learn the basics of sound behaviour and propagation in indoor spaces

» Follow the ABCDs of sound control

» Learn space acoustic requirements before beginning a project

» Specify the amount and performance of the material according to the intended and future purpose of the space

» Consider the acoustic impact of other material and objects in the space

» Understand the difference between absorbent and reflective materials

» Learn the basic types of acoustic treatment materials and what they do

» Remember to check the performance rating of treatment materials at the frequency range of interest

» Place acoustic panels symmetrically and spread them out to improve their effectiveness

» Consider the geometry and volume of the space you are treating

Don’t

» Sacrifice function for art when selecting and placing treatment material

» Forget to consider space planning

» Over or under specify the amount of treatment needed

» Forget to involve a professional acoustician if the pre-conditions are difficult or the client requirements are high

» Place acoustic treatment too high where sound will take a longer time to reach them

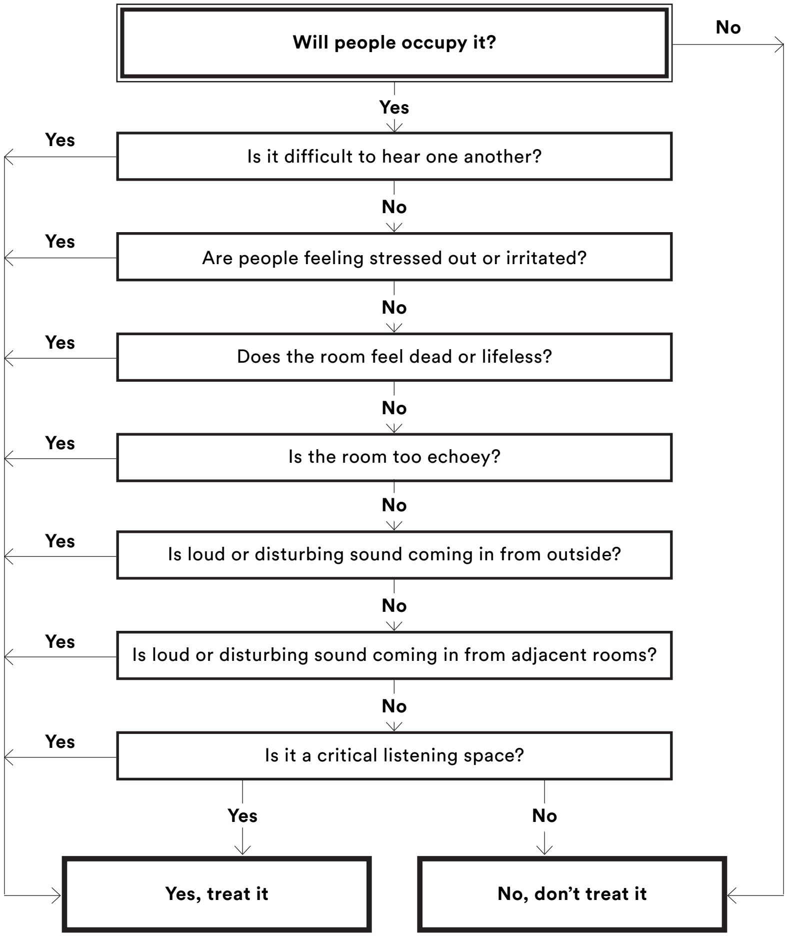
» Leave two parallel walls untreated

» Forget to comply with relevant codes of practice

QUICK GUIDE TO SOLVING COMMON PROBLEMS

Problem	**Likely source**	**Treatment options**
The room feels dead, lifeless and uncomfortable	Too much absorption	Reflectors, diffusers
Sound localised in another part of the space is causing disruption outside or around the corner.	Diffraction	Absorbers, blockers along sound pathway, sound masking in zones where extra privacy is needed
Difficult to localise where a sound in the space is coming from	Diffusion	Reflectors
Room feels loud, irritating, and echoey	Too much reflection	Absorbers
Difficult to hear even though the sound source or speaker is within view	Refraction	Reflectors, diffusers
Can hear sound from the room next-door	Transmission	Block & cover
Difficult to understand speech, spoken words reverberate so much they overlap one another	Too much reverberation	Absorbers, diffusers

DOES THIS SPACE NEED TREATMENT?



GLOSSARY OF ACOUSTIC TERMS

Absorption	When a sound wave encounters a surface and the energy is absorbed by the surface rather than reflected.
Absorption coefficient	A measurement used to evaluate the sound absorption efficiency of materials.
Acoustics	The science of sound; a branch of physics dealing with mechanical waves.
Amplification	Increasing the volume of sound.
Audio	Sound, transmitted in the form of signals.
Auditory system	The body system responsible for the sense of hearing.
Aural	Related to the sense of hearing.
Auralisation	The modelling and simulation of acoustic phenomena rendered as a soundfield in a virtualized space.
Anechoic	Free from echoes.
Bandwidth	A measure of the width of a range of frequencies, measured in Hertz.
Binaural	Relating to hearing involving two ears. Human hearing is binaural, which allows the listener to determine the direction and origin of sound.
Block	Sound blocking is the introduction of barriers that prevent the travel of sound waves from one space to another.

Cover	An acoustic treatment by which noise is masked by another layer of sound, such as a water feature in a public space or pre-recorded music played on a speaker system.
Dampening	Used variably to describe either absorption, diffusion and/or blocking of sound to achieve a more quiet and less resonant acoustic environment.
Decibel (dB)	A standard unit used to measure the intensity of sound.
Density	The degree to which a material is compact, which can affect the extent to which it allows sound to pass through it.
Diffraction	The bending of sound waves around obstacles and the spreading out of sound waves beyond openings.
Diffusion	The spreading out of sound waves to achieve a more “even” acoustic environment.
Dispersion	Where a sound wave separates into its component frequencies as it passes through a material.
Echo	The sound caused by the reflection of sound waves, which arrives at the listener later than the original sound.
Environmental noise	The accumulation of noise pollution that occurs outside.
Frequency (Hz)	The speed of vibration which determines the pitch of a sound, measured in Hertz.

Intelligibility	A measure of how comprehensible speech is in given conditions.
Interference	A phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude.
Loudness	The subjective perception of sound pressure.
Mechanical wave	A wave that is an oscillation of matter, and therefore transfers energy through a medium. Sound waves are a type of mechanical wave.
Noise	Sound, particularly that which is loud, unpleasant or causes disturbance.
Noise Rating curve	A standard determining the acceptable level of sound in an interior environment for hearing preservation and verbal communication.
Noise reduction coefficient (NRC)	A representation of the amount of sound energy absorbed upon striking a particular surface, measured on scale between 0 and 1 where NRC 0 = complete reflection and NRC 1 = complete absorption.
Oscillation	Repeatedly and regularly fluctuating above and below a mean value. Sound oscillates as it travels, hence the wave pattern.
OSHA	Occupational Safety and Health Administration, the body responsible for setting the acceptable limit of noise exposure for workers in the USA.

Psychoacoustics	The study of the psychological and physiological effects of sound on human beings.
Room absorption	The sum of Sabine absorption due to objects and surfaces in a room.
Reflection	When a sound wave hits a surface, it reflects, either in a relatively straight line or in scattered pattern, depending on the texture and density of the surface.
Refraction	Acoustic refraction, in which the path of sound waves is redirected, occurs when sound waves enter a medium in which their speed changes. The temperature of the air, for instance, can cause sound waves to be refracted.
Resonance	The reinforcement or prolongation of sound by reflection from a surface, or by the synchronous vibration of a neighbouring object.
Resonator	A device or system that exhibits resonance or resonant behaviour.
Reverberation	The persistence of sound after the sound is produced. Created when a sound is reflected, causing numerous reflections to build up then decay as the sound is absorbed by surrounding surfaces and objects.
Reverberation time	The lifetime or persistence of a sound wave in an enclosed space.
Room acoustics	A broad term representing how sound behaves in an enclosed environment.

Sabin	Unit of sound absorption, named after Wallace Clement Sabine, founder of the field of architectural acoustics.
Sabine formula	Formula developed by Wallace Clement Sabine that allows designers to plan reverberation time in a space prior to construction and occupancy.
Sound absorption class	A set of internationally recognised sound classes for materials, ranked from A to E. A higher ranking sound class (A) is not necessarily better, depending on the needs of the project.
Sound absorption coefficient	Alternative name for the Noise Reduction Coefficient (NRC) described above.
Sound wave	Longitudinal wave consisting of areas of high and low air pressure.
Soundscape	A sound or combination of sounds that forms an immersive acoustic environment.
Soundproof	To reduce or eliminate the transfer of sound from one area to another.
Transmission	The movement of sound through and between materials.
Ultrasound	Sound waves with frequencies above the human hearing capacity, often used in medicine.
Wood wool	A common material in acoustic design, made of processed timber, that absorbs sound when installed on interior surfaces.

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