MACH ACOUSTICS

GUIDE TO MUSIC SPACE DESIGN

Grand Central Hall

Austin Smith Lord

INTRODUCTION

Often seen as a 'dark art', acoustics can often be a source of frustration or confusion for anyone working within building construction. However, acoustics is an integral part of a building's design that is always a high factor in perceived comfort levels and functionality for almost all buildings. This is particularly important for performance spaces, where acoustics can be the deciding factor on how 'successful' the building design is.

Acousticians are not always present at the early stages of a project, particularly for larger developments where there are lecture theatres or halls within larger developments. The result from this is that there is rarely input from the acoustician in regards to the building layout and shape, which are one of the most significant aspects of room acoustic design.

This document is intended to provide some design rules-of-thumb to consider for any auditorium project when setting out the building layout, the room shape, height and what finishes to use. We would always recommend including an acoustician at the earliest stage for concert halls.

CHARLES GARNIER
(Designer Of Grand Opera In Paris)

"The credit is not mine. I merely wear the marks of honour. It is not my fault that acoustics and I can never come to an understanding. I gave myself great pains to master this bizarre science but after 15 years of labour, I found myself hardly in advance of where I stood on the first day... I had read diligently in my books, and conferred industrially with philosophers – nowhere did I find a positive rule of action to guide me; on the contrary, nothing but contradictory statements. For long months I studied, questioned everything, but after the travail, finally I made this discovery. A room, to have good acoustics, must be either long or broad, high or low, of wood or stone, round or square, and so forth. Chance seems as dominant in the world of the opera house as it is in the dream world in which a child enters Wonderland."

THE SPACE

When deciding how to design your performance space, it is important to look at what it will be used for and how it will be used. This will affect all aspects of the design from room shape, volume, depth and type of wall finishes.

Will the auditorium be used for music, speech or both? If it is used for music, what type of music will it be used for – classical, choral, chamber or amplified? If it is used for speech, what type of speech – drama, lectures or A/V presentations?

Audience size is also important, as although you will need this to set out seating arrangements, you will need to determine a suitable volume for the space as well. This is discussed in more detail further on in the report.

Determining what the expectations are from the start, and using this to inform the design of the space, will make all subsequent stages of detailed design easier. Throughout this guide we will look at music, speech and multi-use spaces, comparing the differences in criteria and design.


Wiener Musikverein - Vienna


Boston Symphony Hall


Kings Place - London


Snape Maltings Concert Hall

ACOUSTIC ENVIRONMENTS & YOU

The acoustics of your environment can have a huge impact on how you behave and what you create.

By looking back to various time periods and locations of music we are able to find links between the acoustic environment and the characteristics of music made within it. Churches with large volumes and lots of stone and glass surfaces provide long reverberation times, and as a result of this, the music composed for these spaces is often slow moving choral and organ pieces, thereby making sure that notes can be heard clearly rather than blurring into each other.

African villages situated in large open plains with almost no acoustic reflections would create complex rhythmic drumming patterns as the acoustic environment would not colour the music made. Additionally the percussion instruments are louder and would travel further over larger, less densely populated lands.

Even still, by looking at modern dance music, it is seen that the environment provided by a night club, consisting of high noise levels and lots of loud talking, has influenced the musical output, where there is a big emphasis on low frequency bass and high frequency hi-hats/cymbals, both of which sit either side of the spectrum of frequencies used for speech thereby allowing it to cut through the noise it is played in.

Therefore, it is clear that the acoustic environment is important and influential in both music creation and performance, and the appropriate time and care should be taken to ensure that the design of a performance space supports and inspires the performer, rather than act as a distraction.

WHAT TO AIM FOR

The ideal acoustic performance of a lecture theatre will always be different from that of an opera house or music hall, and when looking at multi-use spaces the target criteria is usually a compromise between the two.

A long reverberation time will 'muddy' sound, blurring notes and words into each other, so while this is largely desired for a lot of choral music, it can be detrimental to definition and clarity for speech, amplified music or chamber groups.

On the other hand a short reverberation time will sound too 'dead' for classical or non-amplified music, where the lack of reinforcement from reflective surfaces will not help projection across the space. Reverberation is also very helpful in hiding small imperfections within a musician's performance, so this will surely be detrimental to the performers confidence as well! Whereas for speech a shorter reverberation time is better as this allows for high clarity and intelligibility. Provided that there is a good level of coverage the shorter the reverberation time the more clarity, so you may want to consider targeting a lower reverberation time if there are going to be hearing impaired audience members.

Apart from reverberation time there are many other methods of measuring the room acoustic performance, as explained opposite. These are different ways of objectively measuring what is essentially a very subjective experience, where one listener may find that 'warmth' is more important than 'intimacy', but the person sitting adjacent may think the exact opposite! By ensuring that all factors are suitably accounted for will ensure that the majority of listeners are happy.

ROOM SHAPE & VOLUME

For either music or speech, the first factor you want to consider when setting out a space is making sure that the distance between the stage and furthest listener is not too great. By maintaining this minimum distance, you will ensure that all of the audience has good visibility to see face and hand movements (which is important for speech intelligibility) and that the signal is suitably loud. The maximum distance for music and speech are shown below.

When designing larger spaces, you may find that you will need to incorporate fan-shaped seating plans so to fit a higher density of people within the minimum distance. For smaller venues the maximum distance is usually easily achieved, which gives you greater freedom with room shape.

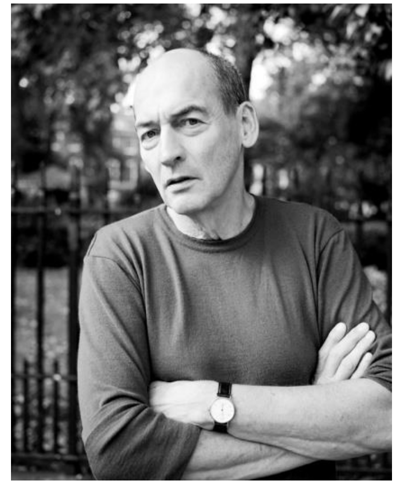
PREFERRED ROOM SHAPES

It is widely considered that a 'shoebox' shaped space is the best space for acoustics, in that it provides strong reflections off the side walls and ceiling which helps with intimacy and spaciousness. Contrary to Rem Koolhaas above, there have a number of modern 'shoebox' type spaces that are both architecturally and acoustically successful, for example Kings Place, London.

As discussed above, the shoebox is not a good option if you have a larger audience, as you will end up with a shape that is either too wide or too deep, thus you will need to allow for fan-shaped seating. The problem with this, however, is that this leaves large areas of audience with no adjacent walls that provide early reflections. These early reflections are a significant factor in room acoustics and will effect the clarity and intimacy of the sound from the stage.

The way to achieve early reflections within these open audience spaces is to include low level partitions throughout the seating area. This is often referred to as a 'vineyard' layout, shown in the image across.

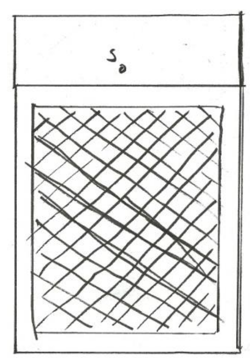
If using parabolic curved surfaces be careful to ensure that this does not focus sound into a specific point. These surfaces can help project sound if used behind a stage, however reflective curves behind the audience may cause unwanted reflections.



"The great problem of the concert hall is that the shoebox is the ideal shape for acoustics but that no architect worth names wants to build a shoebox."

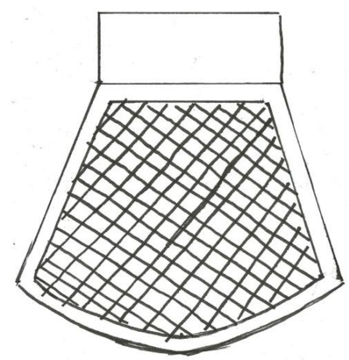
REM KOOLHAAS

SHOEBOX



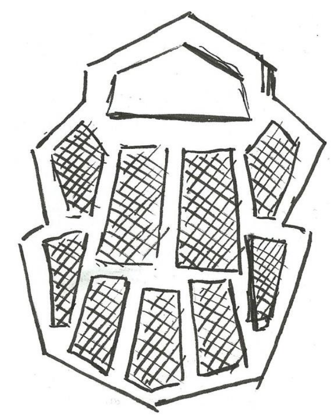
Best for smaller venues either for music or speech

SPLAYED WALLS



Best for reducing distance for drama or lecture theatres

VINEYARD



Best for larger music spaces as it provides nearby reflective surfaces

ROOM SHAPE & VOLUME

The dimensions and aspect ratios of a number of halls are provided in the table to the right. These are then compared to the approximate dimensions of the four options provided by Austin Smith Lord. Comparing the aspect ratios, the ratio between the width and the height appears to be quite consistent across the halls around 1 : 0.8.

Option 1

An option that is quite similar to the Dora Stoutzker hall in overall shape.

Option 2

Whilst looking at the table to the right this option appears to be comparable to Option 1, the asymmetrical positioning of the audience would result in the performers appearing off centre to the audience, so is therefore not a desirable layout acoustically. Therefore this option will not be considered later on in the report.

Option 3

A large option that features a large volume per seat, comparable with Hoddinott Hall. Based on the expected capacities of the hall, this option could result in a space that is a little too large, therefore will rely on large amounts of acoustic absorption for smaller performances.

Option 4

As the only option that retains the existing concrete floor, this hall layout does has the smallest volume per seat. A relatively straightforward design, that would allow more floor space to be used for other spaces within the building. Comparing to the other halls, the floor to ceiling height is a little on the small side.

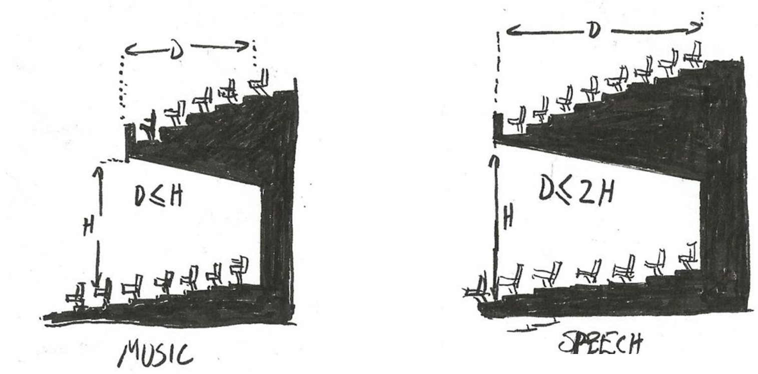
Hall	Capacity	Volume Per Seat (m^3)	Length	Width	Height	Aspect Ratio (Length : Width : Height)
King's Place London	420	8.5	25	13	11	1.9 : 1 : 0.8
Wiener Musikverein	1744	9.5	48.8	19.1	17.8	2.5 : 1 : 0.9
Boston Symphony Hall	2371	6.8	38.1	22.9	18.6	1.7 : 1 : 0.8
Hoddinott Hall	350	20.4	30	17	14	1.8 : 1: 0.8
Dora Stoutzker Hall	450	12.3	28	18	11	1.6 : 1: 0.6
Grand Central Hall						
Option 1	250	15.1	21	15	12	1.4 : 1: 0.8
Option 2	250	15.8	22	15	12	1.5 : 1: 0.8
Option 3	250	19.6	24	17	12	1.4 : 1: 0.7
Option 4	250	9.7	20	17	7.1	1.2 : 1: 0.4

BALCONIES

As well as splayed walls, including a balcony is an effective way to keep audience members within the required maximum distance. However, as a balcony introduces a large volume within the space the acoustical consequences from such a feature can be significant, thus it is important to ensure that both spaces above and below the balcony are not negatively effected.

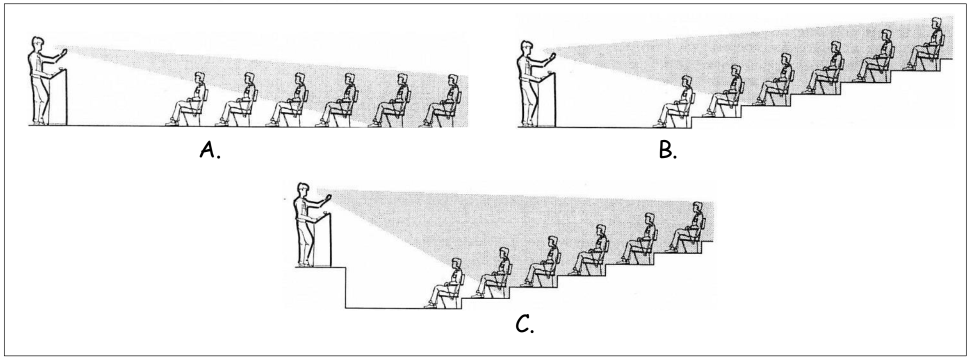
An angled ceiling below the balcony will help to ensure sound is reflected to the seats below. The depth of the balcony is also important as this can create an 'acoustical shadow'. For lecture theatres or drama spaces, it is important that the balcony overhang is no more than twice the length of the balcony height. For music spaces, the rule is stricter in that the depth must not be greater than the height.

The positive effect of balconies is that they can also provide a large amount of diffusion into a space, however it is important to ensure that the balustrade does not cause any unwanted echoes – see the section on diffusion.



SEATING

Raked floors are important for visual reasons and are also extremely desirable for acoustic reasons because they provide a better sight line than flat seating. An audience seated on a flat floor with a speaker at the same elevation has very little direct sound. This is shown by the narrow beam in Figure A below. Raked seating improves the sight line by broadening the angle of sound reaching the audience, thus increasing the amount of sound energy, see Figure B. Staggered seating can be used to maximise this effect and can reduce the rake angle by half with no detrimental effect on intelligibility.



Further improvements are also gained by a raised stage and is shown in Figure C. The ideal and maximum height for the stage is 1.05m and is so the first row may see the stage floor. The acoustic absorption provided by a seat can vary significantly depending on the type of finish, and due to the relatively large area within a hall this can have a large effect on the overall room acoustic of a space.

Ideally, a seat should provide the same absorption when either empty or occupied. This can be achieved through folding seats with additional absorptive areas. If this is not an option then medium to heavily upholstered seating should be considered.

CEILING REFLECTORS

By positioning large surfaces at ceiling height at specific angles, it is possible to provide strong reflections from the stage that will give significant aid to the voice projection of the speaker on stage. These ceiling reflectors can be achieved by angling the ceiling or alternatively by hanging panels above the stage and audience areas. Either option will require some minimum mass to ensure that the sound is adequately reflected. Two layers of plasterboard will often be enough.

Please note that the angle and size of the reflector can make a large difference and that an acoustic consultant should always be approached to provide advice on this. Ceiling reflectors are predominantly used for lecture halls and drama spaces however they can be incorporated within music spaces, particularly if it is a multi-use space.


Concert Hall at College Community

VOLUME

The volume of a room is equally as important as room shape as it effects the reverberation and loudness within a space. A volume that is too small will create an acoustically 'dead' space, while larger volumes may create uncontrollable reverberation or uneven sound levels across the audience.

An example of poor volume within a space is the Royal Albert Hall in London. The cylindrical shape of the hall resulted in a very high volume that sent delayed echoes back down to the audience. The remedy to this was to install a number of hanging reflectors (also referred to as 'mushrooms' or 'flying saucers') below the ceiling, which helped both reduce the volume of the hall and also provide some diffusion. A suitable volume for a space can be determined through applying a certain volume for each audience member. The table below provides a suitable range of volume for various types of spaces. -

Type of Use	Volume per Audience Member
Music	7 – 15m^3
Speech (Drama)	<6m^3

For multi-use spaces it is recommended that a volume is taken that falls within the ranges of both music and speech. However, it may also be desirable to achieve a variable volume through the use of movable partitions or ceilings.

Royal Albert Hall

"Due to the strong reflection from the roof, the Royal Albert Hall was jokingly referred to as "the only place where a British composer could be sure of hearing his work twice".

REVERBERATION & ABSORPTION

The amount of absorption required will depend on the reverberation time target of the space, which in turn is dependent on how the space will be used. As discussed before music spaces generally require a longer reverberation time than those used for speech, while a multi-use space will require a target somewhere between the two.

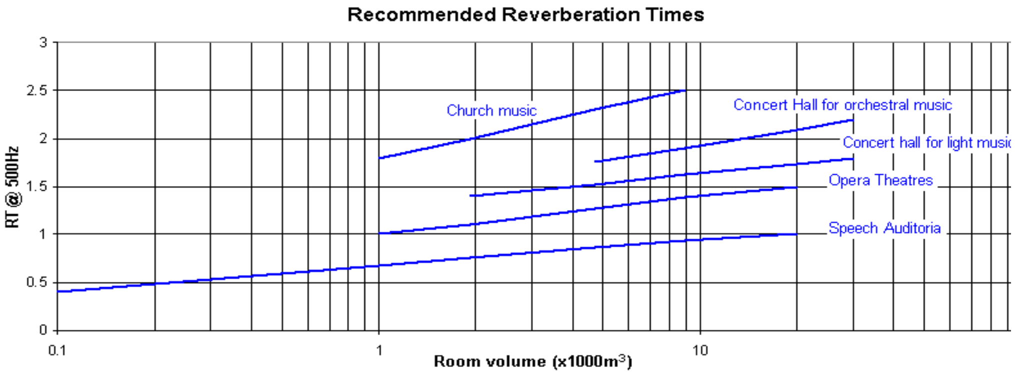
The graph opposite provide typical reverberation time targets for various spaces. The reverberation time is largely related to the volume of the space, where smaller spaces require a lower reverberation than that of the larger spaces.

Although an acoustician can provide a set of targets, it is always important to discuss with the client about how they will use the space and what their expectations are. For multi-purpose halls some clients may want an emphasis on musical acoustics while others may focus on speech and drama.

The location of absorption within a space will have an effect on the reverberation as well as how the sound propagates within a space. Poorly positioned absorption around a stage may reduce those important early reflections which in turn degrades the definition/clarity as well as the intimacy.

For most spaces, it is the preferred method to locate the majority of acoustic absorption on the wall directly behind the audience. This helps to prevent unwanted late reflections which can distract both audience and performers. Additional absorption may also be required on the side walls to the back of the hall.

The majority of the ceiling of all performance spaces should be reflective as this aids the propagation of sound. If absorption is to be located within the ceiling, it should be located to a band around the perimeter only.



VARIABLE ACOUSTICS

It is possible to vary the amount of acoustic absorption within a space through numerous ways such as using heavy curtains, moving ceilings or through adjustable panels, as shown across. By doing this, it is possible to maximise the multi-use potentials of a space.

If variable absorption is to be used within a space it is very important that sufficient time is taken during handover to ensure that the team running a space know when and how to utilise these units. It may also be prudent to allow for revisits every few years to re-train the building managers in case of staff turnaround.

PRACTICE SPACES

In regards to reverberation time, a practice space and performance space will often have different performance targets. Practice spaces tend to require a shorter reverberation time as this gives a greater clarity that is needed for rehearsals. However the performers will still need to have an idea of how the performance will sound within a concert hall, so a completely dead practice room is also unsuitable.

Through the use of variable acoustics it is considered that a space can be used successfully as both performance and practice space. The use of folding partitions is an effective method of reducing the volume (and thus reverberation time) of a space to provide higher clarity for rehearsal sessions.

Stanford Bing Concert Hall

Abbey Road Studio

THE EXISTING HALL

To quantify the acoustic treatment within the hall in it's current state and thus gain an understanding of the absorption provided by the ceiling, MACH Acoustics carried out some acoustic testing of the space. Reverberation times were found to be in the region of 6.7 seconds in the mid frequencies.

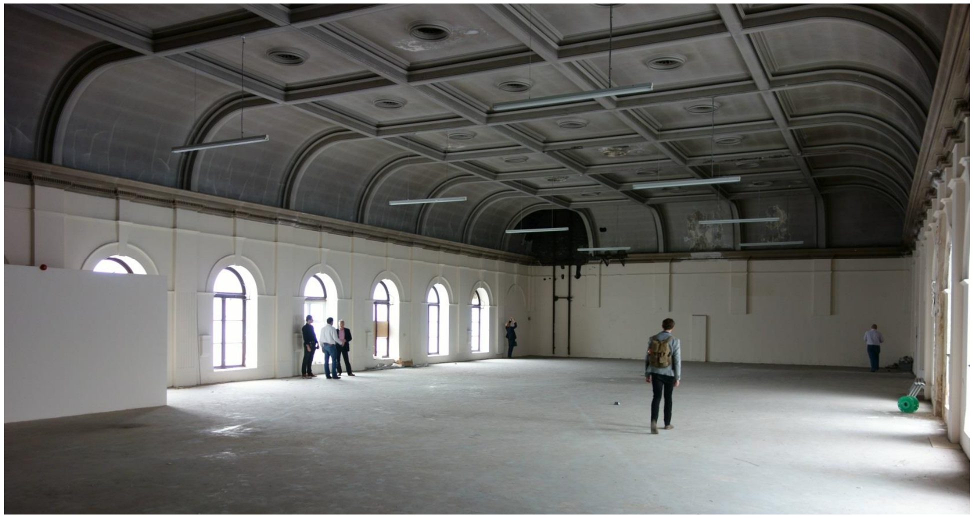
These results were then used to calibrate calculations in providing areas of additional treatment required in for a number of different reverberation targets to suit different performance types.

DIFFERENT OPTIONS

Varying the acoustics within Grand Central Hall will be essential in utilising the space for different types of events, including using the hall as a practice space. The table to the bottom right provides different absorption requirements to meet different reverberation times for each of the options provided by Austin Smith Lord.

For each reverberation target a range of absorption has been provided. This is to account for variation in capacity for keeping the performance of the hall as consistent as possible. Capacities were varied from completely empty to a total of 300, accounting for 250 audience members and 50 orchestra members.

The minimum areas required to meet the 2.0s target should be fixed absorption, whilst the additional treatment areas required to meet the maximum requirements for the 1.2s targets should be included as some form of variable acoustic treatment.



Hall	Approximate Volume (m^3)	Volume Per Seat* (m^3)	T_{mf} Target	Class A Absorption Required** (Class A m^2)
Option 1	3,700	12.3	2.0	70 - 220
			1.6	150 - 300
			1.2	280 - 430
Option 3	4,600	15.3	2.0	150 - 300
			1.6	250 - 400
			1.2	420 - 570
Option 4	2,600	8.7	2.0	0 - 160
			1.6	80 - 210
			1.2	150 - 310

*Based on a capacity of 250 audience members and 50 orchestra members
**Range provided based on variation in capacity from 0 - 300

DIFFUSION

Well placed diffusion will ensure that sound propagating from the stage is spread evenly across the audience. Typical positions for diffusion are on the side walls of an auditorium as well as behind the audience, provided that there is no requirement for absorption.

A diffusive element can be considered anything that is not a large smooth flat plane. However it is the variation in depth of the finish that will determine how effective a diffusive element is, as larger depth variations are required to diffuse lower frequency notes. Therefore, when dealing with a lecture theatre or drama space you will need to provide diffusion for speech frequencies, which is generally shallower than diffusion for music, which require a greater range of frequencies.

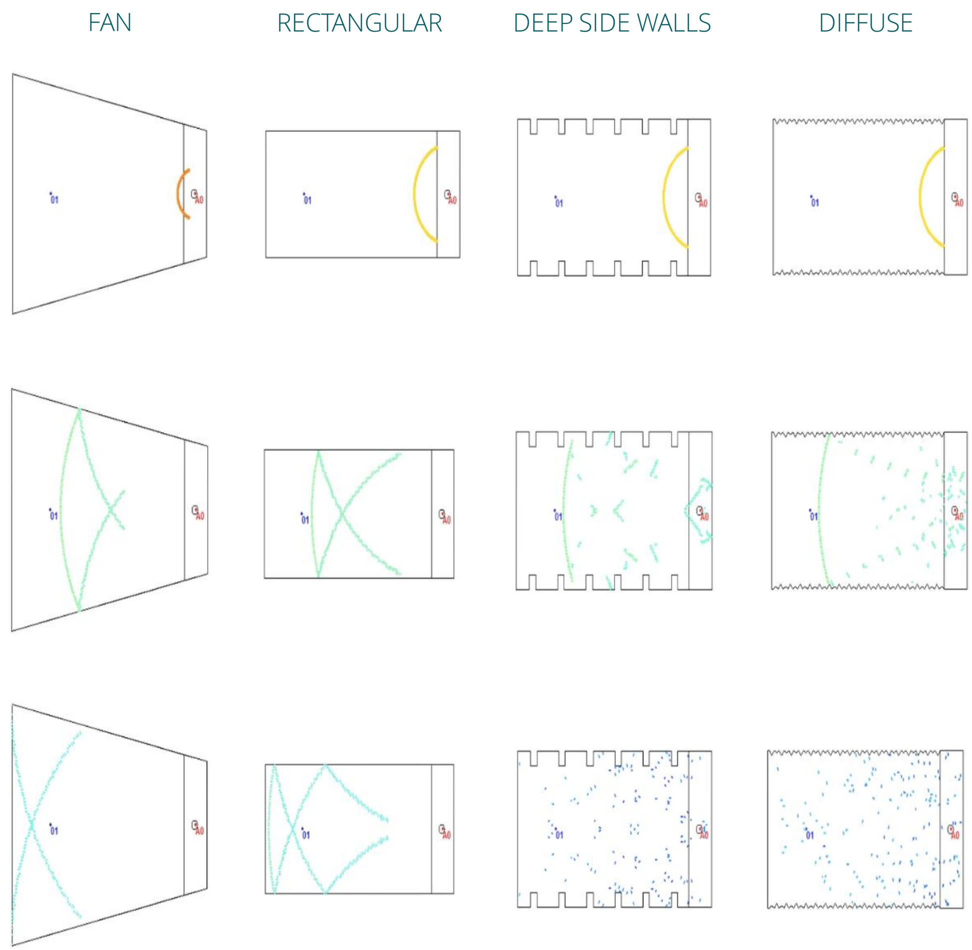
The images opposite provide indication of suitable positioning for diffusion, as well as various designs for diffusive elements.

Balconies will also require a diffusive finish so to ensure that they do send strong reflections back to the stage.

MAXIMISING LOUDNESS

Loudness is key to ensuring that good speech intelligibility is achieved. Generally, it is found that by ensuring that the other acoustic parameters are achieved then a good level of loudness (G) is generally achieved. When a space quite larger or oddly shaped then this will become a factor that needs to be considered.

Ensuring that the background noise is suitably low will lower the risk of problems in regards to speech intelligibility, but only up to a certain point as the audience will always create a certain level of background noise themselves, as aptly demonstrated by John Cages infamous piece “4 ‘33”.



SOUND INSULATION

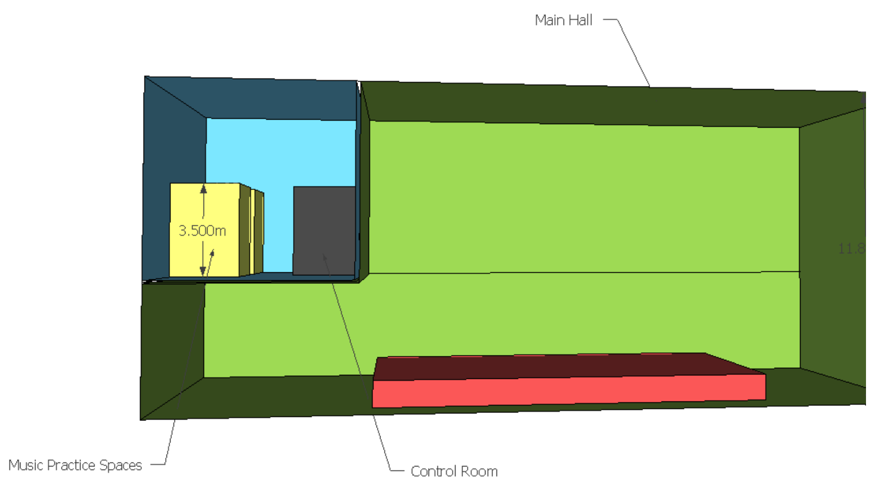
The existing roof is understood to be a lathe and plaster finish with a large void above. If it is proposed to introduce internal partitions up to the existing ceiling, the existing ceiling will provide a sound flanking path that may significantly limit the sound insulation performance that can be achieved. This should therefore be a serious consideration when considering the setting out of any spaces within the first floor.

It would be possible to reduce the risk of sound flanking through the introduction of barriers positioned within the ceiling void, however the height of the ceiling void will make this a costly and impractical solution.

An alternative option would be to set out spaces as 'pods' within the first floor, where a higher sound insulation can be achieved by adding an additional ceiling. An additional benefit of including cellular 'pod' spaces is that it provides the opportunity for an mezzanine levels above.

Note that for some spaces, noise break-out from the hall may be somewhat desirable, in which associated spaces such as offices may not be disturbed by such noise. It is for spaces such as practice rooms, living quarters, dance spaces or recording studios that may benefit from increased sound insulation performance.

The figure below shows how music spaces and a recording control room 'pods' can be located on the first floor.



AURALISATION

There is a famous quote that goes “writing about music is like dancing about architecture” and at MACH Acoustics we often feel that this is often applicable to writing about room acoustics as well. As such we often feel that the best way to get our message across is to let people hear for themselves.

Auralisations are a great way to show both the client and design team how the finished space will perform. By creating a 3D model of the development MACH Acoustics are able to predict how the proposed space will sound with both music and speech. Through the flexibility provided through 3D modelling software we are able to offer auralisations for various different scenarios. This is a great way in determining whether or not your space will really benefit from variable absorption or if the reverberation time needs to be changed.

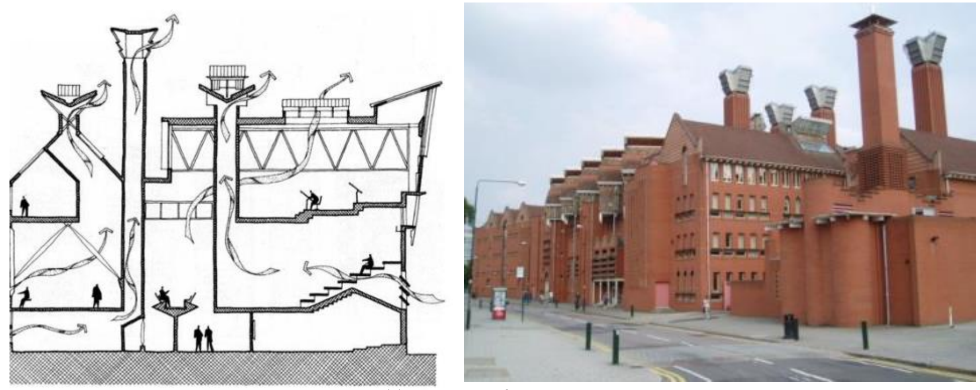
MACH Acoustics have software available that allows you to listen to a typical small shoebox auditorium and switch between various design changes. This is just an indication of what can be provided, with various levels of interactivity between the software and user.

VENTILATION

Due to large numbers of people and high heat gains from lighting, it is often the default option to apply a mechanical ventilation strategy to a performance space, however there have been multiple recent theatre spaces that successfully demonstrate how such a space can be ventilated through natural means.

By using stacks with large cross sectional areas, high ventilation rates can be achieved without resorting to mechanical aids. It is also through these stacks that high levels of acoustic attenuation can be achieved, meaning that noise break-in to a performance space can be as low as a mechanically ventilated space.

Previous developments such as the National Theatre’s The Shed or the Hull Truck Theatre show that developments can be positioned in high noise environments and still function to a high standard.



Queens Building, De Montfort, Leicester University

Sky Studios

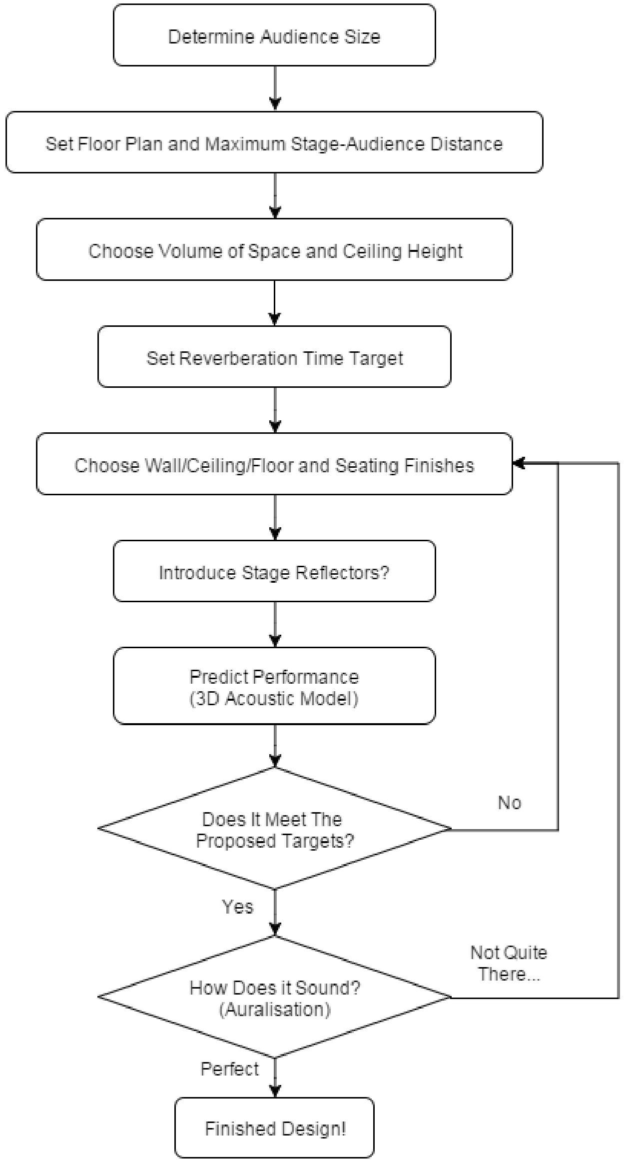
The Shed, National Theatre, London

WORK FLOWS

The workflow opposite gives an rough idea of how to approach the acoustic design of a music space.

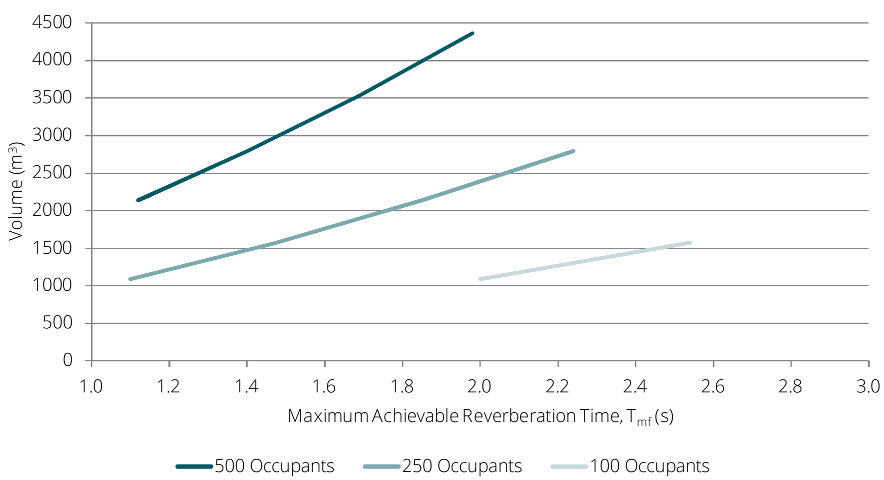
Each step should take into account all the previous points covered in the previous pages and provides a process and context to show how all the various design elements feed into and interact with each other.

Of course, this process is indicative only and it is recommended that an acoustician is consulted at all stages if possible.



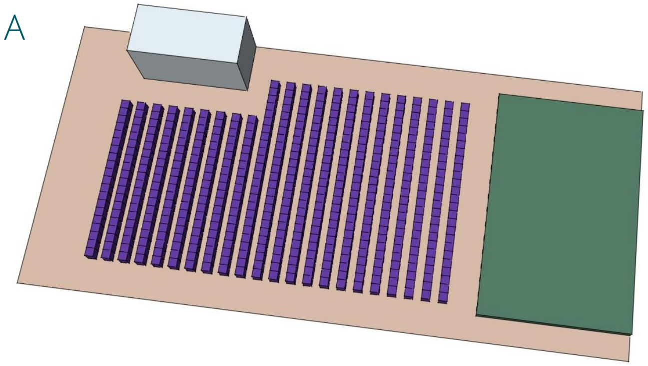
SPACE LAYOUTS

MACH Acoustics have investigated dividing up the Grand Central Hall and the effect that varying the volumes and capacities has on the acoustics of the space. The graph shows the limitations in terms of reverberation times achievable with different audience capacities for different volumes, whilst the table presents areas of additional absorption that would be required to reduce the reverberation times from the maximum achievable values. The images to the right show what the three configurations investigated could look like.

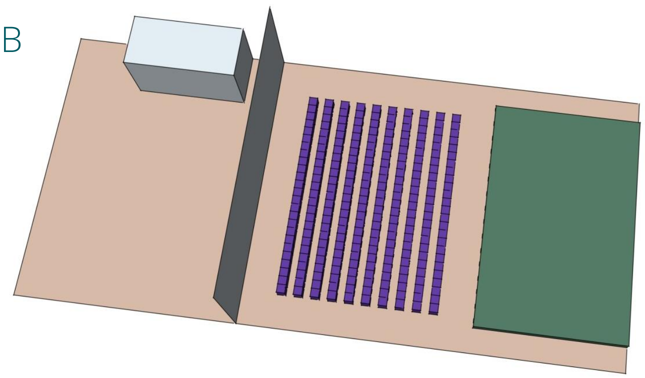


Space	Volume (m^3)	Capacity (People)	Volume Per Seat (m^3)	Maximum Reverberation Achievable (T_{mf}, s)	Absorption Required For Different Reverberation Requirements (Class A, m^2)		
					1.8s	1.5s	1.2s
A	4350	500	9	2.0	40	120	250
B	2790	250	11	2.2	55	105	185
C	1090	100	11	2.0	10	30	65

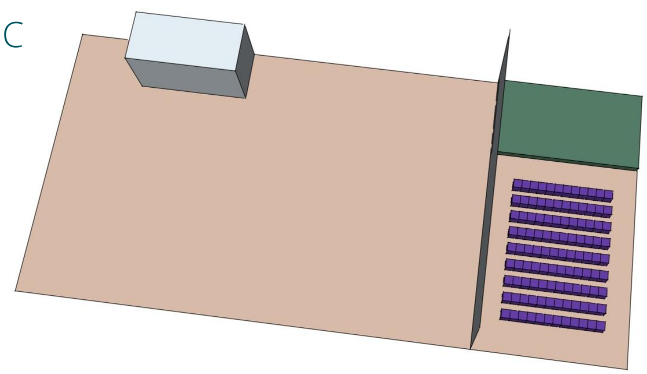
SPACE A



SPACE B



SPACE C



MOVABLE CEILING

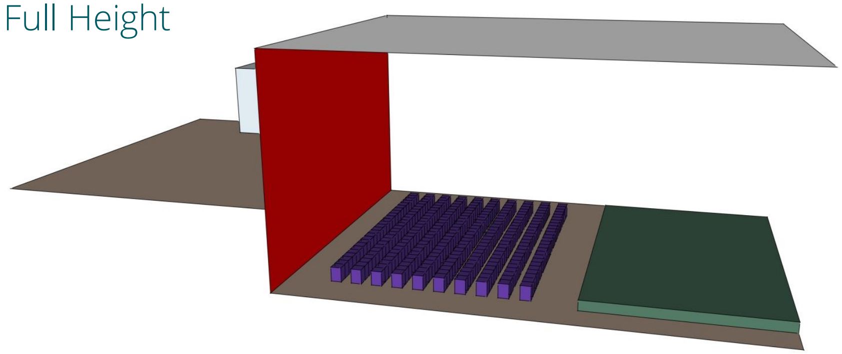
By cutting through the existing concrete slab, the effective volume of the space can be increased greatly. If this space is to also include a movable ceiling, thereby allowing the users to vary the total volume, this will give a number of room acoustic options that are suitable for a large range of uses.

A raised ceiling will give a longer reverberation time for classical performances to large audiences, while it can be lowered to give a more intimate atmosphere and low reverberation for small audiences or spoken word.

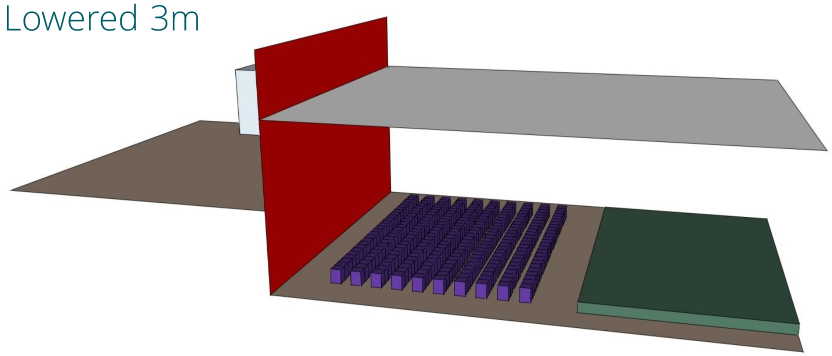
The table below gives an indication of the reverberation time that can be achieved with different capacities and ceiling heights, with an acoustically absorbent back wall. Note that a reverberation time of 2.0 is considered the top end of what is suitable for orchestral music.

Ceiling Height (m)	Volume (m^3)	Capacity (People)	Reverberation Time Achieved T_{mf} (s)
11	4350	250	2.0
8	3181	250	1.7
6	2396	100	2.0

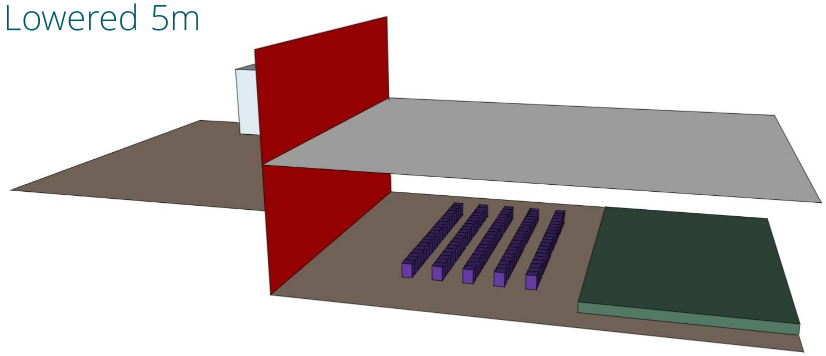
Full Height



Lowered 3m



Lowered 5m



GRAND CENTRAL HALL CEILING

Within Grand Central Hall the existing ceiling is quite intricate so would therefore present quite a challenge in terms of allowing the volume to be altered.

A possible solution would be to install a series of ceiling reflectors could be looked at that sit recessed within the existing ceiling. These could then be lowered to reduce the effective volume of the space when required, and could also be lowered at angles to be used as ceiling reflectors.

The images to the right present a simplified illustration of what these reflectors could look at when recessed and extended.

Whilst these reflectors would allow some sound to pass between them into the roof void above, having a relatively tight arrangement of panels as illustrated would reduce the effective volume of the space changing the acoustic characteristics of the space.

Ceiling Reflectors Recessed

Ceiling Reflectors Extended

REVERBERATION

Defined as the time it takes for sound energy in an enclosed space to decay by a factor of one million or 60dB.

EARLY DECAY TIME

Defined as the time it takes for sound energy to decay by 10dB multiplied by 6, the initial rate of sound decay in a room is perceptually the most important parameter governing perceived reverberation. EDT consists of relatively few isolated early reflections and is dependent on room geometry and positioning of acoustic treatment, since early reflections come from identifiable room surfaces. Whereas reverberation is due to reflections from all room surfaces, thus it is not significantly affected by room geometry.

CLARITY

Orchestral Clarity (C_{80}), which as the name implies, defines the clarity of speech and music. If there is no reverberation in a dead room, the music will be very clear and C_{80} will have a large positive value. If the reverberation is large, the music will be unclear and C_{80} will have a relatively high negative value. A greater value of C_{80} gives music a sensation of definition, whilst decreased definition adds fullness of tone (or muddiness when excessive). A C_{80} value between +1 dB to -4 dB is often preferred for orchestral music.

DEFINITION

A measure of the degree to which the individual sounds, e.g. notes in music stand apart from one another. The higher the value of D_{50}, the more distinct the sound will become. The room is suitable for music listening to music or speech if D_{50} is less than 50%,.

WARMTH

Determined by the ratio of low to high frequency reverberation. The value of Bass Ratio that is desirable for warmth in music is greater than 1.0. Only hard and heavy surfaces should be used for music hall interiors as lightweight panels tend to provide more bass absorption than is wanted.

BRILLIANCE

The ratio of reverberation of high frequency sound to the overall reverberation time. A good level of brilliance gives a bright, clear and ringing sound. Excessive high frequency sound absorption can lead to a lack of brilliance. The recommended minimum values of brilliance are between 0.8 - 0.9 depending on the frequencies assessed.

LOUDNESS

Loudness (denoted by G) is the comparison of the level of sound within the hall to the sound 10m away in free field (something similar to a wide open space). Loudness should be as uniform as possible throughout the hall, in which the recommend value of G_{mid} is between 4.0 and 5.5 dB.

INTIMACY

Otherwise known as the initial time delay gap (ITDG), intimacy is defined as the time between the direct sound and first reflected sound at a listener. The shorter the time is the smaller the space feels, thereby allowing the listener to feel more involved with the performance.