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Music practice rooms: Ambitions, limitations and practical acoustic design

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Abstract

The acoustic design of music practice rooms is a well-researched and investigated topic. This study reviews critically the acoustic parameters generally accepted as desirable for these rooms and provides insight from a practitioner's perspective. A series of music practice rooms are discussed and a holistic discussion is provided on the design challenges and successes as part of a multidisciplinary team of acousticians, architects, building services and structural engineers.

Keywords: Music, Acoustics

1 REHERSAL ROOM ACOUSTIC DESIGN CONSIDERATIONS

1.1 Parameters

A number of considerations of music rehearsal rooms are common among research and design advice. These include but are not limited to; room size, room dimensions and symmetry, sound isolation, reverberation time, early reflections, diffusivity, room modes, as well as coordinated design for environmental factors such as lighting, ventilation and temperature control.

1.2 Sizing

There is a range of rehearsal room sizing recommendations from recent research. Drotleff et al investigate rehearsal room case studies and recommend a minimum of 1.4m2 per musician with minimum distance parameters to each wall in a space that is 70% as high as its width (14). While the Finish code of conduct specifies volumes per instrument type such as wind instruments at ≥20 m 3 /person, grand pianos require ≥80 m 3 /person and other instruments ≥10 m 3 /person for the purpose of education (13).

1.3 User requirements for music practice rooms

The music practice room probably receives the greatest level of usage of all the specially built music spaces. Music practice rooms vary in size, and accommodate diverse groups ranging from a solo instrumentalist to small music ensembles. In the past noise control and isolation have been the main concerns in their design. As music students can spend up to 40 hours per week in music practice and rehearsal rooms, these rooms are very important in the daily activity of a music school or department (18). Good room acoustics in a music practice room enable a music teacher to more effectively teach subtle concepts such as intonation, articulation, balance, dynamics and tone production while a poor acoustical environment can adversely affect the development of basic musical skills of a music student (22).

Although many acousticians may have a musical background, they may not be acquainted with the problems of teaching music, which requires a different acoustical situation from that of the auditorium or concert hall. Another issue confronting the acoustician and architect in the design of music practice rooms is the lack of understanding of the problems of teaching young musicians. The job of solving the acoustical problems has been complicated, in part, by the lack of communication between the musician-teacher and those involved in building

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construction. This has been complicated further by the failure of music teachers to separate acoustical problems from the general problems created by the inexperience of young performers. For example, in teaching situations involving balance, intonation, articulation, dynamic control, and tone-colour control, the teacher may it difficult to determine whether the disappointing result is due to inexperience or a poor acoustical environment (27).

1.4 Music practice rooms design issues

As recently as 2015, in the British Government guide [Building Bulletin 93] for the design of rooms for music teaching in schools only specified the desired room reverberation times and general mention of sound diffusion in the music rooms. Most of the focus of the acoustical issues is still the background noise from external (e.g. vehicular traffic) and internal (e.g. building services) sources and sound isolation between the adjacent music rooms. This indicates that not much has transferred from research work in small room acoustics to the design and construction of them since the days of Sabine (31) and Knudsen (16).

In this paper the acoustical issues in the design of small music practice rooms addressed are:

- Room Modes and Standing Waves
- Room Reverberation Times
- Room Diffusivity and Flutter Echoes
- Room Noise Isolation and Background Noise are mentioned but not covered in any detail.

1.5 Room modes and standing waves

As early as 1896, Rayleigh had recognised and shown that the air enclosed in a rectangular room has an infinite number of normal modes of vibration. The frequencies ‘f’ at which these modes occur are given by the following equation: [Beranek,1986] [Everest, 1991].

$$f = 0.5c\,((p/L)^2+(q/W)^2+(r/H)^2)^{0.5} \qquad (1)$$

Where c is the speed of sound (344m/s),
L is the length of the room in metres,
W is the width of the room in metres,
H is the height of the room in metres,
p, q, and r are the integers 0, 1, 2, 3 etc.

With the rapid growth of radio broadcast industry in the first half of the twentieth century, interest in small room acoustics, particularly small rectangular announcers’ studios and music studios, revealed the negative impact of room modes. As a consequence of this, Gurin & Nixon (12) proposed a height, width and length ratio of 2:3:5 for radio broadcast studios so as to minimize the objectionable grouping of resonant frequencies in the space.
In 1965, Sepmeyer (33) suggested that to minimise the room modal effect (an improvement on Gurin & Nixon, (12)), the following room proportions as the best starting point:

Table 1. Room proportions (12)

	Height	Width	Length
A	1.00	1.14	1.39
B	1.00	1.28	1.54
C	1.00	1.60	2.33

(The room proportions A, B, and C are ratios relative to the room height. If in the case of room Type B, the height of the room is 3.0 metres, the width should be 3.42 metres and the length should be 4.17 metres.) A summary of studies relating to room modes done by other researches in this field is summarised below in Table 2.

Table 2. Recommended room dimension ratios for small rooms

Name of Ratio	Ratio of Room Dimensions	Normalised for Equal Volume	Relative Floor Area	Normalised Equal Height	Relative Floor Area
Harmonic	1:02:03	1:02:03	6.00	1:02:03	6.00
V.O.Knudsen	1.6:3:4	1.09:2.04:2.71	5.53	1:1.88:2.5	4.69
European	3:05:08	1.11:1.84:2.95	5.43	1:1.67:2.67	4.44
J.E.Volkmann	1:1.6:2.5	1.14:1.83:2.86	5.24	1:1.6:2.5	4.00
Golden Ratio	1:1.25:1.6	1.44:1.80:2.31	4.16	1:1.25:1.6	2.00
Golden Section	(5½-1):2: (5½+1)	1.12:1.82:2.94	5.35	1:1.63:2.63	4.25
P.E.Sabine	2:03:05	1.17:1.75:2.92	5.13	1:1.5:2.5	3.75
Sepmeyer 1	1:1.14:1.39	1.56:1.78:2.17	3.85	1:1.14:1.39	1.58
Sepmeyer 2	1:1.28:1.54	1.45:1.86:2.23	4.14	1:1.28:1.54	1.97
Sepmeyer 3	1:1.6:2.33	1.17:1.88:2.73	5.12	1:1.6:2.33	3.73
Louden	1:1.4:1.9	1.31:1.83:2.49	4.55	1:1.4:1.9	2.66
BBC Prototype	3.25:4.9:6.7	1.25:1.88:2.57	4.82	1:1.51:2.06	3.11

Adapted from: (12, 20, 29, 37, 10).

Bonello (4) noted that at low frequencies, in small rectangular rooms, the room modes (eigentones) spacing can be very large and usually greater than half octave apart and he asserted that this caused ‘peaks and valleys’ in the room response which is undesirable. To minimise the effects of the ‘peak and valleys’ Bonello proposed the criteria for the acceptability of room modes distribution pattern based on his prescribed spread of the room modes (eigentones). Bonello’s first criterion for room acceptability is to plot the eigentones over each one-third octave band and examine the resulting plot to check that each one-third octave has at least the same number or more modes than the preceding one-third octave. This provides an even spread and gradual increase in room modes as the frequency increases. Bonello’s second criterion is to examine the modal frequencies to make sure that there are no coincident modes (11). A check of the above combinations in Table 1 using the ‘Bonello Criteria’ shows that the Knudsen, European, Volkmann, Golden Section and Sabine marginally failed the first criterion, but all the combinations passed the second criterion. The second criterion is probably the more significant of the two.

1.6 Music practice room reverberation times

The Reverberation time (RT) is probably the most widely used parameter in room acoustics, and is usually measured using the Schroeder integrated impulse response technique (32), and linear regression between -5 and -35 dB (or -25 dB when the dynamic range is insufficient) (28). Studies by Lamberty (18) on room reverberation noted that 59% of music students preferred a ‘live’ room while 11% preferred a ‘dead’ room and 30% preferred something midway. By the process of elimination, it was found that when the students were thinking of a ‘dead’ room they were thinking of a room with a reverberation time of 0.4 to 0.5 second and a live room having a reverberation time of 0.8 to 0.9 seconds. Over 85% of the students found domestic bedrooms far too dead to practise in and the majority felt that a bathroom would be impossible to practice in. The overall preferred reverberation time was in the region of 0.7 seconds. Most students agree that the ideal room would have variable acoustics, which would enable them to practice in different conditions, including difficult ones: e.g., in dead conditions (which the students believed to be better to practice in) for a certain period, and then live conditions which are far more pleasurable and more rewarding for them. Most students agreed that a room of 15m2 would be acceptable.

In their study in determining the optimum reverberation times and minimum acceptable size for music teaching studios and practice rooms, Lane et al (19) concluded that for small practice rooms a reasonable design for the reverberation time would be between 0.4 to 0.5 seconds. A slight rise to 0.6 or 0.7 sec at 100 Hz is acceptable. For the teaching studios with a volume of approximately 60 m3, a reverberation time of 0.5 to 0.6 seconds with a rise to approximately 0.8 seconds at 100 Hz is satisfactory. As a relative comparison with larger spaces, Kuttruff (15) considers an RT of 1.8 to 2.1 sec. a sensible target for concert halls and an RT of 1.4 to 1.6 sec as appropriate for recital halls (for solo and chamber music performances). Table 1.2 below shows the typical dimensions and the recommended mid-frequency (Tmf) reverberation times for the various music rooms normally found in educational facilities.

Table 3. Recommended reverberation times for small practice rooms

Music Activity Space	Area m2	Height m	Volume m3	AS2107 2016	DfES 2002	BB93 2015	OCPS 2003	ANSI S 12.60
Music theory classroom	50-70	2.4-3.0	120-210	0.5-0.6	0.4-0.8	<1.0	N/A	<0.6
Ensemble /music studio	16-50	2.4-3.0	38-150	0.7-0.9	0.5-1.0	0.6-1.2	0.5-0.7	<0.6
Recital rooms	50-100	3.0-4.0	150-400	1.1-1.3	1.0-1.5	1.0-1.5	N/A	N/A
Teaching/practice room	6.0-10	2.4-3.0	14-30	0.7-0.9	0.3-0.6	<0.8	<0.5	<0.6
Studio Control room	8.0-20	2.4-3.0	19-60	0.3-0.7	0.3-0.5	<0.5	<0.6	N/A

In their White Paper on Acoustic Criteria and specification, the British Broadcasting Corporation (37) stated that "the reverberation time is the only objective measure of the internal acoustic conditions within a small studio or room that is reasonably well understood, but it is, at best, a poor guide to the subjective acoustic environment. Many proposals for alternative or additional measurements have been made over the years but none can, at present, be interpreted subjectively, at least in small rooms. There is some good evidence that these alternatives are meaningful in concert halls and other large spaces."

1.7 Room noise isolation and background noise

Lamberty (18) noted that when asked about the back-ground noise levels, 86% of the music students found the noise from other students practicing most disturbing, followed by 9% that found traffic noise most disturbing and 4% found other noises disturbing. This emphasizes the importance of the isolation between music rooms and the need for proper zoning of music rooms and facilities.

As musical instruments can produce as much sound power in small rooms as in large auditoriums, they can be uncomfortably loud in small spaces. This is a common problem in small music rooms with insufficient acoustic absorption, and can give rise to sound levels which could, in the long term, lead to hearing damage. Many professional orchestra musicians have noise-induced hearing loss due to extended exposure to high noise levels both from their own instruments and, to a lesser extent, from others instruments nearby. For reduced sound intensity, sound absorbing materials or membrane absorbers are normally used extensively in music buildings (9, 39). Small practice rooms also require a good deal of installed sound-absorbing material for the sake of reverberation control, and in particular instances, elimination of flutter echo paths between parallel walls (21).

AS2107 (2016) recommends an ambient sound level of 30dBLAeq for music studios, 35dBLAeq for drama studios and 40dBLAeq for music practice rooms. DfES (9) recommends the indoor ambient noise level by for all school music facilities is 30dBLAeq,30mins, and for some uses noise limits below 30 dB LAeq may be required. Table 1.4 above shows a summary of recommended maximum levels.

Table 4. Summary of recommended maximum levels

Music Activity Space	Cav.(6)	AS2107 2016	ANSI 2002	DfES 2002	BB93 2015	OCPS 2003
Recording Studio	20dBA	25dBA	N/A	S/A	30dBA	NC 15-25
Recital Hall	25dBA	S/A	N/A	25dBA	30dBA	N/A
Rehearsal Room	35dBA	35dBA	35dBA	30dBA	35dBA	35dBA
Music Classroom	35dBA	40dBA	35dBA	30dBA	35dBA	N/A
Ensemble Practice	38dBA	45dBA	35dBA	30dBA	30dBA	35dBA
Individual Practice	42dBA	45dBA	35dBA	30dBA	35dBA	35dBA
Music Listening	42dBA	35dBA	35dBA	30dBA	35dBA	N/A

S/A = Special Advice N/A = Not Available NC = Noise Criteria
(from AS2107-2016, 6, 1, 9, 10, 23)

1.8 Room diffusivity and flutter echoes

Brown (1964) stated that although diffusion is an issue, but for practical reasons it is not always possible to alternate types of treatment evenly over all surfaces. In such cases the following prescriptions should be observed for broadcast studios.

a. Some of each type of absorption should be applied normal to each of the three planes (longitudinal, transverse and vertical of each room).

b. Untreated areas should not face each other.

Brown (5) did not specifically comment on potential problems with parallel walls and flutter echoes but this was addressed in later work by others. (38, 9). There have been various ways 'traditionally accepted' ways of dealing with problems of parallel walls and flutter echoes such 'item b' above described by Brown (5) and treating the walls with absorptive fabric wrapped panels, or absorptive materials directly applied on the walls. Flutter echoes can also be reduced and room diffusivity increased with the use of the quadratic residue diffusers proposed by Schroeder (32), and later commercially developed by D'Antonio (8). Unlike absorptive wall panels or finishes, the quadratic residue diffusers can minimise flutter echoes and improve room diffusivity without significantly reducing the room reverberation times.

1.9 Music room requirements for various musical instruments

Various types of musical instruments have differing requirements from a small music practice room. Issues to be taken into consideration are the potential sound power that can be generated by the instrument, the frequency range of the instrument and the type of instrument itself (wind, string, percussion etc.). This would determine the sound insulation requirements between music rooms and the type of internal acoustic treatment.

Research conducted on subjective listener assessments of the sounds of various instruments in practice rooms indicates the following are the preferred mid-frequency reverberation times for the various types of instruments for rooms between 20 and 100 cubic metres (24, 25).

Table 5. Preferred reverberation time per musical instrument type

Instrument Type	Preferred RT
Percussion Instruments	0.3 - 0.5 secs
Bowed String Instruments (violin, cello)	0.6 – 0.9 secs
Wind Instruments (trumpet, flute)	0.4 – 0.7 secs

The lower range of the reverberation time is recommended for room volume of about 10m3 and the higher range for room volumes of about 100m3.

Other factors such a loudness, signal to noise ratio, clarity, balance (interaural level difference) and music genre has a slight influence the ideal reverberation times (25) but this is beyond the scope of this paper.

1.10 Start with the room shape and size

Although rooms with non-parallel walls, floors and ceilings are preferred for music rooms, to maximize the utilisation of the available space the rooms in music teaching facilities are normally rectangular in size with floors and ceilings perpendicular to the walls. Where rectangular rooms with parallel walls, floors and ceilings are adopted, care should be taken to determine the ratios of the room length, width and height.

Computer modelling by the author shows that based on a 3 metre room height and the musical instruments tuned to the noted in a tempered scale, the BBC prototype ratios provided the room dimensions for the optimum predicted performance, taking into consideration the Bonello criteria and Room Mode frequencies (at standard speed of sound of 344m/s).

For rooms with non-parallel straight walls and ceilings, it is recommended that the optimised dimensions be applied to the room dimensions in the middle of the room (i.e. averaged room length, width and height). Curved walls are not recommended for small practice rooms to avoid focusing and other undesirable effects.

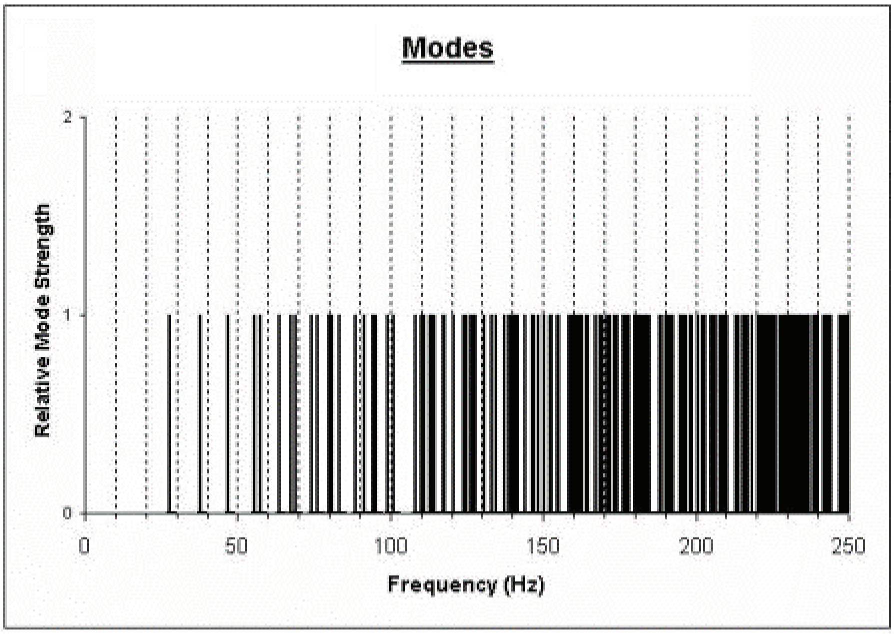

Figure 1. Room modes for a 6.58m X 4.52m X 3.0 high (BBC Prototype ratios) room.

2 CASE STUDIES AND PRACTICAL DESIGN

Two case studies are briefly presented, an existing large rehearsal space upgrade and a new design.

2.1 Existing rehearsal space upgrade

The existing studio is able to accommodate a full symphonic orchestra and is currently the main rehearsal space of a prestigious orchestra. It is intended to be the daily practice venue of the company and is used by both instrument players and opera singers.

The volume of the studio is approximately 2400 m3 and it has existing curtains, diffusion and some absorbers. The scope of the acoustic consultancy was to optimise the space to be more suitable in terms of reverberation and diffusion, as well as sound levels.

Figure 2. Acoustic measurements in an unoccupied rehearsal space

The measured reverberation time is long at 1.98s, and whilst this is good for performance venues, it is not ideal for rehearsal studios.

A detailed acoustic 3D model has been developed for the rehearsal room, with a view to auralize the space for the orchestra with the levels of reverberation they are satisfied with.

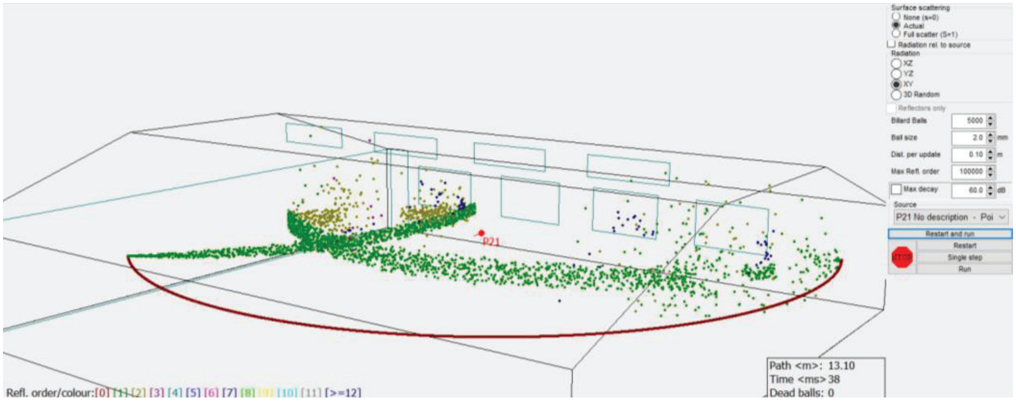

Figure 6. Optimizing acoustic parameters

A close collaboration with the orchestra players was considered essential, and incorporating the details and their experience into the design was paramount. The space is a difficult room to play in - the biggest issues being difficulty hearing other sections, resulting in poor ensemble and balance, and high noise levels. This is evident in rehearsals for both opera and ballet repertoire, and as a result conductors often have to spend considerable time trying to remedy the shortcomings of the room, at the expense of working on finer artistic and musical details.

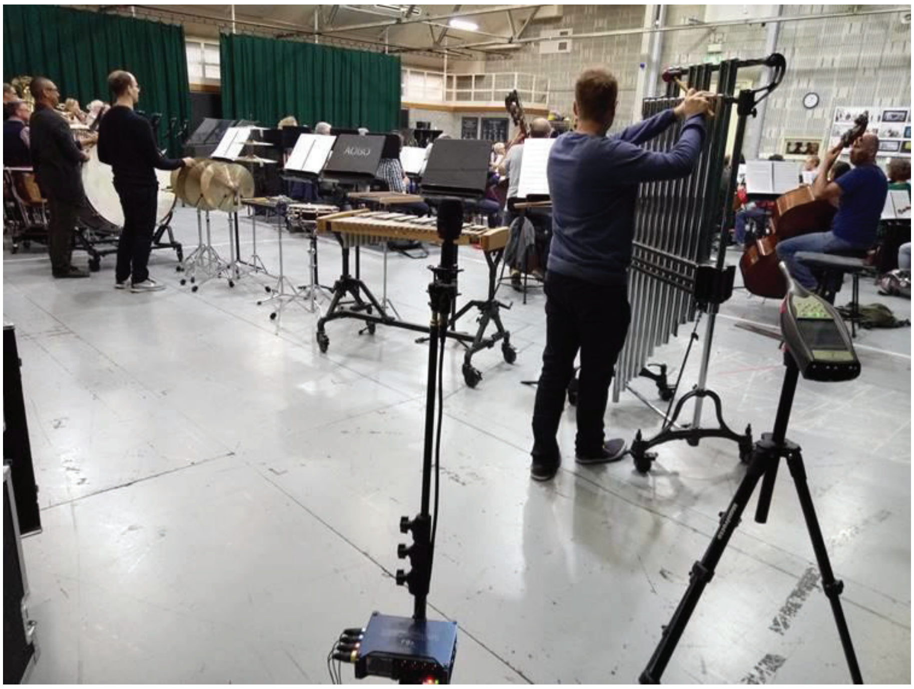

Figure 7. Measurements during rehearsals

2.2 New rehearsal space design

When designing a new rehearsal space, opportunities and challenges are different from the upgrade of an existing studio.

Figure 8. New rehearsal studio design (Courtesy of Visionata Architects and Norrebro Design)

When designing a new rehearsal space, opportunities and challenges are different from the upgrade of an existing studio. Whilst design for acoustic excellence in terms of the objective parameters is possible with a good team of acousticians, the detail work in terms of coordination with the orchestra, chorus, opera singers, but perhaps most importantly the design team is paramount.

In terms of coordination with the end users, we found that sound files from auralization are a great asset in terms of acoustic outcomes. This is important when orchestra and opera singers share a space, as high sound level fatigue is a stress factor for the players, whilst the singers often prefer a more reverberant field.

Perhaps the most important factor in the successful design of a new rehearsal space is the coordination with the design team. All team members must be involved early in the design process, but the collaboration between the architect and the acoustician is where the journey must begin. The careful selection of the location of the materials to diffuse and control the sound field is of great importance. The synergy between the two disciplines must be seamless and collaborative. The acoustician needs to understand the constraints the architect is facing, whilst the architect must be able to design with acoustics in mind to achieve his visual strategy.

The structural limitations of the building, if existing, can impose great constraints on the design of a rehearsal space. Ideally the height of the orchestra spaces should be approximately 9-10m, with more headroom required with the addition of solo singers and Chorus. Sometimes the ambitions of the players and singers, the acousticians and the design team must conform to the limitations of an existing building. For practical acoustic design, the team must always coordinate with the services engineers and work together. In addition to sound levels from mechanical services suitable for rehearsal, the mechanical services treatment in terms if cross talk via the ducting system needs to be addressed to maintain the sound insulation requirements between different practice rooms.

3 CONCLUSIONS

To design for a holistic music rehearsal room experience, it is critical to coordinate and collaborate with all consultants involved in the design. It is important that all of the musician's requirements are met besides acoustic excellence, including temperature control, lighting, aesthetics, and ergonomics of room layout.

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