OPTIMIZING (TOO) SMALL ENSEMBLE REHEARSAL ROOMS FOR ACOUSTIC LOUD MUSIC

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1 INTRODUCTION

The ISO 23591 standard[1] on music rehearsal rooms define minimum values for room volume based on ensemble type and number of musicians. Often these criteria cannot be fully met, especially for larger acoustic loud ensembles like brass bands and wind bands, due to limitations given by the use of existing rooms.

This paper addresses ways to achieve satisfactory ensemble conditions while limiting the risk of excessive sound levels. To control the sound strength G, the reverberation time must be reduced to below the recommended values given in ISO 23591. To what degree can the musicians obtain a satisfactory response from their own playing, and satisfactory ensemble listening conditions, without the extended room response and full ensemble sound that can be obtained in larger rooms?

2 FRAMEWORK

2.1 Prior research on rehearsal rooms for acoustic loud ensembles

Large acoustically loud ensembles include symphony orchestras, wind bands and brass bands. Most of the research done on rehearsal conditions for acoustic loud ensembles has focused on acoustics for professional symphony orchestras, which in an ideal situation have the opportunity to rehearse at the stage of their resident concert hall. In a large symphonic hall, the reverberation properties on stage can often be optimized without causing excess loudness levels for the musicians and the conductor. For rehearsal rooms typically used for wind bands and brass bands on the other hand, the room volume is typically several times smaller than a large symphonic hall, which causes the sound strength G to become key factor in the design of the acoustic conditions.

Anders Christian Gade has made important contributions to the research on ensemble conditions for symphonic orchestra, which formed the basis for the Stage Support (ST) parameters defined in ISO 3382-1[2]. An excellent summary of the early work on ensemble conditions for symphony orchestras is given in [3]. Later important work on stage acoustics and ensemble conditions for symphony orchestras include the PhD thesis of Jens Jørgen Dammerud[4]. A key result in Dammerud thesis is that sparse, distinct early reflections separated in time and direction (and limited reverberant energy) seem to be favorable with regard to both the room response not masking ones' own sound and louder instruments not masking quieter instruments. This aspect has also been pointed by other researchers[5,6].

The challenge of controlling the musicians' sound exposure in smaller rehearsal spaces has been addressed by several researchers[7,8,9,10]. In Wenmaekers PhD thesis[10], methods for extending the measurement of the support parameters to more realistic situations than what follows from ISO 3382-1 is presented. The thesis also includes a thorough discussion on musicians' sound exposure, a section on sound level models for symphony orchestras, and measurements of several rehearsal rooms for wind bands, all of which have importance in future work on rehearsal rooms for brass bands and wind bands.

In the ISO 23591 standard, the recommended reverberation times for the ensemble rooms for acoustic loud music, which typically range from 1000 to 6000 m^3, varies relatively little as a function of volume. This implies that G depends strongly on room volume, which is illustrated in [8]. This paper discusses how parameters like strength (G), ensemble support, timbre/frequency balance and reverberation should be balanced in smaller ensemble rehearsal rooms, and it summarizes the framework for the methodology employed in the design of the two example projects presented here.

Both Gade[7] and Wenmaekers[10] emphasize the importance of the total absorption area as a design parameter, an approach that leads to a much stronger dependence on volume for the resulting reverberation curve than the recommendations found in the ISO 23591 standard, especially for rooms that have volumes below the recommended minimum values for a given ensemble type and size[8,10].

2.2 Relevant standards

The new ISO 23591 standard "Acoustic quality criteria for music rehearsal rooms and spaces", which was published in 2021, provides recommendations on key design parameters like minimum volume, room dimension ratios, reverberation time etc. as a function of ensemble type and number of musicians. The ISO 23591 standard is based on the Norwegian standard NS 8178 "Acoustic criteria for rooms and spaces for music rehearsal and performance" from 2014. Key figures are to a large degree in line, but recommended reverberation times for amplified music have been somewhat increased compared to the preceding Norwegian standard. Also, recommended minimum volumes for acoustic large ensembles were increased to 60 x N m^3 pr. musician for so called "extra loud groups", which in ISO 23591 is exemplified by brass bands and professional symphony orchestras.

Relevant design criteria given by ISO 23591:2021 for the two examples presented in this paper are discussed in chapter 3.

Based on the ISO 23591 guidelines, a standard brass band would need a rehearsal room of at least 1.800 m^3. While this requirement has a well-founded acoustic motivation, reality is that a large part of the worlds brass band, even on a semi-professional level, do not have access to a rehearsal room that fulfill this requirement. The ISO 23591 standard do not address how to handle situations where the minimum volume requirements are not met, and to control the sound strength G, the reverberation time must be reduced to below the recommended values given in the ISO standard. Is it possible to achieve satisfactory ensemble conditions while limiting the risk of excessive sound levels in such (too) small rehearsal rooms?

3 DESIGN EXAMPLES

In the following, examples from the redesign of a rehearsal room for a semi-professional brass band and a professional wind band, respectively, is given. Both share a starting point with a too small, too dry room. Both the residing ensembles were reporting high noise exposure, combined with unsatisfactory room response, as their main motivation for wanting to change the acoustics of their room.

The authors were responsible for the design of modified acoustic treatments for the two projects. Both projects called for high cost focus, avoiding the need for a complete rebuild of the rooms.

In both projects, a survey was conducted in order to get a balanced impression of how the individual musicians and the conductors experienced the existing acoustics, and whether there were indications of systematic differences between instrument groups.

Due to limited size of the data sets and number of variables, a statistical analysis on the data set was not carried out. Instead, the results were examined to aid in defining the design goals for the refurbishment of the two rooms.

Only one of the projects, the rehearsal room for the professional wind orchestra, has so far been carried through. Therefore, the paper mainly focuses on the design and the resulting performance of this project.

3.1 Rehearsal room for a professional wind band

This project involved a 1.600 m3 room, which has been the ensemble's main rehearsal room for decades. The ensemble is one of the professional military bands in Norway. It has a typical military band instrumentation, which resembles the wind and percussion section in a full-size symphonic orchestra, in total 30 musicians. According to the ISO 23591 standard, the minimum rehearsal room volume for this ensemble is 1.800 m^3, if we classify the ensemble as an "extra loud group". Given the size of the brass and percussion sections, this seems like a reasonable categorization. Photos of the room before and after refurbishment is shown in Figure 3.

The acoustics has been modified several times, and the last modification prior to the project described in this paper involved mounting a large amount of 40 mm thick porous absorbers directly to the ceiling and walls. While providing effective reduction of the room's sound strength G, the results from the initial survey showed that a majority of the musicians thought that

- the room was too dry
- mutual listening was hard, especially between instrument groups
- the room felt unbalanced

An interesting observation was that when asked to classify the room's timbral character as "dark/matte", "balanced" or "bright/sharp", the musicians were split approximately in half between the two extremes, while only 1 out of 28 respondents classified the room as balanced. This might indicate that it is hard to judge the timbral quality of the resulting ensemble sound in a room that is so strongly dampened.

Several musicians also reported that they felt that they had to *overplay* due to the lack of room response. The term "overplaying" can be interpreted as playing with unnecessary effort and volume, possibly causing fatigue, muscular damage and excessive sound levels.

It is also worth noting that even though the total absorption is large enough to put the resulting sound strength G within the range seen as acceptable based on ISO 23591 appendix A for the particular ensemble type, more than 55 % of the musicians reported that the room amplification/sound level was *too loud*. This implied that great care had to be taken to not increase G more than absolutely necessary, while still providing improved support and room response for the musicians.

3.1.1 Room acoustic modifications

Based on the preliminary analysis of the room and observations from the survey, the following design goals were defined:

- Improve room response with regards to own playing and inter-ensemble listening, with a particular focus on improved listening between different instrument groups within the wood-wind section, and on own response for the brass section
- Avoid level increase from percussion
- Increase room presence and reverberation, but avoid a significant increase in G (max. ΔG approx. 1 dB)
- Improve reverberation profile towards the ISO 23591 tolerance curves

The acoustic design was based on replacing part of the absorber panels with carefully oriented convex reflectors, and rearranging parts of the absorbers to increase absorption at source and listener level while creating room for more repeated reflections in the upper part of the room, in order to increase the late energy level. Continuing the use of local reflectors in front of the brass and the percussion sections was also part of the design concept. An overall goal was also to provide a transparent reflector coverage, i.e. sparse reflections that were separated in time and space without unnecessary diffusion that could cause "blurring" or masking, especially in the high frequency region. If needed, based on subjective assessment of the listening conditions after taking the refurbished hall into use, more diffusion could be added later.

Convex reflectors were chosen because they provide a balanced (full frequency) response above the cut-off frequency given by the size of the reflector panels, combined with tunable gain and coverage angle. It is worth noting that the damping of a singular reflection, compared to a flat panel reflector, not only depends on the radius of curvature, but also the source and receiver distances[11]. A convex reflector is more effective when either the source or the receiver is close to the reflecting surface. This property can be exploited to adjust the relative balance between the individual reflection contributions to a particular instrument group. See Figure 1 for illustrations of the relative gain for convex reflector as a function of radius, source and receiver distance.

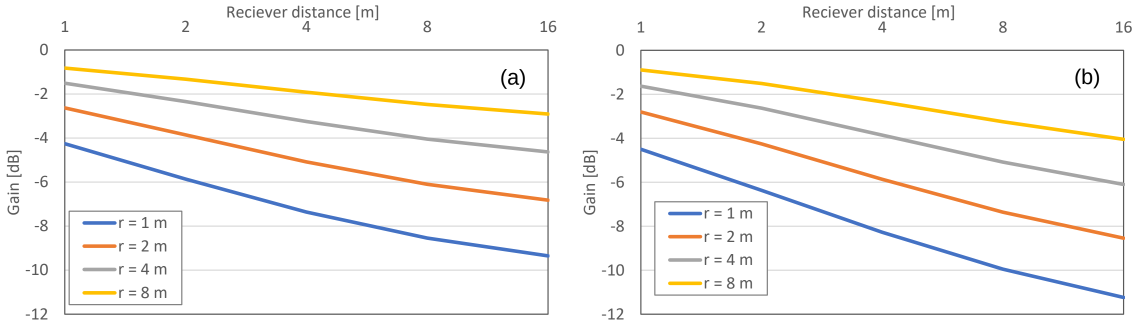

Figure 1 Gain (net reduction of the level of a reflection compared to a plane) for a convex reflector as a function of radius and receiver distance. Shown for (a) 5 m source distance and (b) 10 m source distance.

The final design is illustrated in Figure 2 and Figure 3. See also Figure 5 for an overview of the location of different instrument groups.

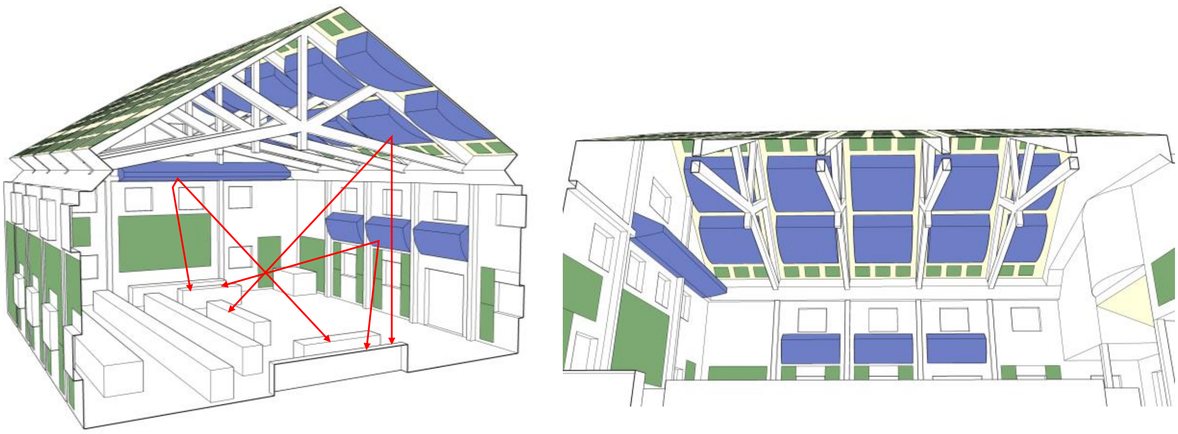

Figure 2 Overview of the acoustic design. Green surfaces are existing or relocated direct-mounted porous absorbers. Blue surfaces are the convex reflectors. The ceiling has an existing slit panel (light yellow) which is partly covered by the porous absorbers and the convex reflectors. Red arrows illustrate some of the reflection paths designed to improve ensemble conditions.

Figure 3 Perspective from the percussion section before (left) and after (right) the refurbishment.

Ceiling reflectors are designed to provide even coverage throughout the ensemble including both self-support and inter-group listening. Reflectors on the side wall are designed to improve cross-listening within the wood-wind section, without increasing reflected energy from the brass section. These are inspired by Dammerud's work on improving ensemble support within the string section of a symphonic orchestra[4]. Reflectors on the front wall (behind the conductor) provide both self-support and inter-group listening. These have a dual-radius design. The large-radius upper part is targeted to improve own and within-group listening for the brass section, and the smaller radius lower section favorizes inter-group listening for the wood-wind section, where both source and listener are close to the reflectors. The design aimed to keep the conductor position within the coverage zone of most of the reflectors.

Reflector coverage was optimized through geometrical studies, and Odeon was used to simulate changes in reverberation time and G, starting from a calibrated model of the existing situation.

3.1.2 Subjective evaluation

The refurbishment of the rehearsal room was performed summer/early autumn 2023. A follow-up survey among the musicians was conducted short time after the completion of all the planned acoustic measures, in order to have the results ready in time for the paper deadline. In total 15 out of 30 musicians have replied at the time of completion of the paper, versus 28 for the pre-refurbishment survey.

Overall, the respondents were positive regarding the impact of the renovation with regards to the listening experience.

Some key results are summarized below:

- 80 % now find the room "balanced" with regards to reverberation / "room sense"
- 67 % now find the room "bright/sharp", while the remainder find it "balanced"
- 80 % now find the room "too loud" vs. 57 % before the refurbishment
- 67 % think that the room's ability to make their own instrument resonate in a natural manner has become *somewhat better* or *significantly better*

Ensemble related parameters are summarized in Figure 4.

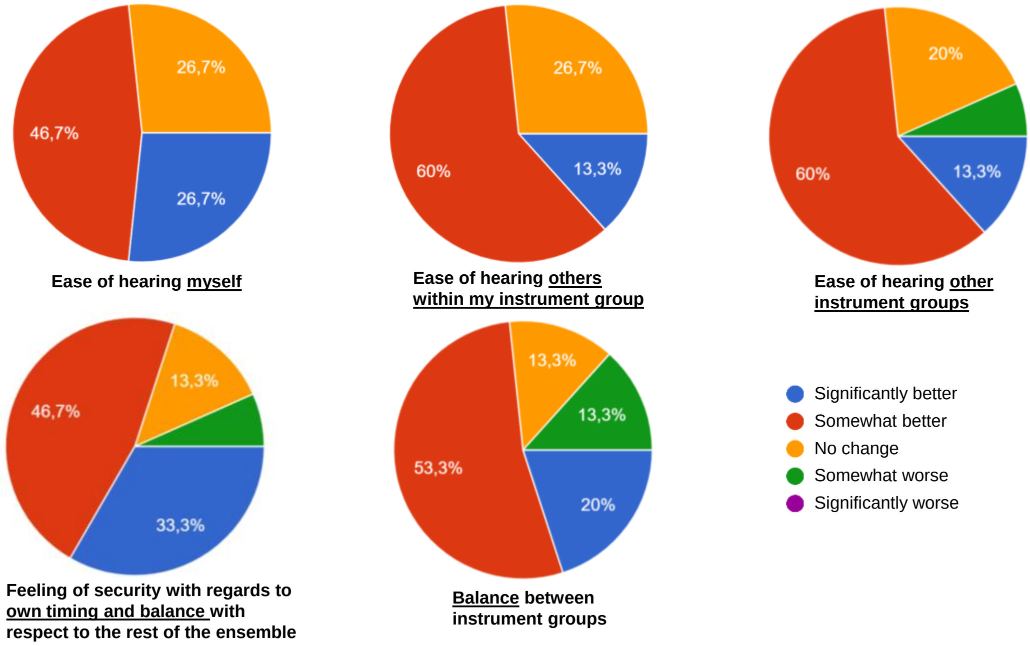

Figure 4 Ensemble related parameters, post-refurbishment survey

Some musicians commented that the limited time to make themselves acquainted with the room after the modifications made it hard to evaluate the impact of the changes, and that the ensemble also needed more time to adjust to the new acoustics. Some also commented that the repertoire so far had been mostly acoustically loud music, and that the evaluation might change after doing more lyrical and chamber music-oriented repertoire.

Overall, the survey indicates that:

- ensemble related properties have improved
- the overall reverberation now seems to be balanced, but the timbral balance is somewhat bright/sharp
- perceived level / sound strength has increased somewhat

Based on the comments from the musicians listed above, a future follow-up survey might be performed in order to evaluate their long-term experience, especially related to sound level / sound exposure.

3.1.3 Measured changes in key acoustic parameters

Changes in key parameters like reverberation time, sound strength and support were analyzed by recording impulse responses between 6 representative positions within the ensemble, in addition to measuring the response at the conductor position and at a reference position a bit further away from the ensemble. Measurements were done by use of the measurement system IRIS and a dodecahedron speaker. All measurement combinations were recorded both before and after the completion of the acoustic measures, in total 96 impulse responses.

An overview of the source and receiver positions is given below.

Figure 5 Source and receiver positions. The numbered locations correspond to the following instrument groups: 1 – Horns, 2 – Flutes, 3 – Clarinets, 4 – Saxophones, 5 – Trombones, 6 – Percussion. Position 7 is the conductor and position 8 is a reference position (both receiver only).

It was decided not to adhere to the requirement of a reflection-free zone for measuring the ISO 3382-1 strength parameters. Instead, care was taken to aim to reproduce the local reflection properties (chairs and music stands) for the comparative measurements. The motivation was to obtain a reflection distribution that was as representative as possible for actual rehearsal conditions. Also, the main topic of interest was the net *change* in the key acoustic parameters. As a positive side effect, this setup significantly simplified the measurement sessions.

Some key results are shown in Figures 5 to 8.

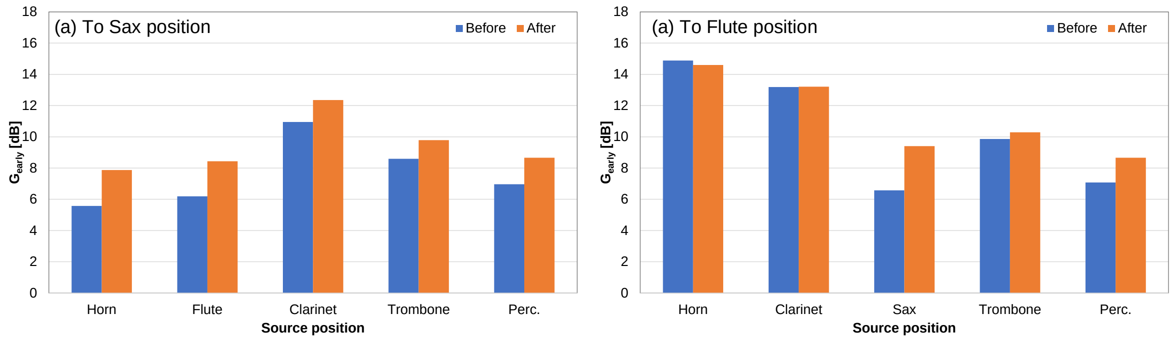

Figure 6 G_{early} before/after refurbishment for (a) Sax and (b) Flute position.

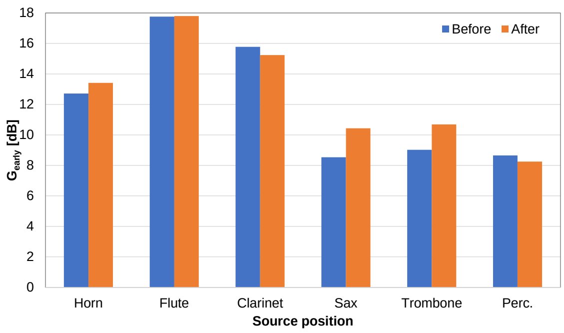

Figure 7 G_{early} before/after refurbishment for conductor's position.

From Figure 6 and Figure 7 the following observations can be made:

- Reflection contributions across the wood-wind section have been increased, and the balance with respect to near groups and with respect to brass/percussion has improved
- The level difference between near and far groups has decreased
- Source positions close to the receiver is, as expected, dominated by the direct sound component.

The net change in early support (ST_{Early}) is shown in Figure 8. (Valid ST_{Late} values were not derived by IRIS.) It can be observed that the wood-wind section has had the largest increase in ST_{Early}, as intended. The differences can partly be explained by distance to the convex reflectors, and partly by which reflectors that are effective for the different instrument groups.

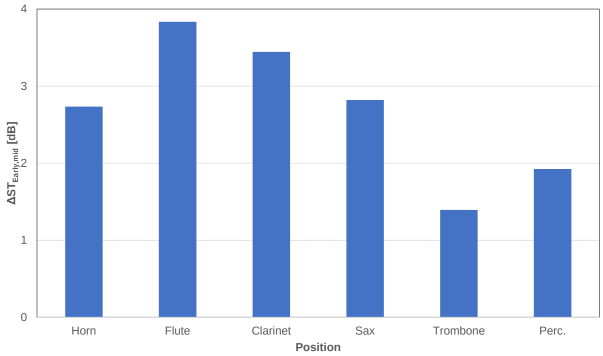

Figure 8 Net change in Early Support after refurbishment.

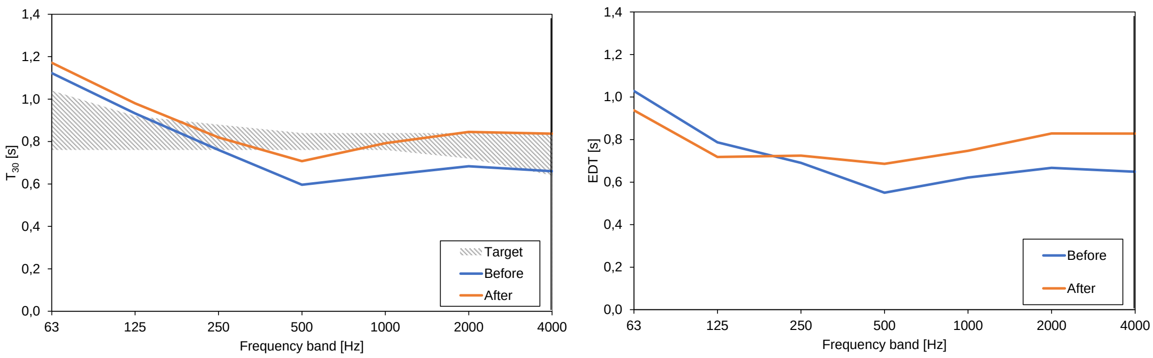

Figure 9 T_{30} and EDT before/after refurbishment. T_{30} is plotted together with an ISO 23591 tolerance curve for acoustic music corresponding to T_{mid} = 0,8 s.

Measured values at different positions showed small variations for the T_{30} values. For EDT, results for the individual positions and frequency bands were within ±0,1 s of the average values shown above before refurbishment, and within ±0,05 s after refurbishment.

As can be seen from Figure 9, the reverberation profile has been improved, but the frequency balance is still not in compliance with the ISO 23591 tolerance curves. The primary causes are:

- Solid brick walls in combination with direct-mounted 40 mm porous absorbers yield absorption primarily from the 250 Hz octave band an upwards.
- The ceiling construction is made by wooden panels acting as slit absorbers with a resonance frequency close to 500 Hz.

From a cost-benefit consideration made in the design phase, it was not seen as an option to replace all or most of the existing absorbers, which would have been necessary to obtain an optimal reverberation profile.

The resulting reverberation curves are mostly within uncertainty limits of the predicted values, but the increase in EDT for the upper frequency bands was somewhat higher than expected.

The slight lift in reverberation time in the high frequency region is worth further consideration. Based on both the measurement results and subjective experience of the tonal quality of the room, means to further optimize the high frequency response will be considered in collaboration with the client. One viable option could be to introduce some more high frequency diffusion, that could aid in both optimizing the timbral balance and creating more "air" in the acoustic response. Such a measure would have to be carefully done in order to not mask or blur the obtained increased clarity and transparence, that was the aim of the acoustic design. Another approach, possibly as an addition to increasing the high frequency diffusion, can be to introduce some high frequency absorption to the reflectors, either by attaching a thin fabric or treating the surface by acoustic plaster finishing spray.

It should be noted that a target reverberation time T_{mid} of approx. 0,8 s is well below the recommended range given in ISO 23591 for the given room volume: 1,0-1,4 s. Based on the results from the follow-up survey summarized in section 3.1.2, there does not seem to be room for increasing the reverberation – and hence G – any further. It is also worth noting that the musicians now find the room *balanced* with regards to reverberation. One might argue that the musicians have been so used to playing in a heavily dampened room that they could be biased towards dry acoustics, but the ensemble regularly play concerts in high quality concert venues, and their most used concert venue is relatively reverberant. Several of the musicians also play in other professional and semi-professional ensembles, including the city's philharmonic orchestra.

3.2 Rehearsal room for a semi-professional brass band

Examples from another rehearsal room with similar challenges as the one presented above is also included in order to show a slightly different approach to improving ensemble listening conditions without causing an unacceptable increase in sound strength. This project has not yet been realized. The presentation is therefore limited to presenting the overall acoustic design.

The room is an old school sports hall that is now being used as the rehearsal room for a semi-professional brass band of 30 musicians. The room volume is only approx. 1.000 m^3, well below the minimum recommended volume for "extra loud groups" (1.800 m^3 for a standard brass band.) The existing acoustic treatment is a combination of wooden panel slit absorbers in the ceiling, wooden paneling on the walls and stage draperies, which are used to adjust the degree of damping. Images from the room and measured reverberation time in the highly dampened and moderately dampened setting, both which are used by the ensemble, are shown below.


Figure 10 The brass band rehearsal room in highly dampened (left) and moderately dampened (right) setting. The conductor is normally located along the right wall.

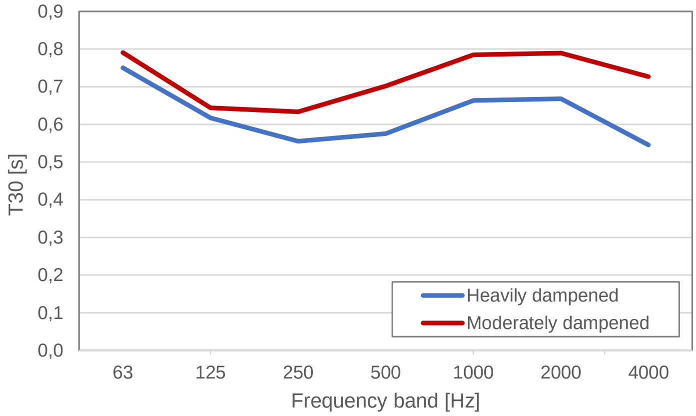

Figure 11 Measured reverberation time, current condition.

An acoustic survey among the musicians and the key conductors was performed also in this project. Some key findings are summarized below:

- 60% of the musicians and all the conductors consider the room *dry*, and 37 % of the musicians consider it *balanced* with respect to reverberation and room sense.
- 53 % of the musicians and 1 out of 3 conductors think the overall sound level is *too high*. When asked an open question on desired improvements, local screens to reduce the sound level from trombones and percussion was a recurring suggestion.
- 87 % of the musicians respond that they hear themselves well, but 50 % respond that it is *somewhat challenging* to hear others within the same instrument group or other instrument groups. 32 % respond that hearing others is *very challenging*.

It should be noted that the brass band have slightly different needs than professional wind band discussed above. First of all, the instrumentation has a better inherent balance, with an ensemble consisting of brass instruments only (excluding percussion), and the number of players within each group adapted to the function and the sound power of each instrument. The directivity of each instrument, with most instruments oriented upwards, but trombones and cornets facing primarily inwards relative to the audience perspective, must be taken into consideration when designing acoustic elements that should aid in mutual listening. Also, the relatively similar sound character of the different instruments, coupled with often dense and highly technical musical scores, call for a focus on clarity and transparency rather than reverberation, especially in the rehearsal situation. Clarity and transparency was also pointed out as a positive quality of the existing rehearsal room by some of the musicians. See [8] for a more detailed discussion on the particular needs of brass band rehearsal rooms.

Based on the preliminary analysis of the room and the results from the survey, it was decided to not aim to increase the reverberation up to the range specified in the ISO 23591 standard, but instead focus on the following design targets:

- Improve ensemble listening conditions and support across the ensemble
- Improve the reverberation profile, i.e. the frequency dependent reverberation time, without a significant increase in sound strength G
- Avoid level increase from percussion

An overview of the acoustic design concept is given in Figure 12. Strategic use of local screens is also part of the framework.

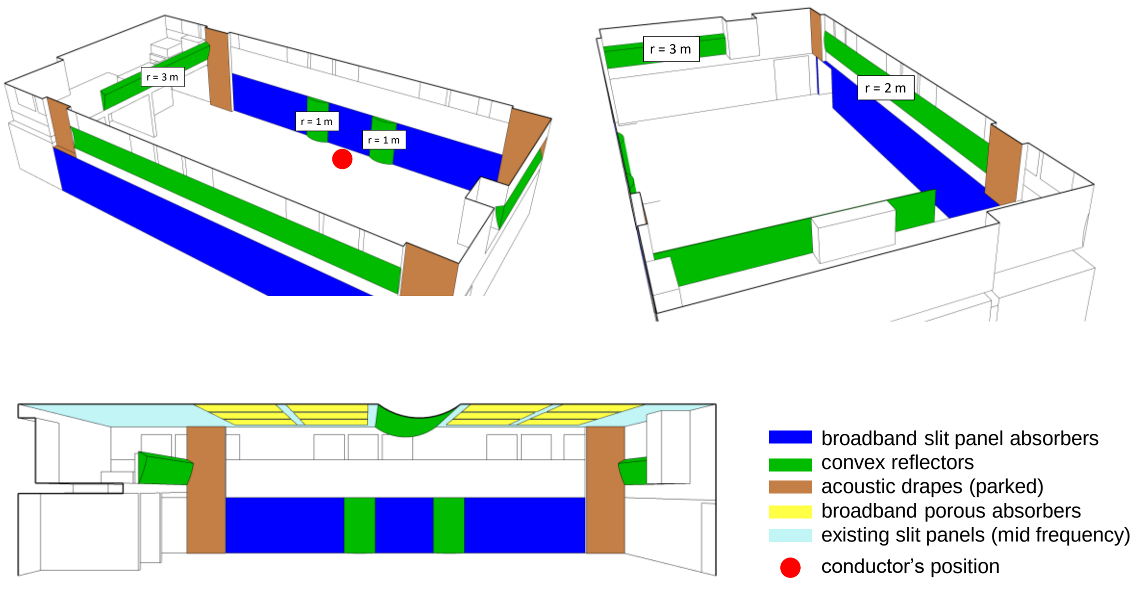

Figure 12 Acoustic design concept

The proposed changes were simulated using Odeon, with a main focus on the net change in sound strength G as a function of position and frequency band, and the shape of the reverberation curve. Simulated T_{30} with acoustic curtains parked/in use is shown in Figure 13.

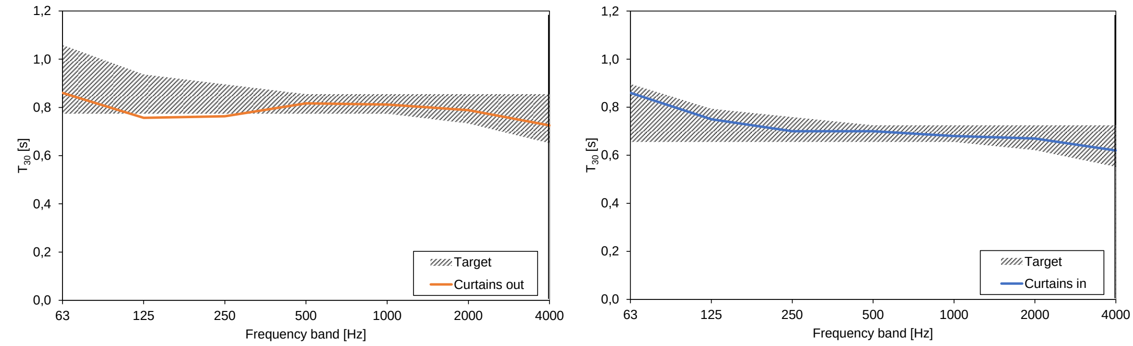

Figure 13 Simulated T_{30} with acoustic curtains parked/in use

The simulations showed that the net change in G will be negligible, though low frequency G will increase slightly, and high frequency G will have an overall slight decrease.

It should be noted that also for this project, the target reverberation T_{mid} was set well below the recommended range given in ISO 23591 for the given room volume: Target 0,7-0,8 s versus recommended 0,9-1,3 s. Based on the survey among the musicians and the focus on avoiding increased sound levels, the room for increasing the reverberation time significantly above 0,8 s seems limited. Although one should be careful about establishing recommendations on optimal reverberation time ranges based on simulations and analysis of an existing room, it is interesting that more than $^1/_3$ of the musicians consider the existing room to be acoustically balanced, and that several musicians comment on the preference for transparent acoustics in the rehearsal situation.

3.3 Summary and further work

In [8] an alternative way of illustrating the recommended reverberation times in the ISO 23591 standard together with the resulting room-averaged G, the total room absorption and the average absorption coefficient of the room surfaces is given. The measured reverberation times for the two rooms presented in this paper have been included in the illustration from [8] to illustrate the effect of setting the target reverberation time lower than the ISO 23591 recommendations. Note that due to the small volume of the brass band rehearsal room, it is not realistic to fulfil the recommended minimum absorption area given in [8] of 10-12 m² pr. person, even for the heavily dampened current situation.

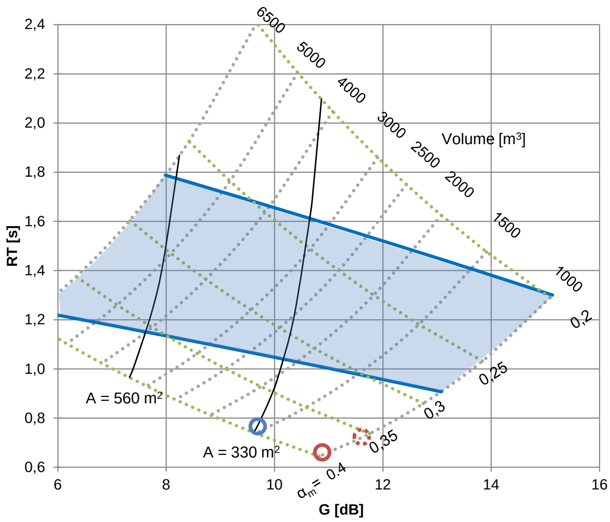

Figure 14 Recommended reverberation times in ISO 23591:2021 for ensemble rooms for loud acoustic music, as a function of room volume, reproduced from [8]. Blue lines correspond to the minimum and maximum values given in ISO 23591. Green dotted lines indicate G-RT contours of equal average absorption coefficient α_m, based on a typical shoe box-shaped room, and grey dotted lines indicate G-RT contours of equal volume. G-RT contours corresponding to the minimum absorption area suggested in [8] for a 70-person professional symphony orchestra (560 m²) and for a standard brass band / 55-person amateur wind band (330 m²) is also shown (black solid lines). The blue circle represents the wind orchestra rehearsal room, and the solid/dotted red circles represents the brass band rehearsal room with/without curtains in use (both after refurbishment.)

For the case of rehearsal rooms for acoustically loud ensembles with a volume below or close to the recommended minimum values for so-called "extra loud groups" (60 m³/person), the results from this study indicate that the recommended reverberation time range given in the ISO 23591 standard might be set too high. The results also indicate that for the rehearsal situation, ensemble-related parameters related to hearing one-self and others, the timbral quality of the room response and controlling the overall sound level is more important than the obtaining a sufficiently "full" room reverberation.

The authors would like to encourage the publication of measurements coupled with subjective evaluation for relevant rehearsal rooms for acoustic loud ensembles, in particular rooms in the 1.000 to 3.000 m³ range, where a trade-off between optimal reverberation and control of sound exposure is most likely to occur. More real-world experience is needed in order to provide the best possible framework for a future revision of the ISO 23591 standard.

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