INTEGRATED ROOM ACOUSTIC AND ELECTRO-ACOUSTIC DESIGN - THE CONCERT VENUE AT ROCKHEIM, NORWAY

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1 INTRODUCTION

There is a significant potential in ensuring a high degree of interaction between room acoustic and electroacoustic design, especially for concert venues optimized for amplified music.

This paper will address key room acoustic criteria for venues for pop and rock music. Also, the interaction between the room acoustic and electroacoustic design through the different design phases will be discussed.

Examples will be given from the new concert venue at Rockheim, the Norwegian National Centre for Pop and Rock.

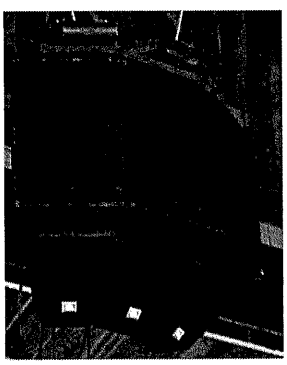
The paper will also address the following open issues: Optimum ways of handling early side wall reflections, desired liveliness at the stage and in the audience area, and the importance of supporting performer-audience interaction through acoustic coupling between stage and audience area.

Unfortunately, these topics has not been treated extensively in the literature. To the authors' knowledge, there has only been published a few papers written by N.W. Adelmann-Larsen et.al. which treat acoustics for concert venues for pop and rock music in depth. Their main results are summarized in [1].

2 DESIGN METHODOLOGY

2.1 Main loudspeaker system principles for concert venues

In order to optimize the room acoustics of concert venues for amplified music, it is important to be aware of the directional properties of the main loudspeaker system design principles. The two main design principles are shown in Figure 1.



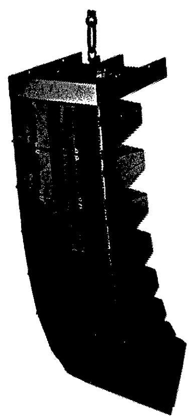


Figure 1. Main loudspeaker system design principles. Point source clusters (left) and line arrays (right).

The traditional point source cluster typically yield directivity control in both the horizontal and vertical direction, but the coverage cut-off is typically not very abrupt, and might vary considerably with frequency. Also, limited coupling between the cabinets can lead to phase cancellation effects that might cause reduced sound quality. On the other hand, point source clusters are favourable with regard to obtaining even coverage close to the stage and reducing strong direct sound components towards the sidewalls. They also yield a more natural perception of source distance than line arrays.

Line arrays aim to assimilate a cylindrical wave, with some modifications, to obtain even coverage from the front to the back of the audience area. Their key property is the ability to cover larger source-receiver distances than point source clusters, with a stronger direct to reverberant sound ratio. When properly designed, the risk of audible phase cancellation effects is also lower than for typical point source clusters. The main challenge when using line arrays is, as mentioned above, to compensate for the limited horizontal directivity control, and to obtain good coverage close to the stage. Acoustic treatment of the sidewalls close to the array is normally necessary to obtain a controlled sound field within the audience area.

2.2 Key room acoustic criteria

In Figure 2, it is attempted to summarize the key room acoustic criteria that need to be assessed when designing venues for pop and rock music. These criteria are related to three overall design objectives, which are shown in bold beige letters in Figure 2.

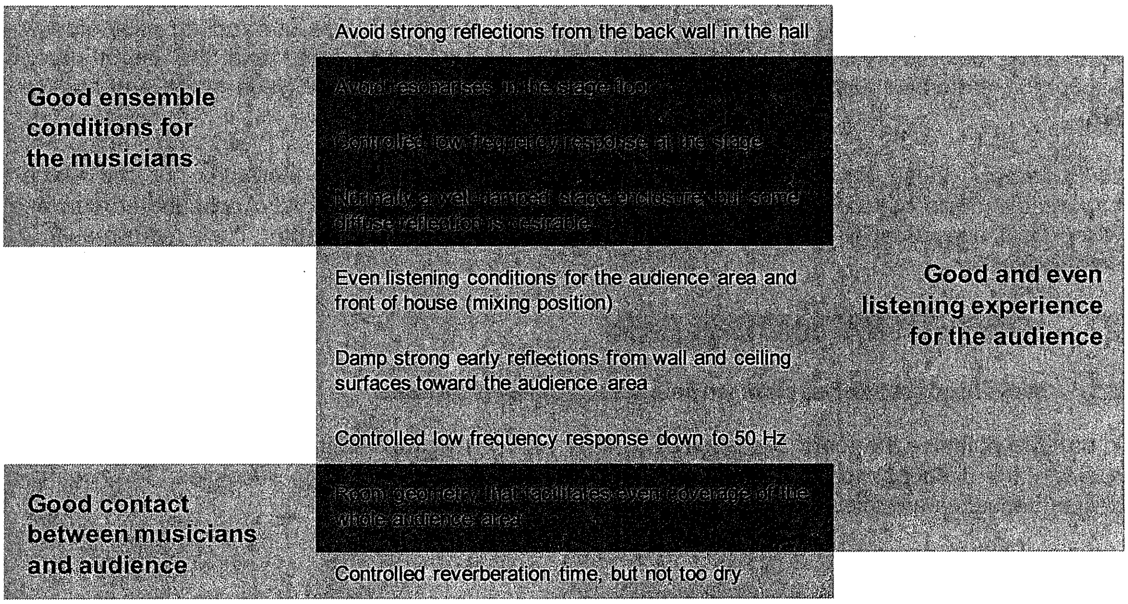


Figure 2. Overview of key room acoustic criteria and related design objectives.

A well thought out room acoustic design can provide more flexibility with regards to choice of loudspeaker systems. In addition, a good room acoustical model is an important tool for robust design and evaluation of different loudspeaker systems.

It is desirable to be able to cover the whole audience area using only one loudspeaker array/cluster at each side of the stage opening. One should avoid ledges and other protruding elements above the audience area.

The importance of having a large ceiling height should not be underestimated, even though the desired reverberation time might be relatively low. A large volume and a correspondingly high absorption area reduces the variation in acoustic conditions with/without audience. This is especially important for halls designed for standing audience. Also, a high ceiling improves the possibilities for optimum loudspeaker placement, and is important with regards to positioning of stage lighting installations.

In order to achieve a reasonably even reverberation curve with audience in the hall, the empty hall reverberation curve should be raised slightly between approximately 1-4 kHz. This will also add some "liveliness" to an otherwise well damped room. Absorption data for standing audience can be found in [1].

2.3 Interaction through different design phases

An outline of a good interaction process between the room acoustic and electroacoustic design through the different design phases is illustrated in Figure 3.

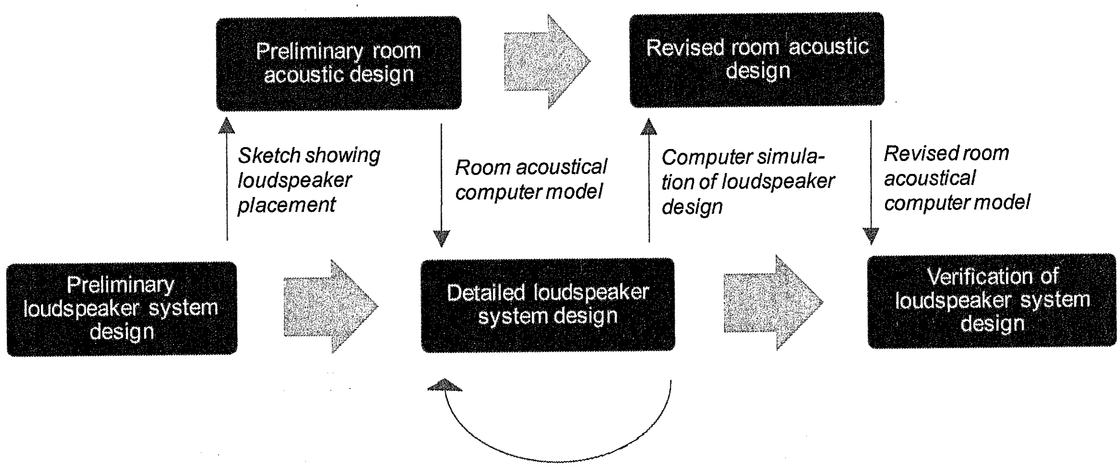


Figure 3. Interaction between room acoustic and electroacoustic design through different design phases.

The key to the model described in Figure 3 is to obtain an iterative process for which it is possible to jointly optimize the room acoustic and electroacoustic design.

Due to overall project schedules the loudspeaker system design process often starts much later than the room acoustical design, and the interaction model described in Figure 3 is therefore often not possible to apply. The room acoustic consultant should therefore encourage the inclusion of the electroacoustic consultant at an early stage, if possible.

3 EXAMPLES FROM ROCKHEIM

Rockheim is a technologically advanced experience centre and museum for pop and rock music in Norway, located in Trondheim. The building is partly a refurbishment, partly an expansion of an old flour warehouse. The concert venue is shoebox-shaped with a flat audience area, and has a raw architectural design. The volume including stage area is approx. 1800 m^3. It were acoustically optimized for pop and rock concerts, but should also accommodate conferences, movies etc. Audience capacity is 350 standing/160 seated.

The architect was Pir II AS. COWI was hired to do both the room acoustic and electroacoustic planning, which made possible a close adaptation of the room acoustic design to the loudspeaker system.

This section will give a brief overview of the room acoustic concepts used and present a comparison between predicted and measured reverberation times.

Figure 4. Photos of Rockheim. The concert venue is located in the leftmost part of the building (left). Inside photos show the concert venue in conference setup as seen from the stage (middle) and a view along the stage back wall (right).

3.1.1 Room acoustic design

Due to a close proximity highway and structural considerations, all untreated surfaces inside the hall are made up of concrete, which yielded very little inherent low frequency absorption. Therefore significant bass absorption had to be included in the room acoustical treatment.

Room acoustic modelling and absorber designs were done using Odeon and WinFlag, but due to limited loudspeaker model support in Odeon, the loudspeaker modelling was done using Ease.

The hall has a 1.3 m deep suspended ceiling based on double-layer mineral wool absorbers. Achieving high bass absorption in the ceiling down to at least 50 Hz was of key importance. To balance the absorption characteristics of standing audience and stage drapes, and to increase stage support, part of the absorbers were designed to have reduced mid and high frequency absorption, as shown in Figure 5.

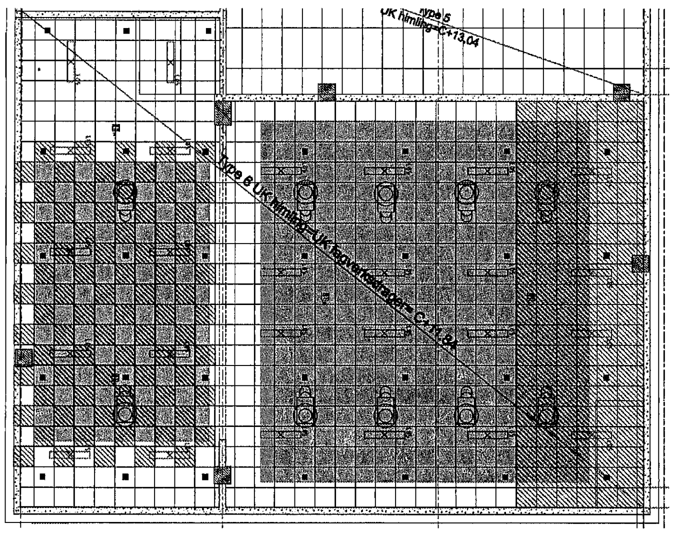


Figure 5. Plan view showing distribution of ceiling absorbers. Red semitransparent region indicates stage area, and blue semitransparent region indicates audience area. Hatched ceiling tiles have reduced mid and high frequency absorption.

The impedance boundaries created by the checker patterned distribution above the stage also introduces increased scattering of the reflected mid- and high-frequency energy.
In order to avoid strong first order reflections toward the stage and audience area, the back wall and central parts of the side walls in the audience area were covered by 200 mm high density mineral wool absorbers. The placement and extent of the side wall absorbers were optimized after selecting the loudspeaker system, as illustrated in Figure 6.

To avoid flutter echoes, to increase diffusion, and to increase low frequency absorption, parts of the side walls were treated by triangularly shaped slit absorbers made up of MDF boards, labeled "c" and "d" in Figure 6. These were also an important architectural element and were distributed to avoid parallel reflecting surfaces. A cross section of two of the slit absorbers is shown in Figure 6. In order to balance the effect of the other absorbers used, the slit absorbers were tuned to respectively 220 and 50 Hz. A significant design uncertainty was attributed to estimating the inherent flow resistance in the panel slits and of the fabric attached to the backside of the slits. Unfortunately, lab measurements were not possible within the framework of the project.

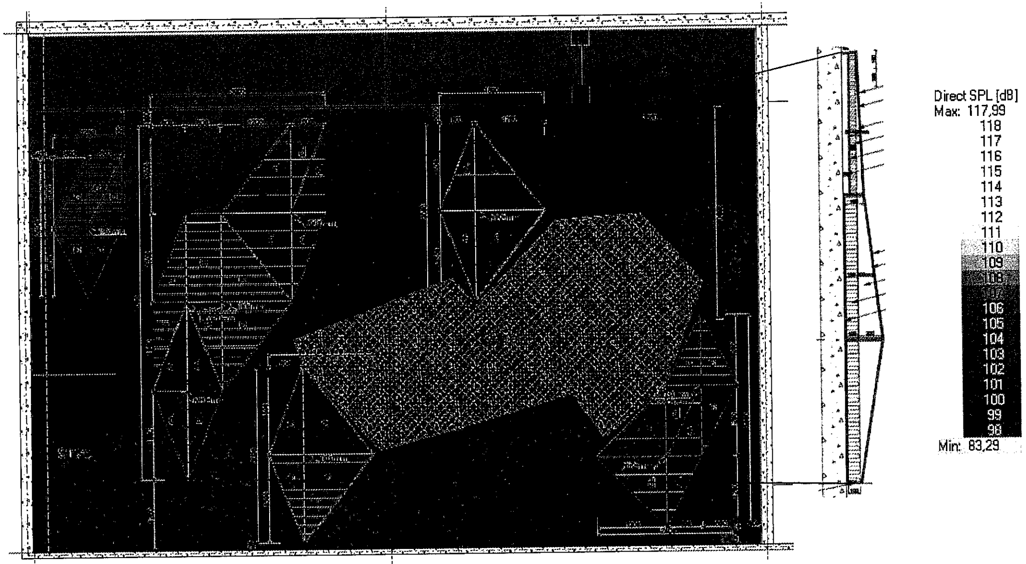


Figure 6. View of left sidewall, with overlaid simulation of direct sound coverage from left loudspeaker array. To the right, an expanded cross section of one of the sidewall slit absorbers/diffusers is also shown.

To increase ensemble support, the triangular slit absorbers were also employed for the stage back wall, see Figure 4 and Figure 7. In addition, low frequency membrane absorbers were mounted on available stage wall surfaces not visible to the audience, to balance absorption from the stage drapes.

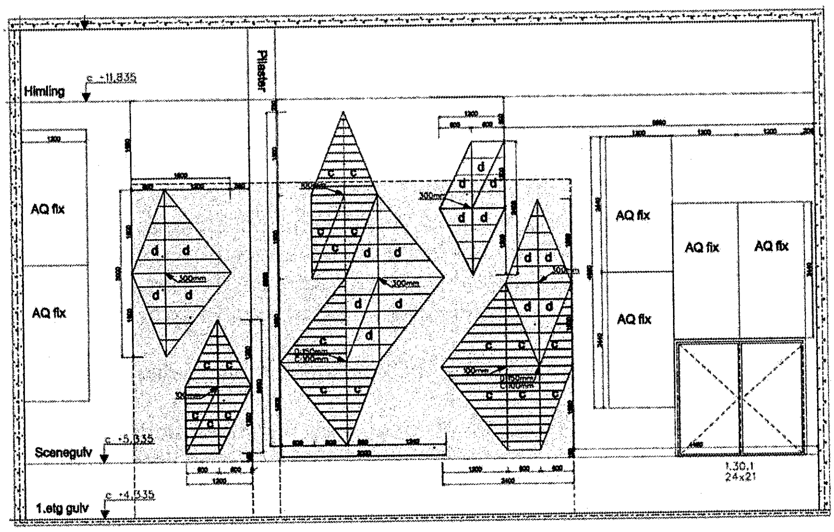


Figure 7. View of the stage backwall. Beige semitransparent area indicates the stage opening.

3.1.2 Measurements

A comparison between predicted and measured reverberation times is shown in Figure 8. It can be seen that the measured values are somewhat lower than predicted for all frequency bands above 100 Hz. 1/3 octave band measurements for different source-receiver combinations all showed high consistency. Maximum deviations between measurement positions, and between neighboring 1/3 octave bands, were approx. 0.05 seconds above 100 Hz (results not included here).

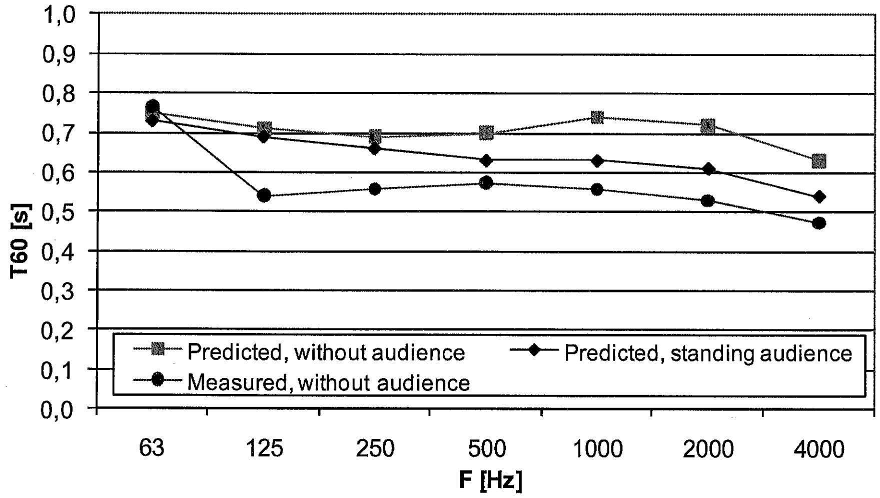


Figure 8. Predicted vs. measured reverberation time for source at stage. Measurements include subwoofer.

The discrepancies might be explained by the following factors:

- Uncertainties regarding estimation of absorption properties for custom-made absorbers, especially low-frequency edge effects.
- Uncertainty regarding low-frequency estimation using geometrical acoustics software.
- Uncertainties regarding flow resistance of acoustic fabrics.
- More porous absorbing materials were installed than estimated (especially stage drapes).
- Possible change of ceiling absorber type.

Even though the venue appears dryer than predicted and also dryer than desired, feedback from artists, technicians and audience has been very positive. Comments generally focus on high degree of control, high clarity, even sound experience, and "hifi-like" sound. Also, many find it intriguing that the room appears visually "hard", but sound very damped and controlled.

4 OPEN ISSUES

As mentioned in the introduction, the number of publications on room acoustics for pop and rock music is very limited. The following open issues should be a topic of further discussion in order to obtain viable guidelines for optimum design of such concert venues. This would also ease prioritizing between different acoustic properties when designing multipurpose halls.

What is the optimum way of handling early side wall reflections from loudspeaker arrays?

As noted in section 2.1, line arrays have a high degree of vertical directivity control, but normally limited abilities to alter the horizontal directivity characteristics. To achieve even coverage for the audience area it is often necessary to accept high direct sound levels at the side walls in front of the arrays. The first order reflections should be damped or scattered, but the question is to what degree strong lateral reflections, if sufficiently diffuse, is beneficial for the listening experience for the audience. It might be that such reflections will improve the audience' perceived envelopment and "live" experience, while still keeping the room controlled and relatively well damped. It should be noted, however, that obtaining broadband sidewall diffusion is more difficult and expensive than absorbing the incident direct sound.

What is the desired liveliness at the stage and in the audience area?

As mentioned above, the feeling of being within an acoustic space, and not only hearing the direct sound from the loudspeaker system and from the stage, might improve the audience' listening experience. On the other hand, low reverberation times increase the technicians' control over the sound stage, enabling him to apply e.g. artificial reverberation or other processing to create the sound stage that he wants. Given the high degree of vertical control from modern loudspeaker arrays, designing the ceiling in the audience area to have high low-frequency absorption and limited mid- and high-frequency absorption might be a good basis for obtaining a balanced reverberation time, and also yields freedom to introduce sufficient absorption at the wall surfaces without lowering the reverberation time too much. Adelman-Larsen[1] has given a good overview of results from subjective evaluation of different halls for pop and rock music. The paper also presents recommended reverberation times based on hall volume.

Also, the degree of acoustic feedback on stage will influence the musicians' ability to hear one another. Many musicians find it favorable to have a combination of support from stage monitors and reflections from the stage enclosure. This is especially the case for many semi-acoustic bands. The author would suggest that the back wall and the ceiling at the stage should ideally be highly diffusing, with strong low-frequency absorption and moderate mid and high frequency absorption. For cases where more damped stage acoustics is wanted, drapes might be placed in front of the back wall.

What is the importance of supporting performer-audience interaction through acoustic coupling between stage and audience area?

Musicians often state that it is important to have a strong connection with the audience. In addition to the degree of intimacy in the hall, the acoustic coupling between the stage and audience area will affect the musicians' ability to communicate with and hear the response from the audience. Therefore, it might be favorable to make the central foremost part of the ceiling above the audience area reflective, but care must be taken if the loudspeaker system radiates significant energy towards the ceiling.

5 REFERENCES

1. N.W. Adelman-Larsen, E.R. Thompson, A.C. Gade, Suitable reverberation times for halls for rock and pop music, J. Acoust. Soc. Am. 127(1) 247-255. (January 2010).