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ANALYSIS OF MUSIC PERFORMED IN DIFFERENT ACOUSTIC SETTINGS IN STAVANGER CONCERT HALL

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This paper analysis the same piece(s) of music performed with four different acoustic settings in Stavanger Concert House. All listeners and musicians were surprised by how big the changes in acoustics were. Even listeners who knew the concert hall from attending and playing the two halls many times were highly surprised over the demonstration. The changes between the different settings are surprisingly large also when listening to the live recordings. Analysing the recordings, however, we find that both the sound pressure levels and the overall frequency spectra are almost the same for all settings! In order to find the clearly perceived differences, we need to look closely into spectrograms, attack times etc., and inspect the lengths of the separate tones and how they are masked (if the reverberation is too long for the jazz/rock), or too short, (so that each note lacks build up to a "full tone" for the strings). Not only the decay time, but also the attack time is longer for the most reverberant settings. For fast piano-jazz trio, this prolonged decay due to long reverb "masks" the attack, and thus "smoothens" the timbre, and reduces the "brilliance". We need to discuss how early reflections influence (reduce) the attack time. A possible method for detecting the clearly perceived differences is to analyse Spectral Flux.

Keywords: Room Acoustics, Performed Music, Attack, Spectral Flux

1. Introduction

Stavanger Concert Hall has gained a very good reputation for its acoustics [1]. We had the possibility of recording the same piece(s) of music performed with 3 different acoustic settings in the main auditorium, the Fartein Valen concert hall, and in one setting in *Zetlitz* multipurpose hall.

2. The Halls

FARTEIN VALEN

Wav-recorder 8th row somewhat off center

Type: Zoom H4n standard mics on top

ZETLITZ

Photos: A. R. Jensenius

Fig. 1 Photos of the two auditoria in Stavanger Concert House

The four acoustic settings analysed were, (See [2] for details): ***"2.Chamber"***, with rehearsal curtain. ***"4. Amplified"*** Fully dampened setting for Amplified Music. (PS! Not meaning that instruments

were amplified, except bass and guitar). Rehearsal curtain half/third down (to dampen reflections from the first ceiling panels up/back to the void and curtains on side walls. ***"5. Zetlitz"*** Fully dampened, stage curtains, curtains on side balconies, small bleacher in the audience area. ***"6. ConcertBig"*** Setting for big, acoustic, symphony orchestras, ceiling and canopy reflectors at highest positions, no absorbing curtains. The measured/stipulated reverberation times**,** T30, for the four settings are shown in figure 2.

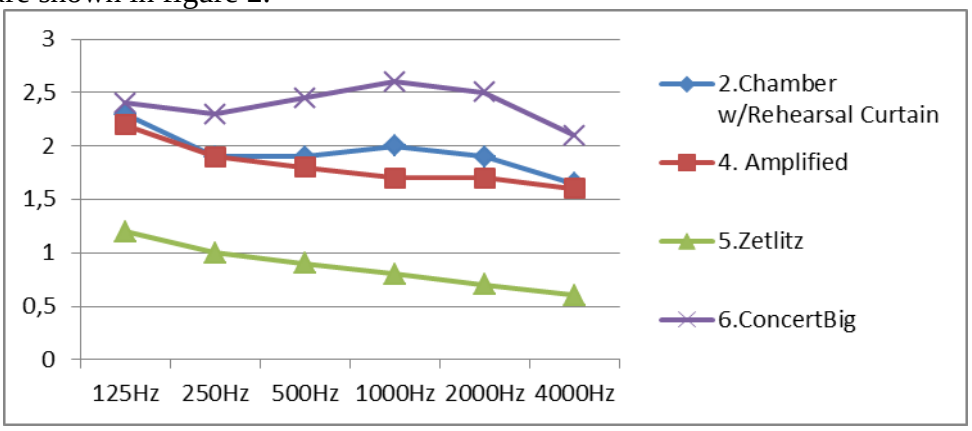

Fig.2 Reverberations times for the different acoustic settings

The same music of total length app. 3:10 minutes was performed four times. Sheet music is shown in [2]. *A)* ***Trumpet Fanfare*** *(from Mahler 5th Symph.) B) Added* ***String Quartet*** *(from the first part of the orch. score of Mahler 5th. C)* ***String Quartet a cappella*** *(adapted/arranged from a somewhat later part of Mahler 5th). D) MM=200.* ***Jazz/Swing*** *Piano/double bass/drums + Trumpet 12 bars (a theme based on the Norwegian national anthem, or: since it is a shortened version: "The Norwegian Rational Anthem"). Followed by 10 bars piano ad lib, and 2 bars with trumpet. E)* ***Rock****: MM=80. 2 bars drum solo (Slow Rock, back beat ad lib) followed by Electric Guitar/ 6-strings el-bass/drums Trumpet: 12 bars. Followed by 8 bars rock guitar solo ad lib, and 4 bars trumpet lead to fermata coda chord.*

No house-amplification was used (only personal amplifiers for bass and guitar). The recording level was kept constant during all recordings. The musicians were instructed that the acoustics of the different settings was the main issue, so they should play as equally in the four settings as practically possible. Minor changes in playing styles etc. for the different settings will of course occur, and some of these were analysed.

3. Analysis of the Recordings

3.1 Sound Power Level

Table 1 shows the analysis of the sound pressure levels for the different settings.

	RMS (MIR toolbox)	***dB Mean***	*dB Max*	**Leq** [dBA]	**L_C,peak,** [dBC]
2.Chamber wCurtain	0.34217	**-0.24**	2.06	**0.80**	**1.80**
4.Amplified Setting	0.33237	**-0.23**	-1.02	**0.00**	**-0.30**
5.Zetlitz:	0.32116	**0.00**	-0.71	**0.50**	**0.20**
6.Concert Big	0.32816	**0.00**	0.00	**0.00**	**0.00**

Table 1. Sound pressure levels. Relative values (0 dB=setting *"6.Concert"*)

Figure 2 shows the sound pressure levels over time for the different settings. 1s smoothing: (not calibrated SPL, but constant gain for all recordings).

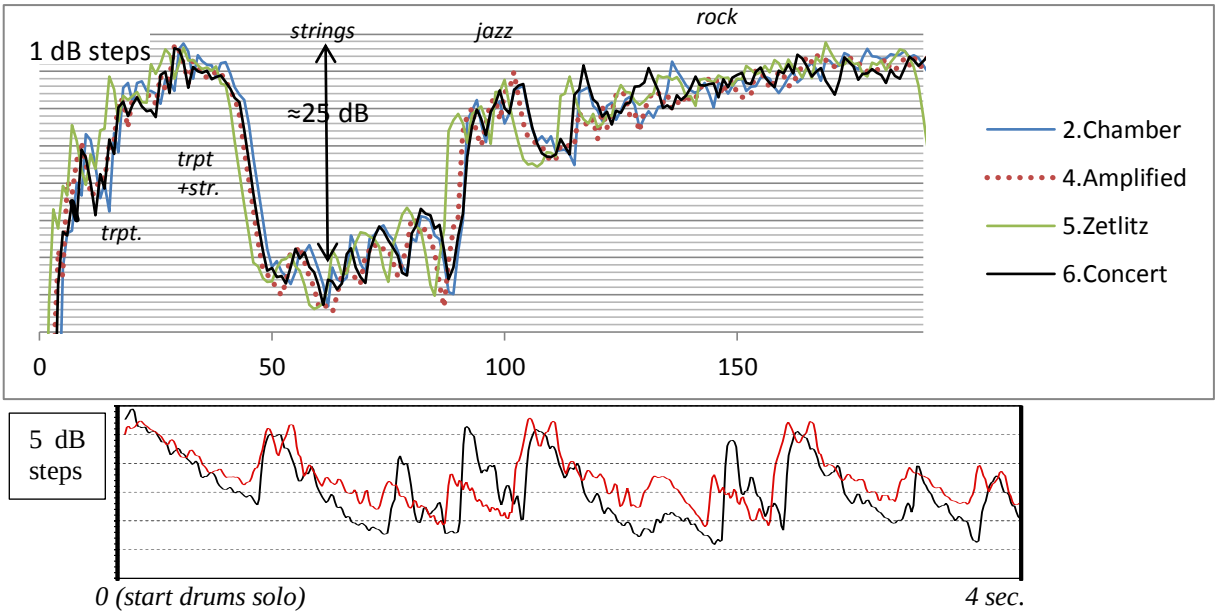

Fig. 2. Upper pane: Sound pressure level for the four settings.
Lower pane: Strength, Drums Solo, for the first 4 seconds: Black= *".5.Zetlitz",* Red= *"6.Concert"*

From fig. 2 we see that the differences in sound pressure levels between the settings is surprisingsly small, also compared to the perceived loudness listening to the recordings. *"6.ConcertBig"* (red in lower pane) shows somewhat stronger peaks (2 dB) than for *"5.Zetlitz",* with longer decays, and the decays do not get as low in dB as for «*5.Zetlitz*», due to the masking long delays in the reverberant *"6.ConcertBig".* But, even if we peceive the most reverberant settings to be stronger, the measured differences in overall SPL are surprisingsly small.

3.2 Strength Compared to G[dB] Measurements in Valen

The Valen hall has free hanging side-balconies with "downstands" (more info in [2]). A wanted effect of this is that the Acoustics Measurements Report shows that the early strength (G,early) changes just 0.1 dB when changing from a dampened hall to a fully reverberant setting. The late reverb, however, increases some 1.6 dB from *"2.Chamber"* to *"6.ConcertBig".* These G measurements are in good agreement with the very small change found in E.1 from the recordings. (0.0 to 2.0 dB, with the highest values for the "peak sounds"). The "almost zero" change of strength for the "mean" and L_{eq} values in Table 1. might indicate a slight "compensation" from the musicians, meaning that they play somewhat softer in the most reverberant setting (*"6.ConcertBig"*). (Earlier measurements in music rehearsal rooms show a bigger compensation, see [3]). Unfortunately, we do not have G-measurements for Zetlitz.

3.3 Frequency Spectrum (for the entire length of music)

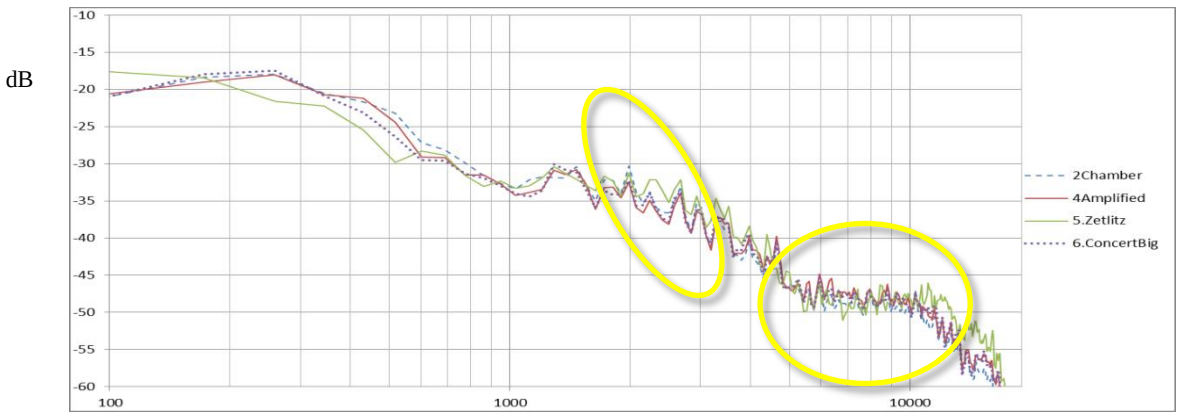

Fig. 3. Frequency spectra for the entire length of music for the different acoustic settings

From fig. 3 we see that the spectra are almost the same for all settings! However, Zetlitz gives a somewhat higher "brilliance", marked with yellow circles.

	Sp.Centroid	**"Sp.Centroid of RT"**
"2.Chamber w/rehearsal curtain":	709 Hz	865 Hz
"3.Amplified":	727 Hz	853 Hz
"5.Zetlitz":	823 Hz	729 Hz
"6.ConcertBig":	720 Hz	907 Hz

In the table above, spectral centroid is compared with a special calculation of the centroid over frequency of the reverberation times in fig. 2. These parameters are of course not directly comparable, but we see that that the columns show opposite trends. From the recordings, *Zetlitz* includes less reflections/reverb, more "direct sound", and shows a higher amount of treble. From the reverberation time measurements, the big, non-dampened Valen, *Concert*, shows the most "brilliant" reverberation time. This comparison **indicates that the amount of reverberation influence the reduction of "brilliance" more than the actual measured reverberation time versus frequency.** This might indicate that **adding reverb will reduce high frequencies, also when the reverb has a (moderate?) increase of reverberation for high frequencies**. (This is somewhat analogue to how allpass filters work in electronic reverberation systems).

3.4 Note Length

3.4.1 Notelength Drums solo

The MIR toolbox (MatLab [4]) parameters "mirNotelength" (and "mirattack/release") were investigated, but showed invalid results for parts with more than one voice, even after filtering the recordings ("mirfilterbank"), because the algorithm has problems detecting the attack of each instrument separately. For the rock drums solo, the result was somewhat more interesting:

Tone length, drums solo (Median values):			
2. Chamber	***4.Amplified***	***5.Zetlitz***	***6.Concert***
0.41	**0.40**	**0.27**	**0.44**

There are still some uncertainties regarding if *"mir"* finds the actual attacks, but the main result is that the note lengths are clearly shortest for "*5.Zetlitz"*. It is also reasonable that the note lengths in *"2.Chamber"* are slightly higher than *"4.Amplified",* and that *"6.ConcertBig"* shows the longest note length. In general, however, the parameter "mirnotelength" does not give exact information about what is happening regarding note length, and we need to inspect the recordings more in detail.

3.4.2 Attack Time, Drums solo

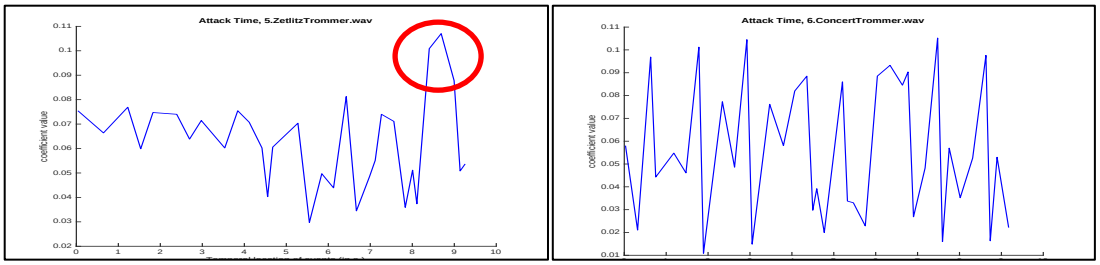

Fig. 4. Attack Time (mirattack) for *5. Zetlitz* (left) and *6.Concert* (right), for drums solo

The attack time is longer in the reverberant *ConcertBig* than in *Zetlitz.* (Apart from the very last stoke(s) which must be due to different performance, marked with red circle). Unfortunately Mir Toolbox did not manage to detect and analyse the attack of each instrument for the String Quartet and jazz/rock, so the "mirattack" did not show reliable results for polyphonic parts. Zoom in on the first part of the drum solos is shown in figure 5. The length of each note shown in spectrograms is, of course, dependent on the FFT-window (and the gain for the colours), but since these were the same for both analysis, we can inspect the relative lengths.

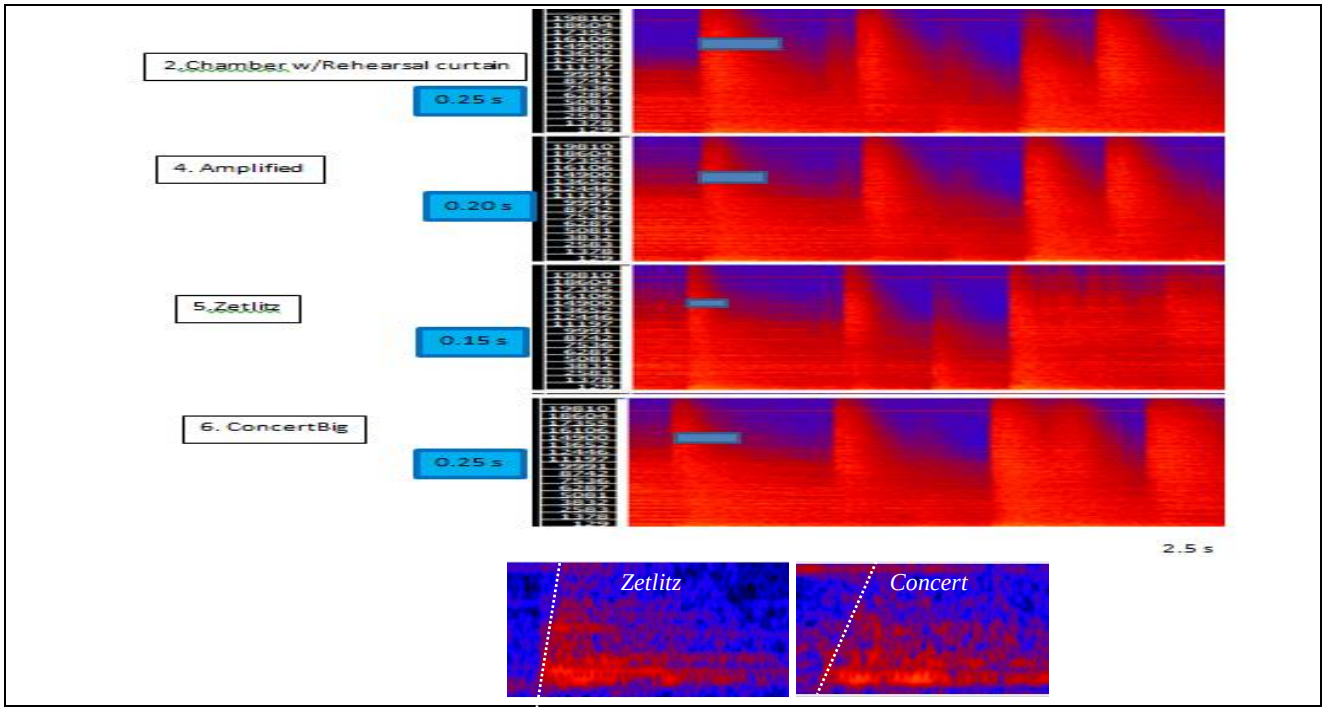

Fig. 5. Spectrograms with indication of Note duration for the different settings, for drums solo. Lower pane: Zoom in on Drum stroke in *Zetlitz* (left) and in *Concert* (right). (0.5 s) Observe that attack for high frequencies are "delayed" in *Concert*

This analysis clearly shows longer decay in reverberant *Concert*, and also longer/softer attack.

3.4.3 Attack Time Guitar

The guitar is a good instrument for analysing attack. The guitar did not play any *a cappella* parts, but a dry guitar lick (without distortion pedal) was convolved with a very moderate reverberation (like in *Zetlitz*), and with the long impulse response measured in *Concert*.

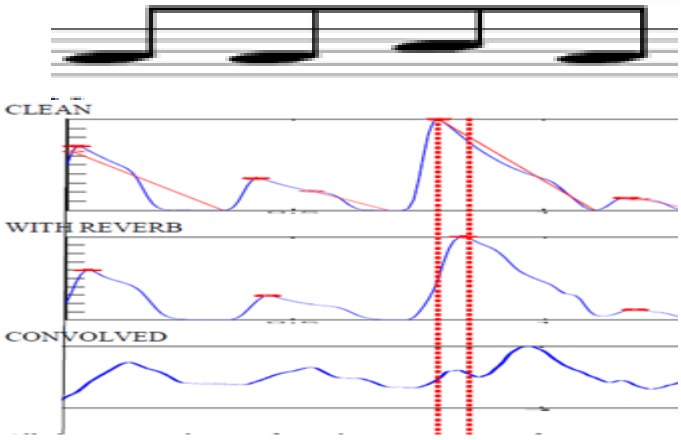

Fig. 6 Attack for clean guitar (upper), convolved with short reverb (like Zetlitz), and convolved with measured impulse response for 6.Concert (lower)

We clearly see how the reverberation smoothens the attack (even though Valen concert hall has more early reflections than most concert halls).

3.4.4 Note Length, Strings

Figure 7 shows Peak Frequency Spectrogram for *Chamber*, and *Concert*. For the chosen setting of Gain and FFT-window for this spectrograms, the length of the cello pizzicatos (*C#*s and *G#*s) are shown to be about 50% longer in *Concert* compared to *Chamber*. In *Concert*, strings are perceived

to be stronger, more «round», because they are longer, even if additional analysis of spectral centroid etc. does not show that much difference. Tempo MM: half note=60.

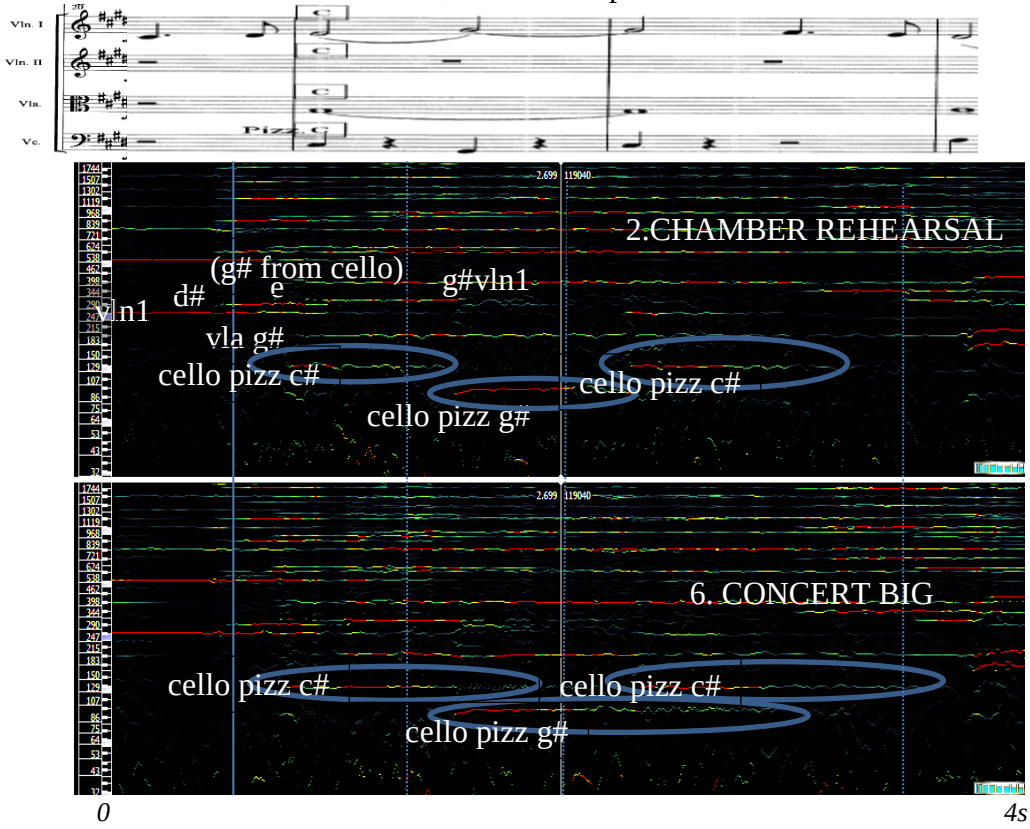

Fig. 7 Spectrogram of strings (Mahler)

3.4.5 Note Length, Trumpet and Piano

The trumpet is difficult to analyse, because it is problematic to distinguish between the actual performed note length and the decay. Fig. 8 shows the start of the trumpet *a cappella* (Mahler 5th).

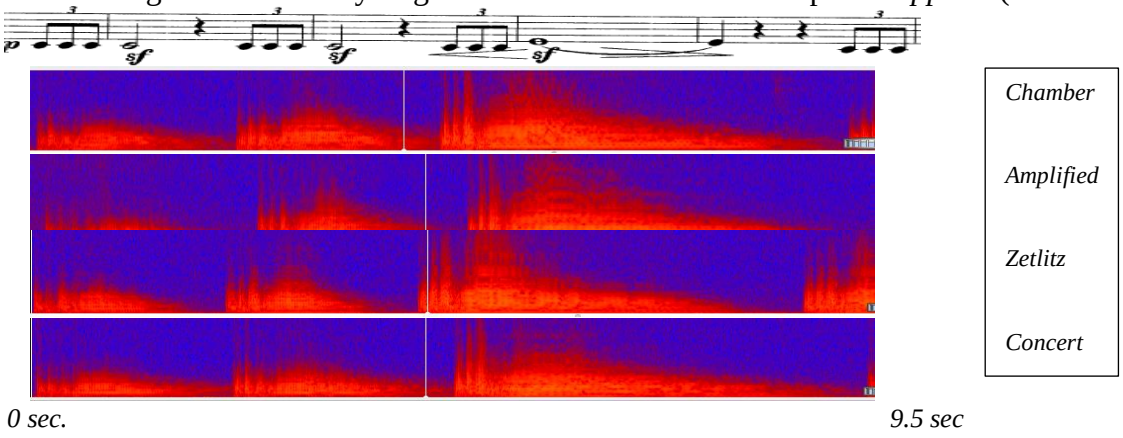

Fig.8. Spectrograms (0-8kHz) of trumpet solo *a capella*, for the different settings

We see that all the decays are all longer in the three settings of Valen (2,4,6). (The fact that the decay of the solo trumpet appears longer in *Chamber* and *Amplified* than in *Concert*, might be an artefact because the performed overall sound pressure for the trumpet part was somewhat lower in *Concert*. It might be noticed that that the very shortest tones in *Zetlitz* seems longer than for the other settings. This is the trumpeter´s way of compensating for the lack of reverb in *Zetlitz.* The trumpeter clearly commented on the difficulty of playing the *a cappella* fanfare in the short reverberation in *Zetlitz*. Additional discussions about note lengths are given in [2]. The following figure

shows the spectrogram of the piano improvisation part of the swing jazz trio. Upper=*Zetlitz.* Lower=*Concert.* (300-4000 Hz, log scale).

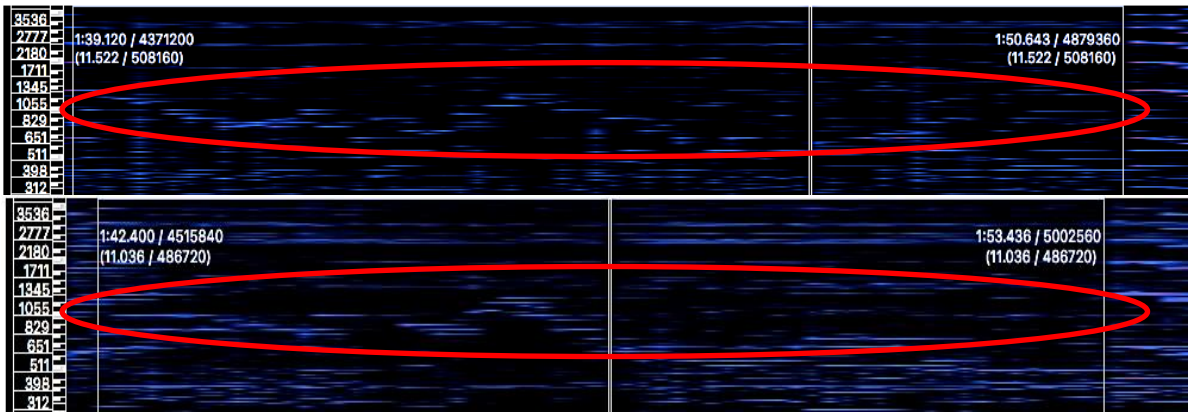

Fig.9. Spectrogram of jazz piano (w/bass and drums)

We see that for the **jazz piano** parts, the **decay of the most reverberant settings will "mask" the following (also prolonged) attack. This is the main reason for the "timbral" change clearly perceived both in the halls and listening to the recordings.** (Unfortunately, *mir* was not able to detect each attack/delay for the jazz piano part when the bass+drums were playing).

4. TEMPO

The tempo was highest in *Zetlitz* (with the shortest reverberation time), app. 5% faster than in *Chamber.* The trumpet also plays his fanfare-intro faster in the "dry" *Zetlitz.* He reported problems regarding lack of "feedback" from this room, and from fig. 8 we can see that he actually prolongs his notes in order to compensate for the lack of reverb. (Surprisingly we found that the tempo was high also for *Concert*, even if this setting has the longest reverberation time. The reason might be that this was the last recording before "going home", or that the faster tempo from *Zetlitz* was "still in the blood" of the musicians).

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5. AUTOCORRELATION AND INTER-AURAL CORRELATION

For analysis autocorrelation over the whole composition, the differences are not big, but there is an indication that the most reverberant setting, *Concert*, has the highest autocorrelation for "time lag" ("*tau*") around 0.6s-1.4s. The "dry" *Zetlitz* seems to have the highest autocorrelation for time lags around 0.5s and ca. 1.5s. Using "mirautocor" for shorter time ("time lag" to 0.2 s) shows that "mirautocorr" "time lag"/"tau" is higher in *Zetlitz* than for *Concert.* This might indicate that the non-correlated reverberation dominates much earlier in Valen than in the dry Zetlitz. Autocorrelation of recordings (and impulse responses) from concert halls should be further investigated with respect to attack/early reflections. (PS! In Fartein Valen the amount of early lateral reflection is measured to be higher than many comparable halls, for all the settings in this investigation).

The recordings were not binaural. However, we might get an idea about the "stereo-width" analysing the *cross correlation* between the 2 microphones on the top of the Zoom recorder: *"Almost IACC"* (Between mics, not binaural). For drums solo we find: *Chamber:* 0.90, *Amplified:* 0.89, *Zetlitz:* 0.92, *Concert:* 0.86. The measurements in the Acoustic Measurements Report (Kahle Acoustics) for Valen showed a value for $1\text{-}IACC_{0\text{-}80ms}$ of app. 0,65 giving a $IACC_{0\text{-}80ms}$ of 0.35. It is natural that our simplified "stereo" recordings give higher correlation between the two ordinary microphones on top of the hand held Zoom recorder, compared to these standardised binaural measurements, so the exact numbers from our *"almost IACC"* analysis from the recordings are not of interest. However, we can compare our different settings, and we see an

increased "envelopment" (lower correlation) in Valen *(Concert*) compared to the dampened *Zetlitz* and the less reverberant setting of Valen (*Chamber*).

6. SPECTRAL FLUX

Spectral Flux is defined as the change in the spectre from one frame of the analysis to the next, and is often used as a parameter for how clear the onsets are perceived.

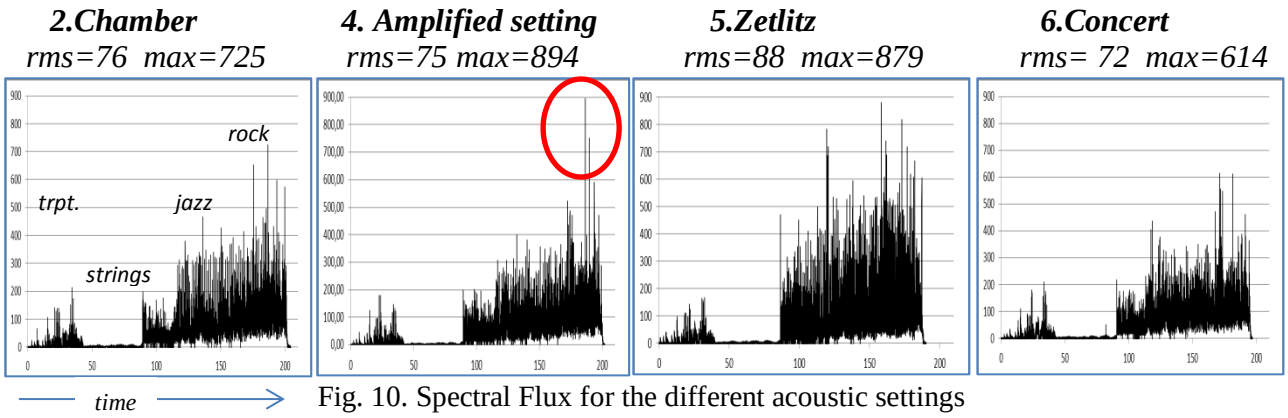

Fig. 10. Spectral Flux for the different acoustic settings

We see that the spectral flux is highest for *Zetlitz* (apart from a single strong stroke in *Amplified*, marked with red circle). This is in good agreement with the perceived attack. (PS! It is interesting that for the "slow attack" instruments; the strings, the spectral flux seems to be equally high (or even higher) in the reverberant settings; *Chambe*r and *Concert*).

7. CONCLUSION

All the musicians, audience and people who listened to the recordings appreciated the excellent and highly flexible acoustics of Stavanger Concert Hall. The settings used in this test were chosen in order to hear and investigate the room acoustics extremes. The setting *Chamber* was appreciated both for trumpet solo and the string quartet. For jazz and especially rock, the much less reverberant *Zetlitz* was clearly the favourite, with *Amplified* as a good alternative. The setting with the longest reverberation time and the largest room volume, *Concert*, was included for the test, but was much too reverberant for jazz and rock, and also "a bit too much" for trumpet solo. In this test, with the extreme dynamic changes between jazz/rock/trumpet and the string quartet, the *Concert* setting was perceived as "perhaps good, probably Too Much" for the string quartet, and *Chamber* was a better choice. This shows that the design of the halls fulfil the demanding brief for the project. The early reflections in Stavanger give quite short attack time compared to other concert halls, but how to achieve both short attack time and long reverberation in general should be investigated further. Attack times are not easily measured for polyphonic music, but spectral flux seems to be a parameter that could be used to detect if the room reacts "too slow". Attack is discussed further in [5].

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