THE ACOUSTIC DESIGN OF A MULTIPURPOSE HALL

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1 INTRODUCTION

This paper presents the acoustic design of a 285-seat multipurpose hall at Kangasala Art Centre in Finland. Kangasala, a small municipality located next to Tampere-city wanted to create an art venue for a wide variety of high standard performances to liven up the quiet town. The design goal was to create a multipurpose hall for different kinds of events varying from movies and theatre performances to acoustic and amplified music.

In addition to the acoustic design, also the functional design of the hall was commented on in the early phase of design. Particular emphasis was laid upon the support facilities and their logistics and demand. These spaces, such as foyers, green rooms and control spaces, are of utmost importance regarding the function of the hall. Also, the audiovisual systems were taken into account in the early phase of design to make sure they became an integral part of the function of the hall and the whole Art center.

Figure 1 Kangasala-hall, Akukon Oy

2 ACOUSTIC DESIGN OF THE MULTIPURPOSE HALL

2.1 Background

The goal for the acoustic design was to create a hall that provides good acoustic conditions for events varying from speech performances to acoustic and amplified music. The hall was designed as multifunctional space, using variable acoustics.

The hall was designed as mainly concrete structure. This had to be considered in acoustic design and material choices, to ensure sufficient amount of absorption at low frequencies. The other challenge was metal net curtains designed by the architect. These curtains were designed to hang in front of every wall. Behind these curtains, only circa 300 mm deep space was left for acoustic treatment and for audiovisual equipment's, electricity and ventilation.

The hall is roughly 16 meters wide, 23 meters long and 11 meters high. The rear wall of the stage is tilted. There is no actual proscenium on the stage; when it is needed, the proscenium will be made with stage curtains. The stage curtains can be moved to storage, so they do not affect the acoustics of the hall when they are not needed.

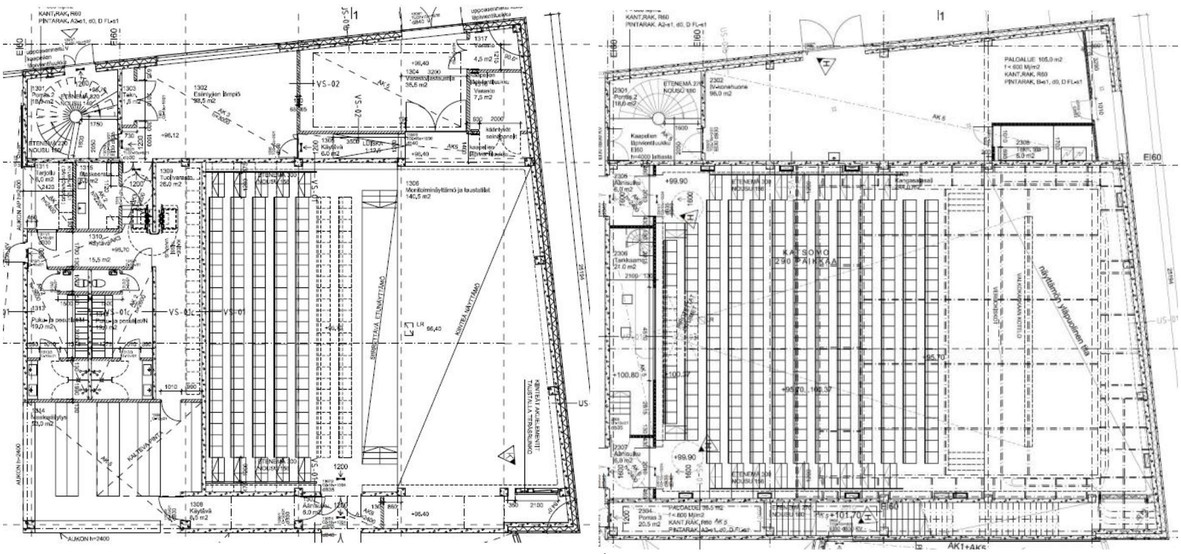


Figure 2 Architect plan, Kangasala- hall, 1st and 2nd floor

The audience area consists of two parts, a stationary back part and flexible front part. The stationary audience area is steep and has been casted from concrete on site. The steep angle provides good sightlines to the stage and the direct sound can reach every member of the audience. The front part is made with lighter structure, so that it is easier to take apart and replace with adjustable seating area in the future. This would make it possible to change the size of the stage for different kinds of productions. There are 13 rows in the hall and the distance between the rows is one meter. A light structured stage is built on top of the pit, to enable a building of a stage lift mechanism in the future phase.

Figure 3 Kangasala-hall, section drawing. The steep audience area and its construction.

2.2 Design goals

The following values were used as a direction of the acoustic design of the hall. The values are design guidelines for different uses, for a hall of this size.

Classical music:
- Reverberation time (T_{60}): around 1,6 seconds (for the chamber music 1,3 seconds)
- Early Decay time (EDT): should be maximum 30 % shorter than reverberation time
- Clarity (C_{80}): between – 3dB and +4 dB
- Classical music needs some sound diffusion; opera more, especially on the stage
- Reflectors for the early reflection are needed, especially for the opera singers

Amplified music:
- Reverberation time (T_{60}): < 1 second (rather < 0,8 second), for the lower frequency the reverberation time should remain as short
- Early Decay Time (EDT): should be maximum 30 % shorter than reverberation time
- Clarity (C_{50}): 3 – 4 dB

Theatre and other speech performances
- Reverberation time (T_{60}): 0,8 – 1,0 seconds
- Speech intelligibility index (STI): < 0,6, note that the background noise effects the speech intelligibility
- Clarity (C_{50}): 3 – 4 dB.
- It is important that there will be support reflections for the performer, and early reflections for the audience. Hence reflection surfaces are needed, especially above

Movie:
- Reverberation time (T_{60}): around 0,5 – 0,6 seconds
- Clarity (C_{50}): 3 – 4 dB

2.3 Acoustic design

For the side walls of the hall it was designed single and double board structures, with varying depth. These enable the control of the lower frequency absorption. The variations of the depth (150 – 200 mm) create also diffusing surface. The width of the elements changes between 300 – 900 mm and is carefully designed to leave space for technical installations, since the space behind the metal net was limited. The elements can be seen in architects section drawing in Figure 3.

The adjustable acoustic was designed with heavy curtains with mechanical adjusts. The curtains are located on the side and rear walls, with two transverse curtains in the ceiling. Curtains are motorized roller curtains, that must carry their own weight and bear the stretch from the guide rail. All the curtains have their own case or storage place, so they won't affect to the acoustics when they are not needed. The curtains are separated in five control groups, from which two of are motorised, two manual and one for the curtains in the ceiling. There are no extra absorbing curtains in the stage besides the normal stage curtains.

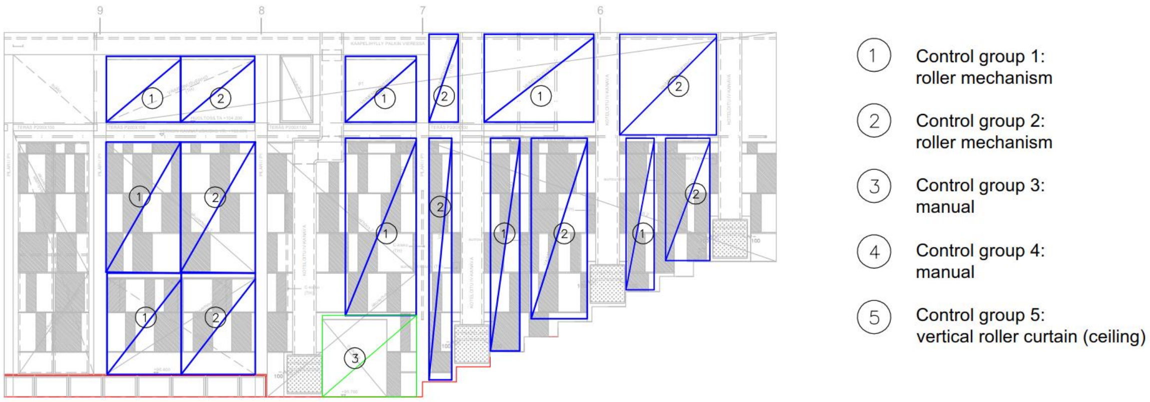


Figure 4 Example of the adjustable curtain (location and control group) in the side wall

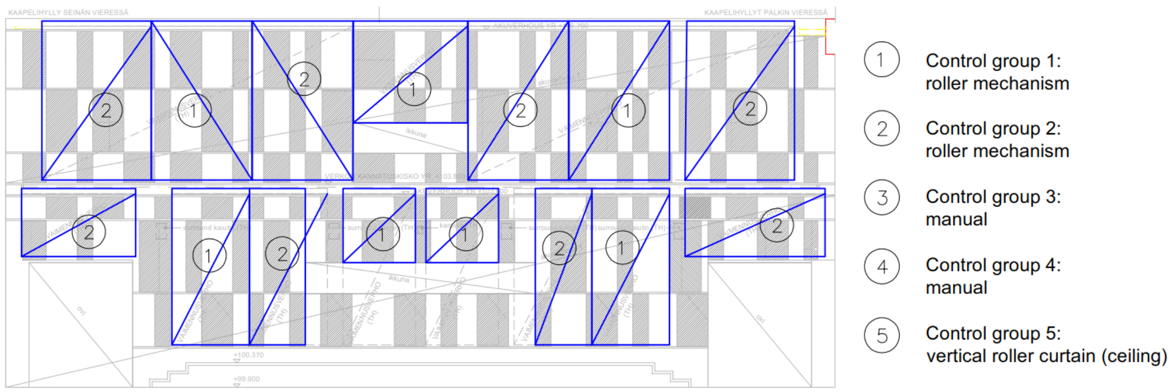


Figure 5 Example of the adjustable curtain (location and control group) in the rear wall

The interior architecture of the hall is created with a metal net placed in front of acoustic elements and technical installations, as mentioned earlier. To enable as high acoustic adjustability as possible, the net was chosen to be as acoustically transparent as possible. The different options for the metal net were measured, and the net whose perforation was more than 50 % was chosen to ensure the acoustic transparency. In addition to the danger of acoustic reflections, too tight net in front of the hard wall would increase the absorption of high frequencies. Since the amount of the net in the space is huge, effect to the absorption in the hall would be significant, lowering the reverberation time at high frequencies. This would affect especially to the acoustic music performances, where the timbre of the hall would lose its brightness.

Reflecting and diffusing elements were designed for the ceiling to ensure early reflections and speech intelligibility.
(see Figure 3 section).

The floor of the hall is hard parquet on top of concrete. The stage floor is medium hard 45 mm solid wood, with 500 mm air space filled partly with absorbing material.

3 COMPUTER SIMULATIONS AND FINAL MEASUREMENTS IN THE HALL

Acoustic model was made to support the design process, using Odeon-software. Model was used to investigate the impact of different materials and adjustable elements to the acoustic conditions of the hall. Room acoustic measurements were conducted after the finalization of the project.

3.1 COMPUTER SIMULATION

This paper presents only one version of the results of the acoustical computer simulation. Investigating the actual effect of the variation of the wall elements was challenging. In the final version of the simulation the geometry of the wall elements was modelled in detail. The metal net was not included in the computer simulation, since the material measurement and investigation verified that they do not influence the acoustical condition of the hall. The source and receiver points were the same in the model and in the final measurement (see Figure 6).

Below (Table 1) are some values of the acoustical parameters from the computer simulation.

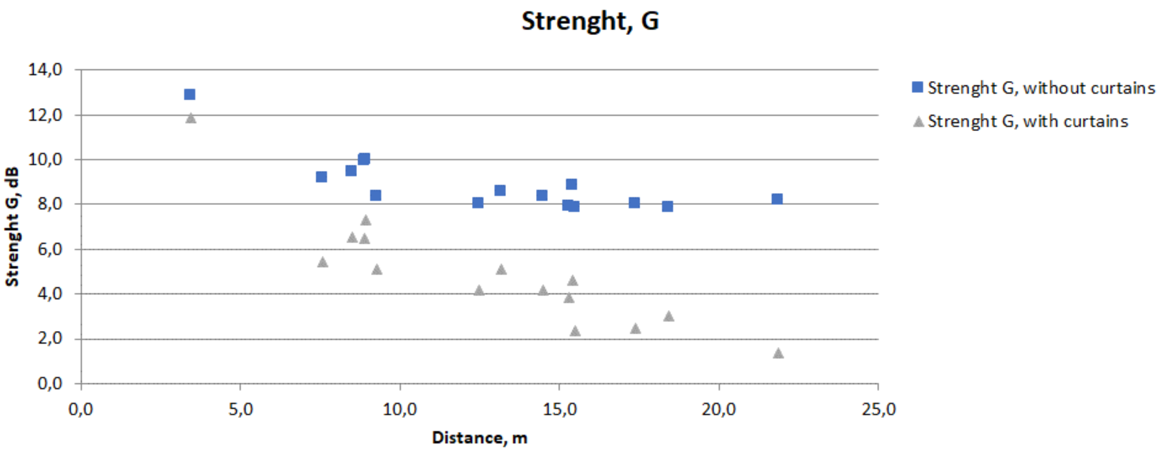
Table 1 result from the acoustic 3D-modelling of Kangasala-hall

Parameter	Hall without curtains	Hall with curtains
Reverberation time, $T_{30,\ 500\text{-}1000Hz}$	1,5 s	0,8 s
Early decay time, $EDT_{500\text{-}1000Hz}$	1,4 s	0,7 s
Clarity, $C_{80,500\text{-}2000Hz}$	2 dB	7,4 dB
Clarity, $C_{50,500\text{-}2000Hz}$	- 0,5 dB	4,4 dB
STI [1)]	0,5	0,6
Stage Parameters:		
ST_{Early}	- 11,7 dB	-13,4 dB
ST_{Late}	- 13,4 dB	- 17,9 dB
ST_{Total}	- 9,4 dB	- 12 dB
Early decay time on stage, $EDTP_{500\text{-}1000Hz}$	1,4 s	0,7 s
Clarity, $C_{80,500\text{-}2000Hz}$	2,8 dB	7,9 dB
Clarity, $C_{50,500\text{-}2000Hz}$	1,5 dB	5,2 dB

1) Background noise level $L_{A,eq}$ = 33 dB (measured), sound level from the source $L_{A,eq}$ = 67,3 dB

Values of strength (G) are shown as a figure instead of single value, since it varies greatly according to the distance.

Table 2 Strength G as a function of distance from the computer simulation



3.2 FINAL MEASUREMENTS

Final measurements were made in the hall with and without curtains. In both measurement there were two ceiling reflectors above the stage. Source (S1-S3) and receiver (R1-R5, P1-P3 and S1 1m, S2 1m and S3 1m) points were according to A. C. Gade [3]. Figure 6 shows source and receiver positions used in the measurements. During the measurements the temperature was 21 degrees celsius and humidity was 47 %.

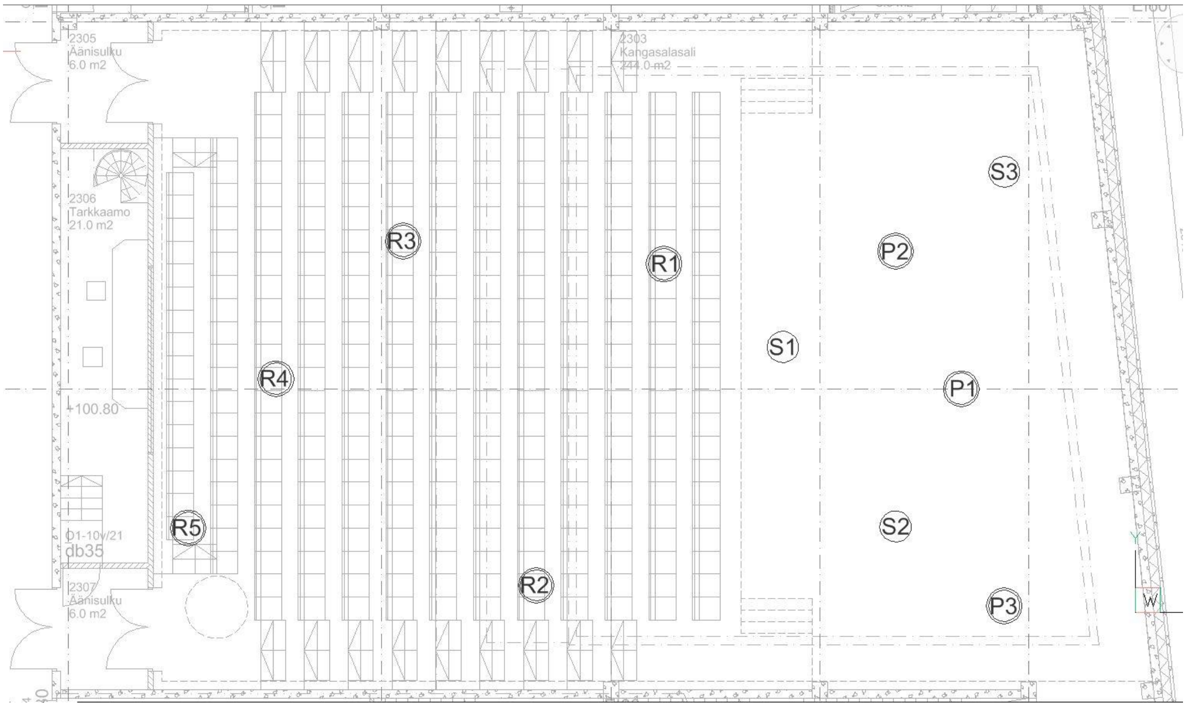


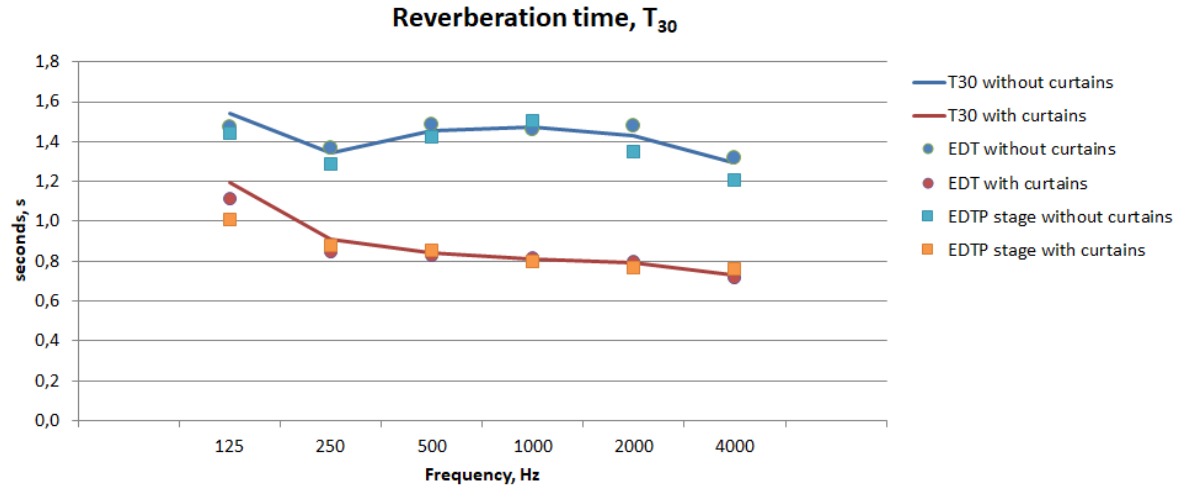
Figure 6 Measurement positions in the Kangasala-hall, Source positions S1-S3, receiver positions R1-R5, P1-P3 and S1 1m, S2 1m and S3 1m.

3.2.1 Reverberation time (T_{30}) and Early decay time (EDT)

The reverberation time and early decay time affect liveness of the hall, especially at mid and high frequencies (more reverberant the hall is, more live it sounds). When reverberation time is long, it effects on experience of fullness of tone; when the reverberation time is short it is experienced as a thin timbre [1], [5]. The long end of the impulse response is experienced as liveness [1]. Reverberation time together with strength (SPL) at low frequencies affect how warm we experience the hall to be. When the reverberation time is longer at low frequencies compared to other frequencies, the sound will be experienced as warm and full bodied [1]. And the other way around: the longer reverberation time in high frequencies is experienced as rise in brilliance.

Because the reverberation time does not fully describe the reverberation in the hall, the early decay time (EDT) has been taken into account. Early decay time on stage (EDTP) has been noticed to correspond to how the musicians sense the reverberation. The value of EDTP is normally 30 % less than EDT. [1], [5] However, the closer the values are to one another, the closer the musicians sensation of the reverberation is to the perceived reverberation in the auditorium.

Table 3 reverberation time (T30), early decay time in audience (EDT) and on the stage (EDTP) with and without the curtains.



As we can see from Table 3, the average reverberation time is about 1,4 seconds without curtains and 0,8 seconds with curtains. Both early decay time curves follow nicely the reverberation time curve, which means that the musicians sense the reverberation of the whole hall.

Bass ratio (BR), which describes the warmth of the auditorium, is 1, when there are no curtains in the hall and treble ratio 1,1. This means that the resulting reverberation hall is flat. With the curtains on, the bass ratio is 1,3 and treble ratio 1,1.

3.2.2 Clarity (C_{80} and C_{50})

Parameter of clarity (C_{80}) describes the ratio between the early reflected energy and late energy [1]. Clarity of sound should be sufficiently high, so that every part of the music can be heard with definition, also in fast moving passages. If the clarity is too high, each sound and tone can be heard separately, and they will not merge together to create a full sound. This parameter is particularly important for an ensemble. [5] For speech venues and for amplified music, the used parameter is C_{50} [6].

The clarity (C_{80}) without curtains is around 1 dB at mid frequencies and with curtains around 6 dB. According to measurement results, the hall has quite good definition, also without curtains.

Table 4 Clarity C_{80} in the Kangasala-hall with and without curtains

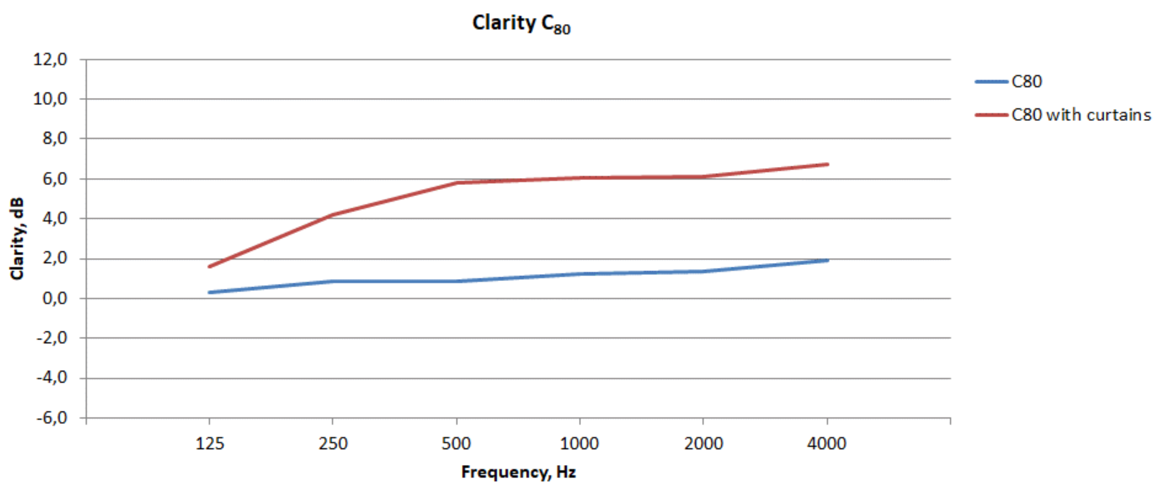
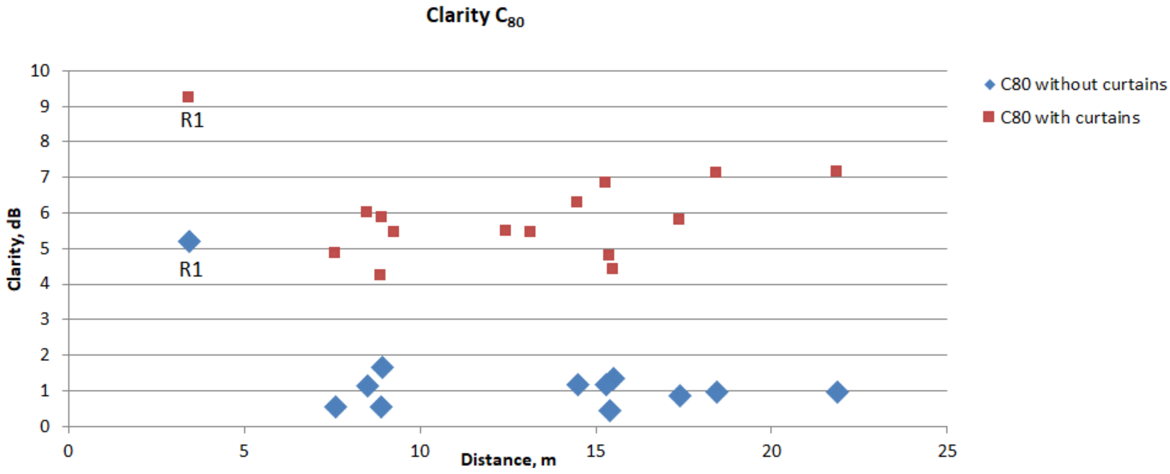


Table 5 Clarity C_{80} as a function of distance in the hall, with and without curtains (receiver point R1 have been pointed on the table)



3.2.3 Speech intelligibility index (STI)

The speech intelligibility index tells how comprehensible the speech is. Values are between 0 – 1, where 1 means that all the syllables will be perfectly comprehensible. [3] The background noise level and sound level of the speech, reverberation time, distance between speaker and receiver and speaker's directivity all have an influence on STI.

The speech intelligibility in the audience area is around 0,5 when there are no curtains. When curtains are added, the value arises on average to 0,7. On the stage area, the average value of STI is 0,6 when there are no curtains in the hall, and rises to 0,7 when curtains are deployed. As a result, the speech is distinctive in the audience and on the stage when all the curtains are in use.

Table 6 Speech intelligibility index as function of distance in audience

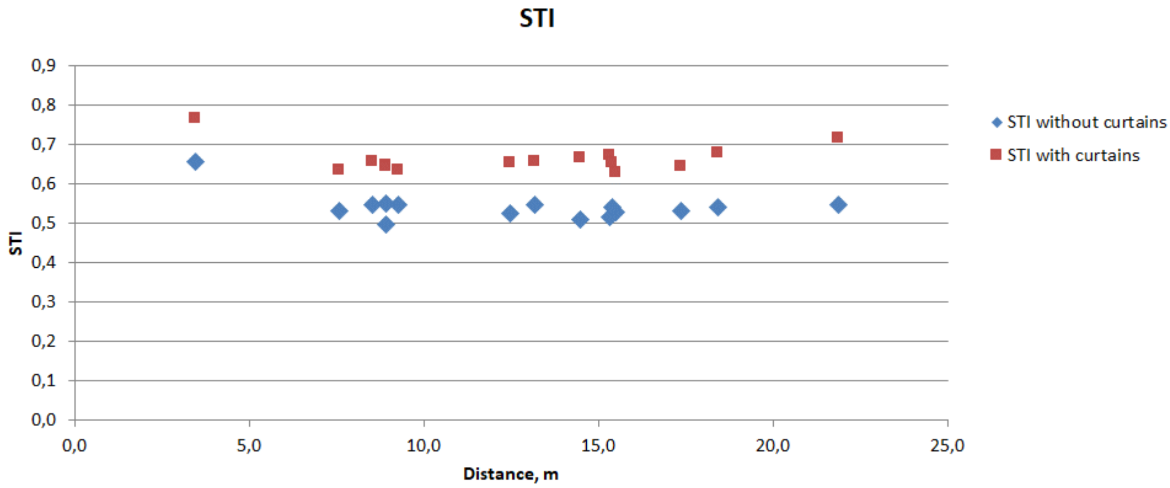
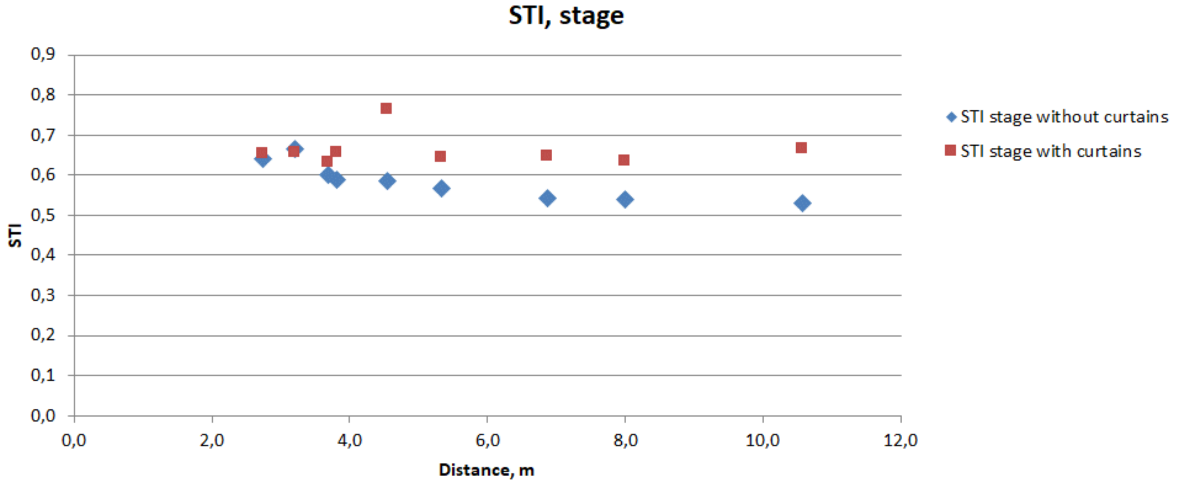


Table 7 Speech intelligibility index as function of distance on stage



3.2.4 Stage parameters

ST_{Early} describes ensemble situation on stage, ie how easy it is to hear another musician. ST_{Late} describes how musicians sense the reverberation on stage. ST_{Total} describes the support of the room to the musicians own instrument. All support parameters should be around -10 dB, but not below -17 dB. [5] The stage parameters were measured with omni-directional microphone (S1 1m, S2 1m, S3 1m), one meter away from the source.

Table 8 Stage support parameters ST_{Early}, ST_{Late} and ST_{Total} on stage, when there are no curtains in the hall

Parameter	S1 1m	S2 1m	S3 1m	**Average**
ST_{Early}	- 11,4	- 10,7	- 9,3	**- 10,5**
ST_{Late}	- 11,9	- 11,3	- 12,4	**- 11,9**
ST_{Total}	- 8,6	- 8	- 7,6	**- 8,1**

According to Table 8 (above) the members of the orchestra can hear each other easily and sense the reverberation of the hall on stage. The room support for the musician’s own instrument is good, because of hard reflecting surfaces on the stage.

On the stage the average clarity (C_{80}) between 500-2000Hz frequency range is 3,2 dB, and the average C_{50} is 1,1 dB, respectively. The early decay time on the stage (EDTP) is 1,4 seconds. These parameters correlate nicely to each other, and resulting acoustic environment makes the ensemble work easy, as the musicians can easily hear and distinguish each others’ instruments and playing.

On stage, when all the curtains are in use, the clarity C_{80} between 500-2000Hz is around 8,7 dB, while C_{50} (500-2000Hz) is around 5,6 dB. The early decay time (EDTP) on stage is 0,8 seconds. These values correlate well with very clear ensemble.

According to Table 9 below, when all the curtains are in use, orchestra members hear each other easily. The sense of reverberation naturally decreases when the hall is dry. The hall still gives enough support to the stage, despite that there are curtains on the stage.

Table 9 Stage support parameters ST_{Early}, ST_{Late} and ST_{Total} on stage, when there are curtains in the hall

Parameter	S1 1m	S2 1m	S3 1m	**Average**
ST_{Early}	- 14,5	- 13,4	- 13,8	**- 13,9**
ST_{Late}	- 19,1	- 17,4	- 20,1	**- 18,9**
ST_{Total}	- 13,1	- 11,9	- 12,9	**- 12,6**

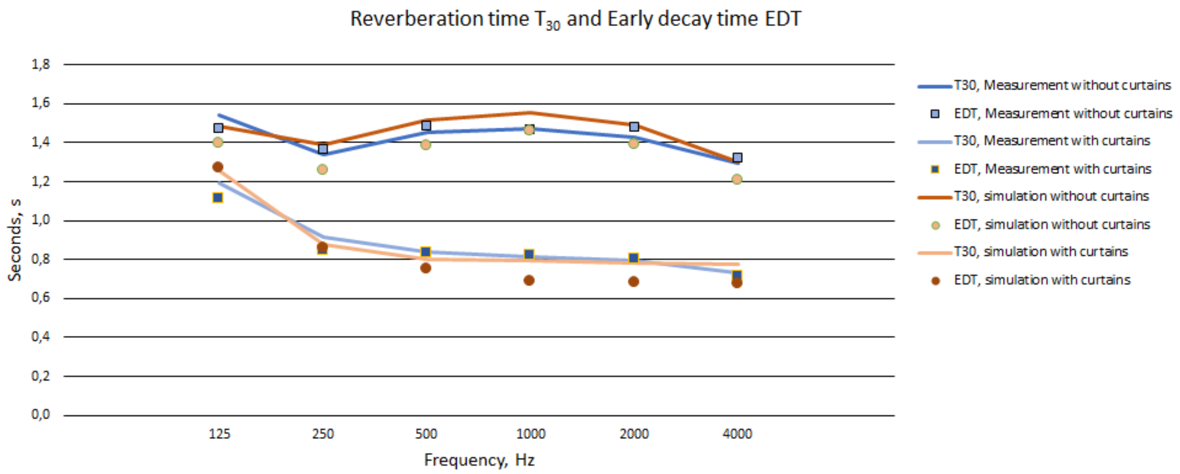
3.3 Comparison of computer model and measurements

The results from the computer model do not differ greatly from the measurement results, as can be seen below from Table 10.

Table 10 The comparison of the acoustical parameters between computer simulation and measurements from the Kangasala- hall

	Computer simulation		Measurements	
Parameter	without curtain	with curtain	without curtain	with curtain
Reverberation time, $T_{30,\ 500\text{-}1000Hz}$	1,5 s	0,8 s	1,5 s	0,8 s
Early decay time, EDT $_{500\text{-}1000Hz}$	1,4 s	0,7 s	1,5 s	0,8 s
Clarity, $C_{80,500\text{-}2000Hz}$	2 dB	7,4 dB	1,1 dB	6 dB
Clarity, $C_{50,500\text{-}2000Hz}$	- 0,5 dB	4,4 dB	- 1,4 dB	3 dB
STI [1)]	0,5	0,6	0,5	0,7
Stage Parameters:				
ST_{Early}	- 11,7 dB	-13,4 dB	- 10,5 dB	- 13,9 dB
ST_{Late}	- 13,4 dB	- 17,9 dB	- 11,9 dB	- 18,9 dB
ST_{Total}	- 9,4 dB	- 12 dB	- 8,1 dB	- 12,6 dB
Early decay time on stage, EDTP 500-1000Hz	1,4 s	0,7 s	1,5 s	0,8 s
Clarity, $C_{80,500\text{-}2000Hz}$	2,8 dB	7,9 dB	3 dB	9 dB
Clarity, $C_{50,500\text{-}2000Hz}$	1,5 dB	5,2 dB	1 dB	5,6 dB

Table 11 Comparison of results of reverberation time and early decay time from computer simulation and measurements



Noteworthy was, that estimation of the correct absorption of the ceiling had a great influence on the results of the modelling. Because of the small size of the hall, the chosen absorption coefficient of the ceiling influenced the results much more than with a larger concert hall. An average absorption coefficient used for the concrete ceiling, performance equipment and HVAC-installations was 0,3 and the scattering coefficient in Odeon was 0,3.

When comparing different model versions, it was noticed, that the model version where the side wall elements were modelled in detail, corresponded best to the measured reverberation time T_{30} values. Drawn from this, it seems that at least for a hall this size, it would be good to make a detailed enough model. If the scattering surfaces are modelled as simple flat surfaces, with only scatter values used to compensate the diffusion of the elements, the modelled prediction might differ noticeably from the finished hall.

4 REVIEWS

The Kangasala- hall got good reception and feedback from musicians, audience members, as well as from staff-members. Some comments that were published in Finnish are translated below.

“Kangasala Art Center impressed with transformable auditorium, versatile and sculptural appearance”, Kaija Saariaho (finnish composer)
“No problem… it works perfectly fine with just this sized orchestra (writers note: the orchestra in question has 60 musicians).” Santtu-Matias Rouvali, Chief conductor of Tampere Philharmonic orchestra, answer to question from reporter; how hall works with Philharmonic orchestra.
“A positive surprise. When I arrived here, I thought that the hall is quite small. But musicians can hear each other well and everything works.” Joonas Pulkkinen, Solo cellist of Tampere Philharmonic orchestra.
“It felt as if the audience and orchestra lived and breathed the music within a common experience The same would probably not happen in a bigger concert hall.” Jyrki Lähteenmäki, Doctor of Music.

5 REFERENCES

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