Yann Jurkiewicz, Henrik Möller, Perttu Laukkanen, Eckhard Kahle, Sara Vehviläinen 14.4.2022

Turun Musiikkitalo

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Turun musiikkitalo

SALIEN AKUSTISTEN TAVOITTEIDEN MÄÄRITTELY – ACOUSTIC BRIEF

LAADUNVARMISTUS

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Kirjoittaja

MSc Yann Jurkiewicz

Kirjoittaja

DI Henrik Möller

Kirjoittaja

DI Perttu Laukkanen

Kirjoittaja

BA Sara Vehviläinen

Dokumentin tarkastaja

TkT Eckhard Kahle

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This Acoustic Brief sets out the acoustical aims for the project with specific and detailed acoustical description of the main Concert Hall and the Small Hall. The ambition of this Brief is to establish the highest possible standards in acoustic quality while enabling both an architecturally and acoustically creative design concept to be developed. The acoustical aims are therefore described in both architectural and technical acoustical terms.

The main acoustical aims for the Concert Hall, as described in the Acoustic Brief, are the following:

- Concert Hall of exceptional (acoustical) quality worldwide. The hall will be able to accommodate large orchestral ensembles, together with choir and organ.
- The main use of the Concert Hall will be orchestral concerts for symphonic music.
- Enveloping reverberation: with every audience member feeling that they are immersed in sound and inside the music, rather than looking in.
- Excellent level of clarity and definition: for both players and audience, and even with the required long reverberation.
- Strong and “tight” bass sound.
- Warm tone colour: a rich, warm sound is desired.
- An “open” and engaging sound, that can sometimes get very loud for the largest orchestral forces, while retaining an open and uncompressed sound quality.
- An intimate performer-audience relationship, with some reasonable proportion of audience surrounding the stage, combined with an acoustical character incorporating the best qualities of historic shoebox halls. The result is a hall geometry with a majority frontal audience, arranged over multiple balconies, and 10 to 20% of the audience wrapping around the stage: a so-called “Hybrid Shoebox”.
- Flexible staging and variable acoustics systems are described, to enable efficient and optimised adaptations of the hall for the following uses:
    - Orchestra concerts, rehearsals, and recordings.
    - Semi-staged opera performances with various staging options.
    - Amplified performances, including cross-over and multimedia uses with video projection.
    - Accommodation for an organ and a choir.

In technical terms, the key aspects of the Concert Hall acoustics are:

- An occupied reverberation time of 2.0 to 2.3 seconds.
- Acoustical volume of 18,000 to 20,000 m^3.
- Height of at least over 20 m above the stage, with the width of a similar dimension to the height.
- Optimisation and balance of the early and late sound fields, including:
    - Optimized projection from the stage to the audience and optimized early reflections generated through specific and detailed angling and shaping of the surfaces of the hall.

- An “acoustic centre” of the hall (i.e. the main reverberant volume of the room) in the audience area and not over the stage, to enhance acoustical envelopment and engagement for the audience.

- Optimized orchestral balance with homogenous stage support (ST1) across the stage and without excessive levels at the percussion and brass.

The main acoustical aims for the Small Hall, as described in the Acoustic Brief, are the following:

- The space shall be designed as a flexible, frontal space for Chamber Music Concerts, Jazz Concerts and other events.
- Orchestral rehearsals must be possible in this space under good conditions, for a maximum orchestra size of approximately 70 musicians. For symphony orchestra rehearsal, the space can be used in flat floor mode and it is acceptable that the layout will be turned 90° for this use.
- Given that this space will be used for both non-amplified and amplified events, and will be used for orchestra rehearsals, it is clear that the hall will need relatively extensive variability, concerning both acoustics and with respect to seating/layout.
- Variable reverberation time between at least 0,9 – 1,7 s, for the non-occupied room.
- Strength G less than 11 dB (for seats more than 10m from the source on stage)
- Variability in the acoustics of the room. This variability shall provide more than a simple change of reverberation time (by using acoustic curtains or other absorbing material, or by adding artificial reverberation via an electronic system). The acoustic volume, loudness, lateral energy and potentially also the spectral balance and/or orchestral balance should also be variable.
- Flexibility in the architecture of the room. In some cases, these modifications can be minor, in other cases, they will have to be major to cover the wide range of uses. The simple reason for that is that each performance there is an associated set of needs and often a different relationship between the audience and the artists. To address this issue correctly, one must also respect the expectations of the public, which also vary with the type of performance.

The success of the project depends to a large extent on a good collaboration within the design team and between the design team and the client. Excellent acoustics <u>must be embedded and integrated into all architectural and technical design tasks and considerations: fulfilling the Acoustics Brief is therefore NOT a separate task but integral to the building design</u>. The acoustical quality of a hall is not superficial or skin deep, it cannot be applied with materials and textures, but comes from the fundamental geometry of the hall. Acoustical excellence must be in the very bones and structure of the concert hall. For this reason, we recommend that every member of the client team and design team should read the Acoustic Brief.

YHTEENVETO SUOMEKSI

Tässä dokumentissa esitetään Turun musiikkitalon Konserttisalin sekä Pienen salin akustiikan tavoitteet. Akustisen suunnittelun lähtökohtana on maailmanluokan huoneakustiikka yhdistettynä korkealuokkaiseen arkkitehtuuriin. Akustiset tavoitteet on kuvattu sekä sanallisesti, että akustisin mittaluvuin.

Konserttisalin akustiikan tärkeimmät tavoitteet ovat seuraavat:

- Maailmanluokan saliakustiikka. Konserttisalissa pitää pystyä esittämään suurille orkestereille kirjoitettua musiikkia tarvittaessa kuoron ja urkujen kanssa.
- Konserttisalin pääkäyttötarkoitus on sinfonisen musiikin konsertit.
- Ympäröivä jälkikaiunta: Jokainen yleisössä tuntee istuvansa musiikin ympäröimänä, eikä katsovansa ulkopuolelta musiikkia edessään.
- Erinomainen selkeys ja erottelevuus huolimatta riittävän pitkästä jälkikaiunta-ajasta: sekä muusikoille lavalla, että yleisölle katsomossa.
- Vahva mutta samalla erotteleva matalien (basso) äänien kuuluvuus
- Lämmin ja rikas sointi
- Avoin, dynaaminen ja mukaansatempaava äänikuva, jossa isojen orkesterien fortissimot kuulostavat voimakkuudeltaan todella kovalta, kuulostamatta kuitenkaan kompressoidulta.
- Intiimi yhteys muusikoiden ja yleisön välillä, joka toteutetaan sijoittamalla pieni osa yleisöstä (10 – 20 %) lavan ympärille ja suurin osa yleisöstä lavan eteen ja parvekkeille. Tämän tyyppisessä hybridikenkälaatikossa yhdistyvät perinteisen kenkälaatikkosalin huippuakustiikka ja intiimiys.
- Muunneltava lava, sekä muunneltava akustiikka, joka mahdollistaa seuraavat käyttöskenaariot:
    - Orkesterikonsertit, harjoitukset sekä äänitystilanteet
    - Oopperaesitykset, jotka voivat sisältää videoprojisointia, liikkuvia näyttelijöitä ja lavasteita, kuitenkin ilman näyttämötornia.
    - Vahvistetun musiikin esitykset, esitykset, joissa yhdistyy vahvistettu musiikki ja akustinen musiikki ja jotka voivat sisältää videoprojisointia

Teknisinä mittalukuina tärkeimmät kriteerit ovat:

- Jälkikaiunta-aika yleisön kanssa 2.0 – 2.3 sekuntia.
- Tilavuus 18,000 – 20,000 m^3
- Salin korkeus lavan kohdalla vähintään 20 m, ja salin leveys suunnilleen korkeuden luokkaa
- Optimoitu varhaisen ja myöhäisen äänikentän suhde:
    - Optimoitu äänen projektio lavalta yleisöön. Huolellisesti suunnitellut seinien kulmat ja muodot.
    - Salin ”Akustinen keskiö” (salin merkittävin kaiuntainen tilavuus) katsomon yläpuolella, eikä lavan yläpuolella. Tämä parantaa akustista ympäröivyyttä yleisössä.
- Optimoitu orkesterin balanssi lavalla sekä lavalle tasaisesti muodostuva akustinen palaute ilman liiallista lyömä- ja vaskisoittimien äänitasoa

Pienen salin akustiikan tärkeimmät tavoitteet ovat seuraavat:

- Sali suunnitellaan muunneltavaksi Kamarimusiikkikonsertteihin, Jazz konsertteihin ja muihin tapahtumiin sopivaksi

- Sali toimii myös orkesterin harjoitussalina 70 muusikon orkesterille. Sinfoniaorkesterin harjoituksissa salia voidaan käyttää siten, että orkesteri soittaa 90 asteen kulmassa normaaliin esityssuuntaan nähden.
- Koska salissa pitää pystyä esittämään sekä vahvistetun musiikin esityksiä, että akustisen musiikin esityksiä ja salin pitää vielä toimia harjoitussalina sinfoniaorkesterille, on selvää, että saliin tarvitaan merkittävä määrä muunneltavuutta sekä akustiikan, että katsomo/istuinjärjestelyiden osalta.
- Muunneltava jälkikaiunta-aika 0,9 – 1,7 s välillä tyhjässä salissa
- Akustinen vahvistuksen mittasuure G korkeintaan 11 dB (mitattuna 10 m etäisyydellä lavalla sijaitsevasta äänilähteestä)
- Akustiikan muunneltavuus ei rajoitu ainoastaan jälkikaiunta-ajan muunneltavuuteen (verhoilla tai sähköakustiikalla). Salin akustista tilavuutta, äänekkyyttä, sivuttaisen energian määrää ja mahdollisesti myös taajuusbalanssia ja orkesterin sointibalanssia tulee pystyä muuttamaan.
- Arkkitehtoninen ja toiminnallinen muunneltavuus. Joidenkin käyttötarkoitusten osalta arkkitehtoniset muutokset voivat olla merkittäviä, sillä esityksestä riippuen orkesterin ja yleisön tilatarve vaihtelee merkittävästi, ja lava- ja katsomorakenteita pitää pystyä muuntamaan tapahtuman, orkesterin ja yleisön odotusten mukaisiksi.

Projektin menestys riippuu merkittävästi suunnitteluryhmän yhteistyön syvyydestä sekä suunnitteluryhmän ja tilaajan välisen yhteistyön toimivuudesta. Akustiikkaa ja sen toimivuutta ei voida liimata päälle erillisenä osana, vaan se on saumattomasti integroitava arkkitehdin, sekä muiden teknisten suunnittelualojen suunnitelmiin. Toisin sanoen akustisten suunnittelutavoitteiden täyttäminen ei ole erillinen suunnittelutehtävä, vaan osa kaikkien suunnittelualojen suunnittelutyötä. Konserttisalien akustiikkaa ei voi luoda pelkästään pintamateriaalien avulla, vaan akustiikka syntyy salien perusgeometriasta ja rakenteista. Tästä syystä tätä dokumenttia suositellaan kaikkien suunnittelualojen suunnittelijoiden luettavaksi.

1 INTRODUCTION

The main concert hall in the new Turku Music Centre (Turun musiikkitalo)– with a planned capacity of approximately 1,400 seats – is the heart of the project. In addition to its main symphonic use, the concert hall will be acoustically flexible, providing good acoustic conditions also for recitals, chamber music and semi-staged opera, as well as uses incorporating amplified sound, video projection and new media, such as jazz, world music and spatially and electronically manipulated contemporary music. It is clear however that the main purpose of the concert hall will remain symphony orchestra concerts, and that acoustic design has to focus on providing excellence for that core function. The secondary uses will have to be taken into considerations in the design, but whenever a conflict is identified, acoustic quality for symphony orchestra concerts will always take precedence.

The ambition of this Brief is to establish the highest possible standards in acoustic quality while enabling both an architecturally and acoustically creative, strong, and coherent design concept to be developed. The Client desires a hall that provides the best attributes of a shoebox hall geometry while improving the audience proximity and interaction with the musicians on stage.

This document is structured as follows:

- A chapter detailing the design criteria for the concert hall, providing both architectural criteria to guide architects towards a design concept that meets the desired acoustic quality, and purely technical acoustical criteria. Tables in the beginning of this chapter summarise the various architectural and acoustic criteria to be met.
- A chapter describing the characteristics of the Small hall.
- An appendix on the relationship between the subjective acoustical parameters and objective criteria sought for the design of the concert hall.

Finally, and importantly, the success of the design also depends on a good collaboration within the design team and between the design team and client. This document aims at laying the path for that good collaboration. Therefore, we have adopted a writing style which should be sufficient clear to lay readers, while staying sufficiently precise for acoustics specialists.

2 CONCERT HALL: ACOUSTIC REQUIREMENTS

The principal acoustic criteria are the first instance described in architectural and layman's terms. The goal is to provide a toolbox that establishes the acoustical goals while providing a framework within which the designers can realise their architectural concept.

The tables at the beginning of the chapter summarise the architectural-acoustic criteria as well as the specific acoustic parameter ranges and criteria for the project.

2.1 Sound Quality and Sound Aesthetic

The overarching aim for the Turku concert hall is to create a space of exceptional acoustic quality for symphony orchestra concerts.

In January 2022, a study tour was organized together with representatives of the Turku Philharmonic Orchestra. Visits were made to two recently built symphony halls in Norway: Kilden Concert Hall in Kristiansand, and Fartein Valen Hall in Stavanger, with the opportunity to listen to orchestra rehearsals. This enabled to verify the type of acoustic quality that is sought after by the client and future users. A clear outcome of that study tour was that the desired acoustic quality for the future Turku Concert Hall is very similar to that of the Stavanger Concert Hall.

In general, a warm and rich sound quality is desired, with a strong bass response.

The hall acoustic must combine excellent clarity, definition, and presence of the sound sources with a strong, present, and enveloping room reverberation. Furthermore, the resonance and reverberation of the room are planned to be variable, so that the acoustics can be optimised for different uses. This intention leads to a necessary optimisation of both the early and late acoustic responses of the room.

The desired sound quality will be acoustically “open”, dynamic, enveloping (creating a feeling of being immersed in sound) and not spatially compressed. This quality is typically found in tall shoebox concert halls where the acoustic is characterised by a long, enveloping reverberation that can develop in the upper volume of the hall above the audience due to the generous ceiling height.

2.2 Concert Hall: Summary Table of Architectural-Acoustical Criteria

Architectural Parameter	Requirement
Volume per person	Between 12.5 m^3 and 15 m^3 (ideal between 13 m^3 and 14 m^3)
Total acoustic volume	Based on the above volume per seat and the total number of seats. This results in between 18,000 m^3 and 20,000 m^3 to obtain 13 to 14 m^3 per seat for 1,400 seats
Reflective surfaces	Early efficiency: 800 to 1000 m^2 “Phase preserving reflections”: early reflection surfaces to be smooth. Can be convex curved or planar. Fine surface texture of up to 10 mm depth acceptable to provide high frequency absorption and increased warmth.
Height of the auditorium	The height shall be chosen by the design team to obtain the appropriate volume. The ceiling should not necessarily be horizontal: a projecting angle from the stage should be considered. In the context of a shoebox or hybrid-shoebox hall, a total height (omitting the acoustic reflectors) above the stage of at least 20 m is required, with potentially greater height in some parts of the hall.
Width of the auditorium	The width of the hall is dictated by the width required for the orchestra and stage, plus audience to the sides of the stage. To enable a wrapping of some audience around the stage, a width of over 22 m will be required, but it should be limited to a maximum of 24 m.
Acoustic centre	The maximum cross-sectional area of the hall should be located in the main audience area and not on stage. The largest cross-section area should be located between at least 5m downstage of the stage edge and the rear of the hall. A constant cross-sectional area for the audience area can also be considered.
Reflectors above stage	Total area of an array of over-stage reflectors of minimum 150 m^2 covering a plan area of minimum 250 m^2. Several sets of reflectors are

	required that can be set individually in height and angle in order to optimise the balance between different instrument groups and for different types of orchestra. Required height variability: between 8 m and 16 m. Suggested angle tunability: between 0° (horizontal) and 15° vertical inclination, with the edge towards the main audience raised.
Variable acoustic absorption (curtains or other elements)	500 m^2 to 1,000 m^2 of variable absorbing material. These shall be exposed to sound or removed with the use of motorised or mechanised machinery.

2.3 Concert Hall: Summary Table Objective Acoustical Criteria

Unless otherwise stated, values are the mid-frequency value averaged over the 500 Hz, 1 kHz and 2 kHz octave bands.

Mean values refer to the room average including measurements in all seating areas, at the most distant seats, and in general at distances of at least 10 m from the source on stage. The mean should contain the following measurements:

- at least 3 source points on stage;
- at least 3 “1m receiver points” for ST1 measurements and at least 3 mirror receiver points on stage;
- at least 8 receiver positions, evenly spread in distance from the source.

Acoustic Parameter	Value
Reverberation time (RT)	Mean between 2.0 and 2.3 s with all variable acoustic absorption retracted (fully occupied hall with orchestra on stage) Mean between 2.0 and 2.3 seconds with rehearsal curtain (unoccupied hall, stage occupied by orchestra) Mean under 1.8 s and ideally under 1,6 s with all installed variable acoustic absorption in place (unoccupied, empty stage) Reverberation time can be further reduced by installing rigged curtains.
Early Decay Time (EDT)	For each position in the hall with a distance of > 10m to the source, the EDT should be between 80% and 105% of the RT. EDT values more than 5% higher than the RT values should be avoided.
Strength G *without audience, stage set with chairs and music stands*	Values between 2 and 6 dB for distances of > 10m. For a particular receiver, the variation in G for different source positions on stage (ΔG) must be less than 3 dB. Acoustic variability (mean G reduction when using the variable acoustic features) must be greater than 2 dB.
Early Strength G80 *As above, without audience*	Values between -2 and 2 dB for distances > 10m.
Late Strength G[80ms,∞] *As above, without audience*	Values between 0 and 3 dB for distances > 10m.
C80 *As above, without audience*	Values between -3 dB and 2 dB for distances > 10 m.
Acoustic Variability for Amplified Music *As above, without audience*	Reduction of G_{early} (excluding direct sound) of min. 1 dB* Reduction of G_{late} of min. 2 dB. ** Priority is to be given to reducing lateral reflections and sound emitted off-axis from the loudspeakers.* Reduction applies to both sound sources on stage and elevated loudspeaker positions.

Early Lateral Fraction LF *without audience*	Mean > 0.16 LF > 0.15 for at least 80 % of the seats.
1-IACCe *without audience*	Mean > 0,60, 1 – IACC > 0.55 for at least 80% of the seats.
Late Lateral Strength LJ *without audience*	LJ ≥ -5 dB for all seats
Late Lateral Fraction LLF *without audience*	Mean > 0.31 LLF > 0.30 for at least 80 % of the seats.
Bass characteristics	Bass ratio without audience: Between 0.95 and 1.15 Early reflection surfaces sufficiently dimensioned to efficiently reflect the 125 Hz and 250 Hz octave bands (smallest dimension ≥ 2 m). G(125 Hz) ≥ G(1 kHz) and G(125Hz) ≥ 3 dB G(63 Hz) ≥ G(1 kHz) and G(63Hz) ≥ 3 dB. Haptic response to be taken into account for low frequencies.
Warmth characteristics	Treble ratio without audience - Between 0.9 and 1.0 at 2 kHz - Between 0.75 and 0.85 at 4 kHz
Stage Acoustics, ST1 *without audience, stage unoccupied but with seats and music stands*	ST1 value, averaged across the stage, between -15 dB and -12 dB; The mean value of the ST1 should be variable by at least ±1.5 dB by adjusting the reflectors hanging over the stage and by other variable acoustics features in the vicinity of the stage; ST1 for the strings and soloist position to be above the mean level: ST1 ≥ ST1mean; ST1 for the woodwinds and other instruments in the centre of the stage to be close to the mean level: ST1mean ± 1 dB ST1 for the percussion and brass to be equal to or less than the mean level: ST1 ≤ ST1mean; Variation across the stage: ≤ 2 dB with respect to the mean value.
Background Noise internal noise sources (ventilation, electrical equipment) *With ventilation units at design duty for full audience and full stage occupancy*	< NR10 and 15dB(A) $L_{eq,1hr}$ and $L_{10,1hr}$
Tolerances	Corresponding to the threshold of hearing (5 - 10 % for the RT, usually 1 dB for the other criteria, 5 % for the LF and 1-IACC).

2.4 Room Geometry, Seat Count and Seating Layout

The preferred geometry for the concert hall is a shoebox with some additional seating around the stage to create a more “architecturally enveloping” concert hall. This so-called “intimate shoebox” means that the hall is designed to be as compact as possible, with all seats being arranged to be facing the stage centre, more so than in a conventional hall layout. This needs to be combined with the acoustic concept:

- For orchestral use, a majority of the audience have a “traditional” perspective of the orchestra, facing the stage and receiving a similar instrumental balance to the conductor;
- The seats at the sides of the stage and in the choir create a sense of “architectural envelopment” of the stage and a unity between performers and audience. These seats benefit from their proximity to the musicians and view of the conductor, but receive a different instrumental balance than seats in the main floor stalls;
- Any “boundary” between musicians, performers and audience is to be eliminated and/or maximally reduced. The musicians and audience must share the same space so that they partake in a shared experience. The stage height of significantly over 1 m often found in historic concert halls is too much of a barrier and not acceptable for this project. A stage height of between 60 cm and 100 cm is required.
- Seats in elevated balconies around the stage (above the choir balcony and to the sides of the stage) are highly recommended, as their raised position provides excellent instrumental balance combined with proximity and an exciting visual perspective of the stage. Experience from the KKL Lucerne concert hall, as well as Disney Concert Hall in Los Angeles, shows that seats around the stage at higher elevations than the choir seating have a better acoustic balance, both in terms of the instrument blend and balance of room presence and source presence;
- The acoustic and visual quality for events with amplified sound and video projection must also be taken into consideration. In the intimate shoebox, most seats have a frontal view of the stage, the main loudspeaker arrays and video screens. This provides the ideal relationship for these types of events. Architecturally the aim is to conceal as much of the technical equipment as possible. This will also help to enhance the acoustic perception of the room.

The audience should be divided across a main stalls and multiple balconies. Seating for the choir should be provided upstage of the orchestra platform. Ideally the audience balconies, also at the upper levels in the hall, should wrap around the stage to enhance the sense of architectural envelopment and to provide interesting views and acoustic situations for the audience. In a traditional shoebox hall, the side balconies are horizontal and vertically stacked/superposed – this is not a requirement for good acoustics, and a dynamic architectural expression can and should be considered for the side balconies. However, a vertical stacking of the side balconies should be considered so that the width of the hall does not become excessive. A moderate horizontal set-back between side balconies can also be considered to improve sightlines.

Ideally the stage level shall be equal to the foyer floor level and the stage/floor level of the rehearsal hall to facilitate transport.

For orchestral concerts and other uses with seated audience, the floor and seating shall be raked, with a shallow rake, gradually rising from the stage towards the rear of the hall. The shallow floor rake should be determined according to the sightline targets discussed in Chapter 2.7, while respecting the acoustic needs. A further improvement of the parterre sight lines, by implementing a bowl-shaped parterre, can be considered.

The target seat count is specified as follows:

- A total of approximately 1,400 seats, including choir seating, accessible and wheelchair places, distributed over the main stalls and multiple balconies.
- Choir stalls for up to 100 seats upstage of the stage. Larger choirs shall be possible by wrapping choir seating around to the sides of the stage and possibly by extending the choir seating onto the stage. Choir seating to be arranged in 3 or a maximum of 4 rows. Height of first row of choir maximum 3 m above stage level, ideally 2.5 m or even less (see below).
- Choir seating can be used for audience during events with no choir.
- Target of 10 to 20 % of seats upstage of the stage edge, to architecturally envelop the stage on all three sides, a portion of the seats around the stage should be in elevated balconies.
- Accessible and wheelchair seats are to be distributed across different seating zones, following local codes and an analysis of international best practice.
- The seat spacing for standard seats should be determined largely by acoustical needs (meaning closeness to the stage as the primary goal), while still providing sufficient comfortability for the audience. A row spacing between 900 and 950 mm is acceptable for the parterre, while on the balconies, with steeper ranks the row spacing should be closer to 950 mm. A seat spacing of 520-560 mm is recommended.

For an architecturally “enveloping” hybrid shoebox, or “intimate shoebox”, two further aspects need to be taken into account, and have indeed already been taken into account in the competition scheme:

1. A maximum of 2 rows each side of the stage should be planned, with additional seating at the sides in raised balconies. The design of the side seating and reflection surfaces (balcony fronts, reflectors etc.) must ensure that an adequate amount of both early and late sound reaches the ears of the listeners from a lateral direction, thus creating a good feeling of spaciousness and envelopment. For acoustic reasons, the maximum width between walls creating relevant early reflections should not exceed 24 m.
2. Since some audience will be surrounding the stage, the distribution of the sound must be sufficiently homogeneous, so that all instruments (including those with a high directivity such as human voice) can be heard well in the entire audience area.

To summarise, the Client and users desire a hall with the acoustical qualities of a shoebox hall, while integrating as many spatial and performer-audience relationship advantages as possible from successful surround halls.

2.5 The Acoustical Volume of the Hall: Loudness and Reverberance

The acoustical volume of the concert hall together with the number of seats establishes two important acoustical factors, the loudness and reverberation time of the hall. Larger halls (larger acoustic volume) are in general less loud and more reverberant:

- The hall should be sufficiently large so that the loudness is appropriate for all unamplified music from chamber repertoire to symphonic works. For the largest works, sufficient room volume is required so that sound levels are controlled and do not saturate or become uncomfortably loud. It is expected however that the loudest passages will get very loud. Simultaneously, the sound at all dynamics from pianissimo to triple forte should be engaging, the sound should therefore also not be too quiet.
- For the planned repertoire, a maximum reverberation time of greater than 2 seconds is required when the hall is fully occupied with full audience and musicians on stage.

In historic halls, where seating is more densely spaced, a volume of 10 m^3 per audience is typical. For contemporary standards of comfort, including larger seats with larger row-to-row spacing and larger aisles for emergency escape, this volume per seat becomes insufficient. A larger volume is required. In addition, loudness control in a concert hall of less than 1,500 seats requires additional volume. A range of 13 m^3 to 15 m^3 per seat is required for Turku concert hall.

The total volume should be calculated based on the above volume per seat and the total number of seats. This leads to a total acoustic volume of the concert hall of 18,000 to 20,000 cubic metres. This acoustic volume will enable a reverberation time of over 2 seconds to be achieved together with an optimum loudness balance.

To achieve the desired “open” sound quality, and to avoid a compressed or overly loud sounding room, the ceiling height (measured from stage level) should be greater than 20 m through the entire hall. Ideally, the ceiling should reach a height of more than 21 m, with the highest areas of the ceiling being above the audience and not above the stage. A high-point of the ceiling above the audience enhances acoustical envelopment by placing the audience closer to the “acoustic centre” of the room. If the stage area has the highest ceiling, the risk is that the audience is outside the acoustic centre, with the associated sense of “looking at the event” rather than “being in the event”. A height of 20 m is also required so that the over-stage reflectors can be set at an appropriate height of up to 16 m above stage level.

It is important to note that acoustic reflectors will be suspended within the acoustic volume. Undoubtedly an array of reflectors will be required above the stage, and some might also be required elsewhere in the room to optimise early reflection coverage. The resulting total acoustic volume is therefore not a single architectural volume, but will be subdivided by the reflectors.

It is entirely acceptable from an acoustical point of view to design partially coupled volumes in the room, meaning an internal acoustic volume (including the stage, the musicians and the audience) surrounded by acoustic reflectors. Behind these reflectors can be one or several volumes which constitute part of the total volume of the hall, but which will only be partially visible to the audience. One of these volumes for instance would be the volume above the reflector(s) above stage. Similarly, further volumes can be included behind other reflectors in the room. It is not necessary to close off the outer volumes from the interior one, for instance by using doors, however the ability to tune the coupling area between these internal and external volumes could be an interesting solution both architecturally and acoustically.

Furthermore, it is suggested that elements of variable absorption should be located both within the internal volume (making them visible to the audience and very “visible” to sound) and the external ones (making them less visible to the audience).

2.6 Balance of the Orchestra: Design of the Stage and its Surroundings

The stage is the nexus of a concert hall: architecturally, acoustically and in terms of its necessary flexibility and detailed design. Significant attention must be given to the stage design, balancing the following aspects:

The stage and its surrounding determine the listening conditions on stage for the musicians and are the foundation for the music making. The musicians must be able to hear themselves and other musicians on the opposite side of the stage in an optimum balance. Furthermore, a sufficiently strong and acoustically structured “return” from the room must be provided, so that the musicians sense that their sound is reaching the last seats.

The stage design establishes the balance between musical instruments. Judiciously located variable absorption and variable reflection surfaces should be integrated so that the loudness of dominant instrument groups can be controlled. Variable absorption on stage is also necessary to avoid excessive resonance on the stage when it is minimally occupied (for instance for a solo piano recital).

The stage and its surroundings are also the “sending” part of the hall and are therefore responsible for projecting the sound from the musicians to the audience. Stages have a tendency to become acoustically loud and unclear: by projecting significant acoustic energy away from the stage, on-stage listening can be improved while simultaneously improving the acoustic presence for the audience.

To ensure the best conditions for ensemble, the stage must not be too vast and certainly not too wide. A maximum width of 19.0 m ± 0.5 m between the relevant reflective surfaces at the stage edge is recommended, or a maximum width of 19 m between the faces of the balconies at the sides of the stage. In other words, a wider stage can be planned, as long as the side balconies cantilever over the sides of the stage. The space on stage, under the side balconies, can be an open corridor approximately 1 m wide. This corridor has the advantage of moving the stage sidewalls further away from the musicians, as they usually do not like playing directly against a wall.

The lateral walls of the stage should not be parallel: this is both to avoid flutter echoes and standing waves as well as to improve acoustic projection from the stage towards the main audience located in front of the stage. The stage should narrow by 5 - 10° towards the upstage (choir).

The typical stage depth is in the range of 12.5 to 13.0 m for symphonic orchestras.

The stage height is to be determined in collaboration between the Architects, Acousticians, Theatre Consultant and the Client/users. In the first instance, a stage height of 0.6 m to 1.0 m is sought, creating a stronger connection and less barrier between audience and musicians. Higher stage heights of more than 1 m, as in historic halls, are no longer desirable. The stalls seating rake and sightlines should be designed taking into account this stage height.

The stage floor is the “working surface” of the musicians and must be designed to enhance the resonance and projection of the musical instruments. The surface of the stage should be constructed of softwood: for musicians a visible wood surface where cellists and double bassists can freely use their instrument pins is absolutely necessary.

A set of motorised orchestral risers shall be integrated into the stage construction. Instruments further from the conductor shall be raised to facilitate sightlines and on-stage hearing within the ensemble. The motorised risers shall create an approximately semi-circular or “arena” landscape with typically 4 “rings” of risers. Sub-divisions of the riser rings will be required to enable varying heights to be set within each ring.

Musicians’ entrances to the stage, equipment deliveries and the coordination with the backstage should be considered. Musicians must be able to enter the stage smoothly and safely. Stage access doors are required at a minimum in the following locations:

- Downstage, right and left sides. Doors sufficiently wide for piano transport i.e. minimum 1.8 m clear width;
- Upstage, right and left sides or at the back. Large single doors.

One or several acoustic reflectors will be required above the stage and at least over the front area of the stalls audience. These reflectors should be variable in height between approximately 8 and 16 metres from the stage level and should cover an area of approximately 200 m^2. The reflectors should also be tuneable in pitch, from 0° (horizontal) to 15° with the edge facing the main stalls audience raised.

All theatre technical equipment must be carefully integrated into and between the acoustic reflector(s) with no loss of acoustic efficiency. The design of the reflectors and all other technical equipment in the concert hall ceiling area will therefore require close collaboration between the architect, the theatre consultants and the acoustician.

For classical concerts, it is useful to integrate the basic stage lighting equipment for the musicians into the over-stage reflector(s), also called canopy. For classical concerts, the musicians require warm white light with an illumination level of more than 500 lux at all points on the stage and up to 1000 lux.

Performance lighting positions, in particular front of house lighting positions, are to be considered and coordinated with all moving elements in the hall. The lighting positions should work with all relevant canopy and reflector height settings, as well as with all variable acoustics settings.

The surroundings of the stage must provide efficient reflection surfaces at optimum distances and optimum angles, so that the sound is directed and projected towards all listening areas, including seats in the centre of the room near the stage (seats which are usually relatively far from any reflective walls), seats behind and to the sides of the stage, as well as back to the musicians on the stage itself.

To provide sufficient reflection strength at all frequencies, reflection surfaces require sufficient size and mass. Attention should be given to the porosity of the reflection surfaces with the aim of creating a warm acoustic: open pored wood when finished with oil slightly absorbs the very highest frequencies and leads to a warmer sound quality. For other materials, a very fine surface texture can create a similar effect and reduce the harshness of the reflected sound.

2.7 Direct Sound and Sightlines

The direct sound takes the shortest, straight-line path from each instrument or sound source to each listener in the hall. Acoustically it is critical that the direct sound from the stage reaches every listener, since it is the direct sound that provides important information for the acoustical localisation of the sound sources. Balcony railings should allow the direct sound to pass unimpeded – glass extensions to the balcony railings for instance are not acoustically acceptable.

A clear path for the direct sound is of course fundamentally connected with the sightlines in the hall and requires that each audience member also has sufficiently unimpeded sightlines to the stage. Each area of audience – be it in the stalls, main balconies or side balconies – has a different relationship to the stage and therefore different sightline requirements. Sightlines are also affected by the setting of the stage elevators (extended or reduced stage) and flexible choir stalls. All variations of this system should be taken into account when designing the sightlines.

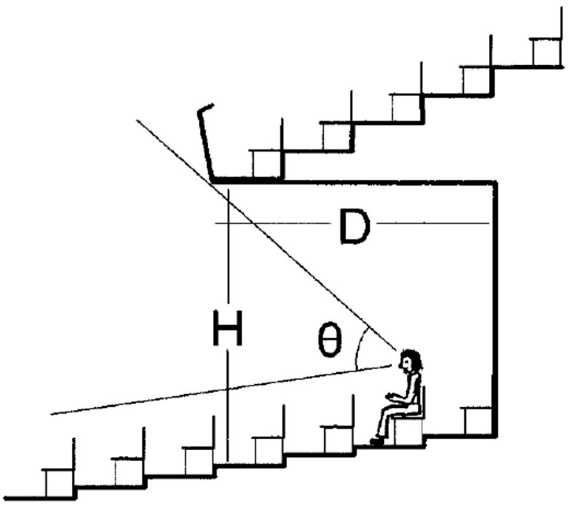
The following sightline (and direct sound) requirements should be considered in the design for the concert hall:

- Sightlines are established for an eye height of 1.2 m above the floor level at the seat in question.
- Seating should be staggered, so that each audience member can see between the heads in the row in front.
- Key reference points for setting out sightlines for the stalls are the following: the bow of a solo cellist on a riser, approximately 0.7 m above the stage level; and the waist of the conductor,

approximately 1.2 m above stage level, 3 m left and right of the hall centreline and 2 m upstage of the stage edge.

- For acoustic reasons, the main stalls should not be raked too steeply (around 3° - 5° rising from the stage is ok). The first 2 - 4 rows may be on the flat and at the same floor level. As such, much of the stage depth will not be visible from the stalls. The cello soloist and conductor should be visible from at least 70 % and ideally 80 % of the seats in the stalls (reduced visibility results from heads blocking certain view directions.).
- In the main (rear) balconies with a frontal view of the stage, 100 % of the stage surface should be visible from every seat. The first 1 - 2 rows should also be visible between the heads.
- In the side balconies, part of the near side of the stage will be visually occluded. The cello soloist and conductor must be visible from at least 90 % of the seat in the side balconies, including upper side balconies (with forward leaning audience in the first rows being accepted). At least 50 % and ideally over 66 % of the stage area and stage width should be visible from every seat.
- Most seats should not be rotated more than 45 degrees off from the axis towards the conductor.
- In the choir balcony, the conductor must be visible for all seats. At least 50 % of the stage depth should be visible.
- Wheelchair locations should be considered, so that they do not worsen sightlines for audience members sitting behind.

Under-balcony seats are a special case since they also have an “upwards” sightline requirement towards the ceiling. A reflection from the main ceiling or from a suspended reflector in the main hall volume should reach all seats under the balcony overhangs. In general, the overhung depth of the balcony (D) must be less than the vertical opening under the balcony (H):



Overhung seats under balconies:

The overhung depth D must be less than the open height H:

D << H

In addition, under-balcony seats should receive a reflection from the main ceiling.

2.8 Reverberation Spatial Balance and Projection

The spatial balance of reverberation between the stage area and the audience area is critical for the acoustic quality and is linked to the “acoustic centre” of the hall. The acoustic centre is generally where the cross-sectional area of the hall is at a maximum, and this is where reverberation will tend to build up. Furthermore, the acoustic centre can be "biased" away from the stage by angling walls and ceiling surfaces to project sound energy from the stage towards the main audience.

As mentioned above, the main audience should be at the acoustic centre of the hall, so that they are in the main reverberant field, fully enveloped by reverberant sound.

If the orchestra is in the acoustic centre, the result is a "fog" of reverberation around the orchestra. This effect is exaggerated by the fact that the orchestra is less absorbing than the audience. The result of this "fog" is excessive loudness on stage, an unclear and unprecise sound for the audience (like looking through a dirty window) and reduced feeling of involvement for the audience.

The acoustic centre of the room can be pushed towards the stalls audience and optimised in a number of ways:

- by reducing the hall cross-section and in particular the width around the stage and by introducing projecting surfaces around the stage e.g. angled walls in plan and an inclined ceiling in long-section;
- by integrating choir seating and an organ which both increase the absorption around the stage and improve the reverberation balance by reducing reverberation around the stage;
- by inclining the over-stage reflector(s) towards the audience;
- by including acoustic volume(s) to the sides of the side audience seating and behind the main balcony seating, so that the reverberant volume around the audience is increased.

All of these approaches should be considered and integrated into the concert hall design.

2.9 Reflection Surfaces: Early Acoustic Efficiency

Large areas of acoustically efficient reflection surfaces are required to provide early reflections, acoustical presence, and strength – efficient reflection surfaces include optimised surfaces of the hall such as walls, ceilings and balcony fronts as well as suspended and applied acoustic reflectors. It is the early reflections that create the dominant acoustical character of the hall.

The early acoustic efficiency can be determined directly from the architectural drawings following these steps:

1. Identify a list of all surfaces within the hall located within 15 meters of the musicians on stage and/or from any part of the audience.
2. Include only surfaces that have an orientation which directs the sound reflections towards the musicians and/or audience.
3. For each of these listed surfaces (referred to as efficient surfaces), the area S [m^2] is measured from the plans and sections.
4. The early acoustic efficiency (in m^2) is finally obtained by calculating the sum of each of these surface area S.

The principle of this efficiency is simple: the larger quantity of judiciously oriented surfaces located close to the sources or the audience, the greater the clarity and the presence of the sources.

This criterion has been calculated for a number of existing concert halls. This analysis has shown that an early acoustic efficiency greater than or equal to 1400 square metres is optimal for the very large symphony concert halls. With smaller values the sources will sound more distant, the clarity and presence are also diminished. With higher values, the sound becomes too direct and the reverberance and the acoustic envelopment of the room would be lacking.

For Turku concert hall, a moderate-sized symphony hall, the surface area of efficient reflection surfaces can and needs to be smaller. The appropriate target is between 800 and 1000 m^2 of efficient surfaces.

In addition, it should be ensured that the stage and every part of the audience are covered by at least two (or ideally more) acoustically efficient surfaces. Areas that receive only one efficient reflection risk "false localisation" of the sound sources. Early reflections from both the left and right are required to create a balanced spatial impression.

When calculating that early acoustic efficiency the following surfaces should be considered:

- Area of the walls which are acoustically efficient. Those located behind an audience and where the reflection would arrive below ear height are not to be considered;
- The ceiling of the room for areas where the audience is less than 15 metres from the ceiling, and only that part of the ceiling that is acoustically efficient, as defined earlier;
- Balcony fronts, including:
    - the face of any balcony that is sufficiently angled downwards to direct reflections towards the audience;
    - the balcony soffits in situations where they can generate early reflections towards the stage or the audience. These reflections may be of first-order or second-order passing via the underside of the balcony (soffit) and the wall (or a "downstand reflector" located under the balcony).
- Specifically designed reflectors, attached to walls and ceiling, for instance "downstand" reflectors attached to the balcony soffits.
- Acoustic reflectors suspended from the ceiling above the stage, or within the volume of the room.

2.10 Reflection Surfaces: Surface Quality, Acoustic Diffusion, Lateral Energy and Envelopment

Acoustic reflections carry information which our brains combine with the direct sound (along with what we see) to create the overall acoustic impression. Smooth surfaces (flat or curved) preserve the information in the reflection, which enables our hearing system to "make sense" of the auditory environment and localise the musical sources within the context of the reverberant concert hall. These kinds of desirable reflections from smooth surfaces are technically called "phase preserving".

If the information in the reflection is "scrambled", for example due to very rough and deep surface texture, our hearing system can no longer make sense of the reflection, which then effectively becomes "noise". Reflection surfaces should therefore preserve the acoustic information in the reflection and not scramble the phase: deep surface texture and "sound diffusing" surface treatments must be applied with care and consideration.

Convex surfaces with a smooth surface are generally acoustically positive, since they preserve the information while spreading acoustic reflections over a wider area and enabling an overlapping of multiple reflections in the audience area. Convex surfaces also weaken the reflection, reducing the "mirror effect" and thereby mitigating both the risk of "false localisation" and harsh sound quality that can occur with strong reflections from flat or concave (focusing) surfaces.

A sense of spaciousness and acoustic envelopment is achieved by providing lateral reflections to all parts of the audience. Scientific and comparative studies of existing concert halls have shown that the overall acoustic quality and subjective preference are highly correlated to the perception of acoustic envelopment. Therefore, significant attention will have to be given to subjective envelopment and the correlated objective parameters (LF and IACC).

2.11 Spectral Balance and Building Materials

The bass response should be strong and “tight”. Bass instruments should be carried by the room with impact and force, avoiding a “woolly” and unclear bass sound. For a concert hall, the low frequency reverberation time (125Hz and 250Hz octave bands, but equally 63Hz octave band) should be equal compared to the mid-frequency RT. A slightly longer RT at low frequencies (compared to mid frequencies) is permissible.

The seating layout and seat design for the hall should minimise the “seat dip effect” (reduction of bass energy due to sound traveling at grazing incidence to the seating). The space between the seats and the floor must be open – a seat design where the space under the seat is closed would not be permitted. To compensate for the reduced bass energy in the direct sound, full-frequency early reflections arriving from non-grazing directions (from a sufficiently high elevation angle) must be generated within the 80ms integration time limit.

To generate full frequency reflections, including early reflections with sufficient bass strength, the materials used for the reflective surfaces must be sufficiently dense and heavy. In addition, reflector surfaces must be sufficiently large so that the long wavelengths at bass frequencies are efficiently reflected. Every seat in the hall should receive at least two early reflections from surfaces where the smallest dimension is greater than 2m. For second-order reflections, e.g. from the underside of a balcony, the combined dimension of both efficient surfaces can be considered.

The perception of bass frequency sound is the combination of air-borne sound and vibration transmitted to the human body (the haptic response) by surfaces and objects in direct contact with audience members. Therefore, to enhance bass frequency perception, both an appropriate vibration response of the floor and seating and the air-borne transmission of bass sound must be considered. In this frequency region, the human sensitivity to haptic stimulations is at least of the same order of magnitude, if not stronger than, the air-borne acoustic sensitivity of the human hearing system.

Low-frequency vibrations of both the chairs and the wooden audience floor increase low-frequency impact and perception. A wood floor construction on joists is recommended both for the main floor parterre and the balconies, enabling the wooden floor and chairs to freely vibrate, for example with an air plenum below the wooden floor.

2.12 Integration of the Organ

The integration of the organ is an architecturally, visually and acoustically important subject since it affects the dimensions required for the hall, becomes a visual focal point and introduces a large area of sound absorption and diffusion in the area of the stage (note: this is acoustically positive, since it helps to move the acoustic centre away from the stage). If the organ is not installed immediately, during the construction of the concert hall, compensation measures must be integrated. An area of absorptive and diffusing wall surface, equal to the area of the planned organ is to be provided. Equally, if the organ is to be covered or hidden, for some uses, the closure should preserve the acoustic absorbing and diffusing characteristics of the organ.

It is advisable to decide about the organ size and dimensions early on in the planning phase, to be able to integrate it perfectly, also if necessary, after the rest of the hall is completed and taken into use.

2.12.1 Space Planning for the Organ

A traditional organ is a complex piece of equipment composed of thousands of pipes organised in multiple rows. Pipes for the lower tones can reach up to 32 feet (10m). It is also a complex mechanical system sitting on a complex wood structure, possibly reinforced with steel.

For a concert hall of such volume, the organ can be 12 to 15 metres wide, up to 10 metres tall and 4-6 metres deep, occupying a surface area of between 40 and 80 square metres.

The pipes of the organ must not be too close to each other so that they can resonate freely. An organ manual (the keyboard) is typically located at the organ, with a remote, movable manual also provided for occasions where the organist should be on stage.

Access is required inside the organ for tuning and maintenance.

In addition, the machine ("blower") room for the organ should be situated close to the organ, but acoustically fully isolated from the concert hall, so that the noise of the air pumps and motors is not audible in the hall. The air mechanism of the organ (pipes, valves etc.) must be designed to minimise noise generation.

2.12.2 Location of the Organ

Organ pipes can all be located in one place, or certain voice groups can be split off to create smaller satellite organs. In the context of a shoebox or hybrid shoebox hall, a central location of the organ behind the choir is typical, but the location is relatively flexible as long as the following considerations are followed:

- The entire organ should be "acoustically visible" – including the top of the tubes – for all of the audience, including the audience in the last row of the top balcony. The entire organ, or parts of the organ can be integrated behind an acoustically transparent screen or façade;
- The position must provide a good balance between orchestra, choir and organ, and consistency of sound for the audience as well as the orchestra conductor;
- The position of the organ must provide a good acoustic quality for the instrument and a comfortable position for the organist playing the instrument. Some organists do not favour having the manual moved onto the stage (even if this possibility is suggested for the project). The fixed manual should be located sufficiently close to the stage, so that there is minimal delay in hearing the orchestra;
- A good balance between the high and the low frequencies will have to be achieved at the organist's position on the fixed manual. Often the low frequencies are too dominant;
- The smallest pipes (high frequencies) are acoustically very directive and acoustic reflections from close surfaces are required to create a good distribution of high frequencies;
- The outlets of the most powerful pipes must not be at the same height as the choir or audience behind the stage;
- Often the installation of an organ leads to an increase in the ceiling height. However, the ceiling height above the organ should remain less than the ceiling height over the audience. In addition, the ceiling height must remain compatible with the necessity for reflectors close to the orchestra and reflecting towards the stage. With acoustic reflectors above stage, it is even more challenging to find a good position for the organ as it should stay fully visible for most of the audience.
- The manual keyboard can be lifted to above the choir balcony, creating more space for choir seating, and a less disturbed workspace for the organist.
- It is quite typical that the organ is "visually cut off" in rooms with reflectors above stage – this is to be avoided as much as possible.

2.12.3 Impact of the Organ on the Acoustics of the Hall

A reverberation time of greater than 2 seconds at mid-frequencies must be achieved in the full configuration for symphony orchestra with choir and full audience.

The organ is a significant element of the acoustics of the concert hall: the absorbing and diffusing characteristics of the organ must be considered when choosing the location of the organ in the room and when determining the total room volume and total absorption.

The recommended acoustic volume range of minimum 18,000m^3 provides sufficient scope to achieve the desired reverberation time with the inclusion of the absorption from an organ, typical concert hall seating, musicians and audience.

2.13 Acoustic Variability

To meet the objective of a large acoustic variability for the room, a significant area of variable absorption will be required. This can be achieved using, for instance, movable heavy acoustic curtains or banners, or other solutions for varying the total acoustic absorption in the room.

The exact amount of variable absorption needed will depend on the acoustic variability demands to the room, the type and the locations of the absorbing elements, although in any case a minimum of 500-1000 square metres of variable absorbing surfaces will be required. Additional elements might be necessary to tune the bass frequency response, especially for amplified events.

The position of the variable absorption affects different aspects of the sound:

- Variable absorption elements surrounding the stage e.g. in an acoustically transparent upstage wall and or integrated into the choir risers, in the vicinity of the sources, primarily influence the balance in the orchestra. Additional absorption can be placed close to louder instruments to optimise the loudness balance within the orchestra;
- Variable absorption elements close to the audience and covering efficient early reflection surfaces primarily reduce early energy and loudness;
- Elements located relatively far from the sources and audience – and less visible to the sound and the audience – will mostly influence the late energy and the late reverberation.

Three further comments:

First, some of the mobile absorbing elements, in particular on stage, will be used very often. The configuration with the maximum reverberation time and therefore without any absorption will not necessarily be the most frequently used set-up for the hall, and the architectural and aesthetic design must take regularly used absorption elements into account.

Secondly, for amplified music performances, musicians often ask that the stage is fully draped, at the rear (backdrop) and at the sides of the stage. This is both to provide the ideal situation for lighting, but also for acoustic absorption purposes.

Thirdly, it should be possible to place variable sound absorbing elements to the sides of temporarily suspended line arrays. This is to absorb the incoherent and tonally coloured sound emitted from the sides of such loudspeaker arrays.

Finally, the temporary installation possibility of a rehearsal curtain should be considered. The rehearsal curtain is typically lowered/added into the rear part of the hall upper volume to lower the reverberation time during rehearsals, as the hall without an audience will have a longer reverberation time.

2.14 Background Noise and Vibration Criteria and Sound Isolation

The absence of noise during the rehearsals, performances and recordings is an integral part of the acoustic quality of the hall. The background noise shall be extremely low, at the limit of the threshold of hearing, both for concerts with an audience and for recording situations. All sources of noise must be considered, including those generated internally in the concert hall (such as ventilation, electrical and performance equipment) along with sources of noise outside the concert hall (such as traffic, air traffic and other rooms in the Music Centre). To achieve an almost absolute quality of silence, a high degree of sound insulation from the exterior as well as from the other noisy rooms in the building will be required.

The corresponding objective criteria are “Noise Rating” (NR) and the sound pressure level expressed in dB(A).

For the main concert hall, the following criteria apply:

- Continuous noise sources such as ventilation noise, electrical and performance equipment (including equipment installed inside the concert hall): NR10 in the octave bands 63 Hz to 8 kHz inclusive and an absolute level of 15 dB(A) L_{90}. This criterion applies to fully occupied concerts with a seated audience.
- Noise ingress from traffic, other venues and spaces in the Music Centre: NR10 in the octave bands 63 Hz to 8 kHz inclusive and 15 dB(A), for both $L_{eq,1hr}$ and $L_{10,1hr}$.

To meet the very low background noise level criteria, it is necessary to have an acoustic movement joint surrounding the concert hall on all levels above the foundation slab, and/or provide isolated finishes and floating slabs/screed for all potentially noisy spaces within the same structure.

2.15 Acoustic Faults (to be avoided)

It is obvious that any perceivable acoustic faults must be avoided: echoes, flutter echoes, individual late and audible reflections, false localisation etc. must be avoided through detailed and holistic design.

Adding diffusion or absorption to surfaces late in the design process or during construction is not an acceptable approach to mitigating or eliminating faults.

2.16 Evaluation of the architecture for Acoustics

The way a room “looks” has a strong effect on how a room “feels”. This should not be forgotten when judging the success of a realized hall. This is the reason why the architectural values should be considered also when evaluating the acoustic outcome. A room which feels good to the audience will create a positive setting, meaning open the ears for the audience, as a concert event is also a multi-sensory experience. A room design considering “closeness” between the audience and the orchestra on stage can significantly enhance the performance experience for both parties.

A strong architectural concept is not only related to a well-balanced and complimenting composition of the architectural elements, but also by materiality and lighting, by a pleasant and exciting audience circulation, and by the grouping concept of the seats.

Typically a successful architecture of a concert hall is related directly to the acoustics. Clear and reduced shaping can increase the readability of the room, meaning the understanding, the “acoustic readability” of the room for the audience.

3 THE SMALL HALL ACOUSTIC REQUIREMENTS

3.1 Basic requirements

The Small Hall is a chamber music and multifunctional hall, as described in the original brief for the architectural competition. In addition, the hall can be used for rehearsals for orchestra, for a maximum of up to 60 to 70 musicians under good acoustical conditions.

The hall will need extensive variability, both acoustics and seating/layout:

- Variability in the acoustics of the room. This variability shall provide more than a simple change of reverberation time (by using acoustic curtains or other absorbing material, or by adding artificial reverberation via an electronic system). The acoustic volume, loudness, lateral energy and potentially also the spectral balance and/or orchestral balance should also be variable.
- Flexibility in the architecture of the room. In some cases, these modifications can be minor, in other cases, they will have to be major to cover the wide range of uses. The simple reason for that is that each performance there is an associated set of needs and often a different relationship between the audience and the artists. To address this issue correctly, one must also respect the expectations of the public, which also vary with the type of performance. For rehearsals, the hall can be used in a configuration rotated 90° so that the orchestra can take advantage of the larger dimension as the width for the orchestra (the width of the orchestra in rehearsal mode is bigger than the depth).

For the Small hall, the following background noise criteria apply:

- Continuous noise sources such as ventilation noise, electrical and performance equipment (including equipment installed inside the concert hall): NR15 in the octave bands 63 Hz to 8 kHz inclusive and an absolute level of 20 dB(A) L_{90}. This criterion applies to occupied concerts with a seated audience. For standing audience and/or banquets, a background noise 5dB higher is acoustically acceptable.
- Noise ingress from traffic, other venues and spaces in the Music Centre: NR15 in the octave bands 63 Hz to 8 kHz inclusive and 20 dB(A), for both $L_{eq,1hr}$ and $L_{10,1hr}$.

To meet the very low background noise level criteria, it is necessary to have an acoustic movement joint surrounding the rehearsal hall on all levels above the foundation slab and/or provide isolated finishes and floating slabs/screed for all potentially noisy spaces within the same structure.

3.2 Rehearsal Hall: Summary Table of Architectural-Acoustical Criteria

Architectural Parameter	Requirement
Volume	> 50 m^3 x number of musicians, in this case ≥ 3000 m^3
Floor Area	≥ 120 m^2 + 2 x number of musician, in this case at least 240 m^2
Height of the hall	Sufficient height to achieve the necessary volume, in this case 12 – 13 m.
Width/length of the hall	Ideally at least equal to the stage width, in this case 18,5 - 20 m.
Reflectors above stage	Total area of an array of over-stage reflectors of minimum 30% to 45% of the floor area. Several sets of reflectors are required that can be set individually in height and angle in order to optimise the balance between different instrument groups and for different types of orchestra. Required height variability: between 8 m and 11m. Suggested angle tunability: between 0° (horizontal) and 15° vertical inclination.
Variable acoustic absorption (curtains or other elements)	about 400 m^2 of variable absorbing material. The elements should be placed both on wall surfaces and transvers underneath the ceiling. These shall be exposed to sound or removed with the use of motorised or mechanised machinery.

3.3 Rehearsal Hall: Summary Table Objective Acoustical Criteria

Unless otherwise stated, values are the mid-frequency value averaged over the 500 Hz, 1 kHz and 2 kHz octave bands.

Mean values refer to the room average including measurements in all areas. The mean shall contain the following measurements:

- at least 3 source points on stage
- at least 3 “1m receiver points” for ST1 measurements and at least 3 mirror receiver points on stage
- at least 6 receiver positions, evenly spread in distance from the source.

Acoustic Parameter	Value
Reverberation time (RT)	Occupied reverberation time with 200 audience members of minimum 1.2s for concerts, which works well for Jazz etc., but is on the dry side for classical music concerts. An occupied reverberation time of 1.5s for Chamber Music concerts could be achieved, but this would increase the need for variable acoustics treatments and therefore possibly the budget.

	Mean between 0.8 and 1.0 s with all installed variable acoustic absorption in place, for the empty hall, with musician's chairs in place (rehearsal mode).
Strength G	Values ≤ 11 dB for distances of > 10m for rehearsal mode
C80 (for concert mode, unoccupied)	Values between -2 dB and 2 dB for distances > 10 m (for maximum reverberation time)
Early Lateral Fraction LF *(for concert mode, unoccupied)*	Mean > 0.20
Bass characteristics *(without audience, in orchestral rehearsal setting)*	Bass ratio: Between 0.90 and 1.05 Early reflection surfaces sufficiently dimensioned to efficiently reflect the 250 Hz octave bands (smallest dimension ≥ 1 m).
Warmth characteristics *(without audience, in orchestral rehearsal setting)*	Treble ratio: - Between 0.9 and 1.0 at 2 kHz - Between 0.75 and 0.85 at 4 kHz
Stage Acoustics, ST1 *(without audience, in orchestral rehearsal setting)*	ST1 mean value, averaged across the stage between -13 dB and -9 dB; The mean value of the ST1 should be variable by at least ±1.5 dB by adjusting the reflectors hanging over the stage and by other variable acoustics features in the vicinity of the stage; ST1 for the strings and soloist position to be above the mean level: ST1 ≥ ST1mean; ST1 for the woodwinds and other instruments in the centre of the stage to be close to the mean level: ST1mean ± 1 dB ST1 for the percussion and brass to be equal to or less than the mean level: ST1 ≤ ST1mean; Variation across the stage: ≤ 2 dB with respect to the mean value.
Background Noise for internal noise sources (ventilation, electrical equipment) *With ventilation units at design duty for full audience and full stage occupancy*	< NR15 and 20dB(A) $L_{eq,1hr}$ and $L_{10,1hr}$
Tolerances	Corresponding to the threshold of hearing (5 - 10 % for the RT, usually 1 dB for the other criteria, 5 % for the LF).

4 APPENDIX: RELATIONSHIPS BETWEEN SUBJECTIVE PARAMETERS AND OBJECTIVE ACOUSTIC CRITERIA

The acoustic criteria listed in the Tables and explained in this report are to be considered in the analysis of acoustic computer simulations and scale model measurements. These will be required during the design phase to demonstrate that the design of the concert hall meets the specified criteria.

In room acoustics, a distinction is made between “subjective parameters” and “objective criteria”:

- The subjective parameters describe the perception of various qualitative characteristics of the room acoustics: reverberance, clarity, loudness, etc.;
- The objective criteria are technical parameters calculated from the measured (or simulated) impulse response of the room and describe the acoustic response of the room between a source and a receiver.

Several scientific studies since the 1950s have sought to derive relationships and correlations between objective criteria and subjective parameters. For better or for worse, some of the objective parameters have been given names relating to the subjective qualities they are considered to best correlate with (for instance the “clarity parameter” C80).

A priori, these relationships can be applied to any room shape and consequently, can be applied to the hybrid shoebox hall desired by the client.

In this chapter, the different aspects of the acoustic quality of the room will be discussed, considering simultaneously the subjective and corresponding objective quantities. The exact definitions of these criteria can be found in the International Standard ISO 3382 Part 1.

4.1 Reverberation and Reverberance

The first objective criteria used to describe the acoustic quality of a concert hall is the reverberation time (RT). This measurement describes the duration of the decay after a short sound (an impulse) over a dynamic range of 60dB.

The subjective parameter related to the RT is the “perception of reverberation” or reverberance. In practice, one distinguishes between two kinds of reverberance:

1. the “running reverberation” perceived during the musical phrase and;
2. the “terminal reverberation” perceived once the musical phrase is over after a final chord.

The latter is directly related to the RT of the room while the former is more related to the early decay time and often calculated over a decay of 10 or 15dB (EDT10 and EDT15).

One of the principal reasons why the RT is generally the first criteria used for the description of the acoustics of a concert hall is that it is the only criteria that does not vary (or negligibly) with the source and receiver positions. Therefore, it characterises the reverberation of the room as a whole.

The RT is directly related to the acoustic volume and the absorption area of the room. Given that, for a concert hall, the total absorption area is essentially made up of the seated audience, the RT is directly related to the total acoustic volume or to the acoustic volume per person in the audience.

The concert hall brief includes the installation of an organ. The hall will therefore be designed accordingly for musical performances with organ as well as performances with a symphonic orchestra and choir.

The maximum RT required for the hall (with full audience, without variable curtains or any movable acoustic features) is 2.3 seconds. In any case, the maximum RT of the room, fully occupied and with musicians must be greater than 2 seconds.

To obtain such a high RT, one must plan for an acoustic volume of 13m3 to 14m3 per audience member and consequently a total volume of 18,000m3 to 20,000m3 for a hall with 1,400 seats.

In large halls where efficient early reflections are required to achieve sufficient strength and source presence, the EDT tends to be somewhat shorter than the RT. In addition, the EDT varies throughout the hall and will be lower closer to the stage compared to more distant seats. Overall, the EDT should vary between 80% and 100% of the RT. EDT values longer than the RT should be avoided. When the EDT and RT and similar (100%) the sound tends to be more blended, while the sound quality in seats with shorter EDTs (80-90% of the RT) tends to be clearer and with stronger source presence.

4.2 Loudness and Acoustic Strength

The subjective parameter of loudness is related to the objective Strength criterion G. This criterion provides a measure of the loudness and amplification of the room. It is defined as the ratio (in dB) of the acoustic pressure measured at a given point of the room (response of the room) to the acoustic pressure generated by the same sound source measured at 10m in free field conditions (i.e. with no reflected sound). This criterion is a function of the position of the source on the stage and of the position of the receiver in the hall.

For the Turku concert hall, with its capacity of 1,400 seats, this acoustic criterion is especially important:

- The strength G must be sufficiently high, so that the sound is sufficiently strong. With such a large audience and total absorption, significant optimisation of the reflective surfaces will be required to maintain a high G value;
- Variations of G with location of the source on the stage and of the receiver in the audience must remain within a sufficiently small range. If G varies significantly for different source positions on stage, this means that there will also be large and detrimental imbalances in loudness within the orchestra for a single listener position.

The human ear is very sensitive to acoustic power. Below a certain threshold, the audience does not feel involved and enveloped by sound. The absolute minimum acceptable value of G that has been established in listening tests for symphony orchestra is 0dB. The Strength G must have a positive value, and in general the ideal value of G is between +2dB and +6dB.

There is a natural reduction in sound level with increasing distance from the stage that cannot be avoided. Based on the planned RT and room volume, values of G should be between +2dB and +6dB for distances of 10m to 30m from the sound source. (In Turku this means for distances above 10m, since the farthest seat is significantly less than 30m away from the stage.) A minimum G value of +1dB should be achieved at the most distant seats.

There is also an upper limit on Strength, above which the sound becomes unpleasantly loud and secondary effects, such as spatial compression and saturation, can occur. Care therefore must be taken, that seats relatively close to the stage do not become overly loud and remain sufficiently well-controlled.

4.3 Early Energy and Presence of the Sources

Recent studies in psycho-acoustics have demonstrated that the perception of acoustic power is more complex than the simple correlation with G or with the room amplification.

The human auditory system – the ear and the brain – differentiates the audio information received into two different "data streams". One is related to the perception of the source while the other one is related to the perception of the space.

This concept is logical from an evolutionary and cognitive point of view: in day-to-day situations, our brain is constantly mapping our environment, using all of our senses, while simultaneously placing "objects", including "sound objects", into this cognitive model of the environment.

When seated in a concert hall, our auditory system is constantly forming and tracking "sound objects" corresponding to the instruments and other sound sources and then placing them into the acoustic environment of the concert hall. The role of the concert hall acoustic design is to enable and facilitate the cognitive system to carry out this process: early reflections must be designed to enhance the presence and localisation of the sound sources, while later reflections should give auditory cues as to the positions of architectural surfaces so that the room presence is simultaneously enhanced and the cognitive system can separate the two perceptual streams. The concert hall design shall therefore aim to optimise independently the early response (presence of the sources) and the late response (presence of the room), so that both are present and in balance.

In a large concert hall, excluding the seats that are very close to the stage (3 to 5m from the sources), between 90% and 99% of the acoustic energy comes from reflections from the room surfaces.

The presence of the source is related to the early energy of the room response. If the reflections arrive within less than 80ms after the direct energy, the human hearing system integrates the energy from these reflections with the energy of the direct sound. The early reflections and direct sound are combined into one "sound object". For this to happen, there need to be sufficient similarities between the direct sound and the reflected sound e.g. frequency content and phase, so that the hearing system can understand that there is a "match". If reflections are highly diffused, or their frequency response is altered by the reflection surface, this "matching" process is made more difficult and our auditory system may consider the reflection as "unimportant" or as "noise". In this case, the benefits of the early reflections are reduced.

The perceptive process is somewhat more complicated, but a limit of the integration to the first 80ms is typically a sufficient description in the context of concert hall design.

In order to obtain a good, perceivable presence of the sources, a sufficient number of reflections under 80ms delay must be generated by the surfaces and reflectors in the hall. This is even more important given the large number of seats and the large volume of the room. A delay of 80ms corresponds to a difference of 25m in the sound-ray trajectory. Since the sound must reach the reflective surface then travel to the ears of the audience, reflective surfaces must be located at a distance of 10 to 15m from the source and/or audience.

Concerning the purely acoustical criteria, the early strength G80 (defined as the ratio of the room amplification for the first 80ms of impulse response to that obtained at 10m in free field conditions) is less universally used, but is nevertheless a useful criterion and will be applied here. For the Turku concert hall, G80 values between -1dB and +3dB should be achieved for distances of more than 10m

4.4 Late Energy and Presence of the Room

As mentioned in the section 3.1, the perception of the final decay (end of a musical phrase) is directly related to the reverberation time RT. The perception of reverberation during continuous musical phrases requires not only a sufficiently long RT but also a sufficient amount of late acoustic energy, arriving 80ms or later after the direct sound reaches the audience. In particular, recent research has shown that sufficient energy arriving in the time range 150ms to 300ms after the direct sound is critical for a strong sense of running reverberation.

For the Turku concert hall, a Late Strength G[80ms, ∞] of between 0dB and 2dB for distances of more than 10m should be achieved.

Moreover, it is required that the Late Strength be homogeneous over the entire seating area. The deviation from the mean must be less than ±2dB when including the seats located at the back of the room and those below the eventual balconies. Even in seats close to the back of the hall, the feeling of a frontal room sound should be avoided – these seats should have the sense of being enveloped by sound.

4.5 Clarity Parameter

Along with the Reverberation Time, the “Clarity” parameter C80 is one of the oldest and most commonly used acoustical parameters. The parameter is calculated as the ratio of acoustical energy arriving within the first 80ms (including the direct sound) to the energy arriving after 80ms.

High values of C80 indicate a stronger early sound and relatively weaker late sound level. This combination generally indicates a good “clarity” of sound, but as described above, there is more than just the early-to-late balance to consider when optimising acoustical source presence. Low values of C80 indicate a relatively stronger late sound and a more reverberant sound quality. Rather than indicating subjective acoustical clarity per se, C80 may be a better indicator of reverberance, with lower values indicating a more perceived reverberance.

Based on the discussion of Early Strength G[0ms, 80ms] and Late Strength G[80ms, ∞] above, a C80 of between -2dB and +2dB should be achieved for distances of 10m to 30m.

4.6 Lateral Energy, Apparent Source Width and Listener Envelopment

Scientific studies and analyses of various rooms have shown the importance of the spatial characteristics of the sound field. There is a strong preference that a part of the reflected energy received must arrive from lateral directions, rather than from in front or from above.

When the reflected energy reaches the ears from a lateral direction, each ear experiences a different sound field: this is perceived as a feeling of acoustic envelopment and has two major subjective effects:

1. Early reflections arriving laterally generate a sense of enlarged Apparent Source Width (ASW). As the orchestra plays louder, the ASW grows, which leads to a positive and enjoyable impression that the spatial quality of the orchestra changes with the musical dynamics. At pianissimo the ensemble appears smaller and grows as the sound level increases.
2. Late reflections arriving laterally, in particular from azimuthal directions from 60° to 150° create the sensation of being fully enveloped and surrounded by sound and reverberation: so-called listener envelopment. When the reverberant sound is also perceived as coming from the rear hemisphere, we call this “full envelopment”. The aim for the Turku concert hall is to achieve full envelopment for all main audience seating areas.

In halls with full envelopment, the audience feels surrounded by the sound and feels like it is participating in the event rather than simply listening and observing it passively.

Lateral reflections (with a minimum angle of 25 degrees with respect to the trajectory of the direct sound) are overall more acoustically advantageous than reflections from the ceiling (unless the latter reach the ears of the listener in a lateral manner, by means of reflectors with optimised angles). Sections 2.7 and 2.9 provide more detailed information on the possibilities of optimising lateral reflections toward the listener, either by using the walls or the ceiling of the room.

To objectively quantify the spatial qualities of the concert hall, multiple objective criteria have been developed: the early lateral energy fraction (LF), the inter-aural cross correlation (IACC) and the late lateral strength (LJ).

For the Turku concert hall, the spatially averaged LF (over several representative seats, excluding those within 5m from the stage) must be greater than 0.15 for each of the 250, 500 and 1000Hz octave bands. The averaged LF over these three octave bands must be greater than 0.16. At least 80% of the seats must have a mean LF greater than 0.15.

The criterion IACC will be used in its 1-IACC form so that a greater value will correspond to a better acoustic impression. A mean value of 1-IACC[E,mid] greater than 0.60 is desirable and a mean value greater than 0.55 is required. The 1-IACC[E] must, in average, remain greater than 0.50 for each of the 500, 1000 and 2000Hz octave bands. It is required that at least 80% of the seats exhibit a 1-IACC[E,mid] greater than 0.55.

The late lateral strength requires both the late energy to be sufficiently strong together with a sufficiently high lateral component to the late sound field. These two aspects are combined into one parameter called the late lateral strength (LJ or GLL). All seats with a distance of less than 30m from the source should have a late lateral strength of greater than -5dB.

4.7 Stage Support (ST1)

In an excellent concert hall, it is vital that musicians have excellent listening so that they can deliver the best performance, without any acoustical obstacles.

To achieve excellent stage acoustics, there are multiple aspects to consider, all of which must be in balance, with no particular aspect dominating:

1. Each musician must be able to hear themselves properly. This means that they can hear themselves sufficiently but not to the point that their own sound masks that of the others;
2. Each musician must be able to hear all other musicians on the stage properly and in balance, even those seated on the other side of the stage. This is particularly important for instrument groups where there is often detailed interplay, for instance between the string groups (1st violins, 2nd violins, violas, cellos and double basses);
3. The acoustics from certain instrument groups must not be too loud, so that they do not mask the sound of other instruments. Typically, excessive loudness and excessive reverberation from the percussion and brass can be problematic on orchestra stages, resulting in poor listening conditions for the entire orchestra;
4. The musicians should receive a structured and sufficiently audible “room response” so that they hear that their sound is reaching the last rows of audience and so that they can judge the orchestral balance. This involves generating multiple reflections with different delay times from the audience part of the hall back to the stage.

The surface area occupied by a large symphonic orchestra is about 200m2, roughly 18m wide and 12m deep. The distance between musicians can then vary between 1.0-1.5m (the closest musician) to more than 10m. The acoustics of the room, and especially of the stage, must enable each musician to hear the furthest musicians almost as clearly as their closest colleagues. To achieve such acoustics, reflection paths must be created across the stage that are uninterrupted by the musicians themselves. The walls of the stage are typically obscured by the musicians and therefore do not generate useful reflection paths. Reflective surfaces located above the heads of the musicians are required, so that reflections can pass over the orchestra, this can for example be achieved by using vertically inclined balcony fronts around the stage area.

In addition, reflection paths can and must be created using suspended overhead reflectors above the orchestra. Recent research has indicated that reflections from a lower elevation are required in addition to the canopy reflections: these lower elevation reflections (precedent paragraph) should arrive earlier than the overhead reflection to avoid a compressed sound quality. In addition, convex curvature of the overhead reflector(s) is recommended to reduce the strength of the individual reflection and to increase homogeneity of the reflection coverage.

Reflections back to the stage are required so that the musicians receive a clear “room response”. The first room response reflections should arrive before 80ms, with further reflections from more distant surfaces reaching the stage with delay times between 80ms and 150ms. The room response reflections should be distributed in time, to avoid any one reflection being heard as an echo.

The most commonly used criterion to define the listening comfort between musicians on stage is the “Support Criterion” denoted ST1. The ST1 criterion compares the acoustic energy reflected during the first 100ms to the acoustic energy of the source.

In the literature, the optimum value is generally accepted to be -15dB to -12dB. This value is difficult to achieve in very large rooms and requires careful and detailed design of the reflection surfaces around the stage. The Concertgebouw of Amsterdam exhibits an ST1 value of about -17dB to -18dB which can be considered as a lower limit for ST1. The listening comfort on the stage of Concertgebouw is challenging (according to the musicians in residence and other orchestras) but remains acceptable. The values in Amsterdam can therefore be considered as the absolute minimum acceptable values. Lower values would be considered unacceptable.

It is important that ST1 is consistent over the entire stage. In particular, a local increase of ST1 at the back of the stage (where the brass instruments and percussions are) must be avoided. These instruments generate high sound levels and an elevated ST1 amplifies these instruments even more for the entire orchestra, resulting in difficult listening conditions and loudness imbalances between instruments, also for the audience. Ideally, the ST1 for the percussion and brass instruments should be below the mean ST1 level of the stage. If reflective surfaces are located in the vicinity of louder instruments, mechanisms to reduce the strength of the sound reflection with acoustic curtains or other absorbent materials must be integrated into the design.

Moreover, the ideal ST1 value depends highly on the size of the ensemble on stage and of the repertoire. A very large symphonic ensemble (possibly with choirs and organ) does not need a very high ST1 value while a chamber orchestra or chamber music can benefit from a higher ST1 value. This can be adjusted, for instance by lowering the over-stage reflector(s) to increase the ST1 for smaller ensembles or by angling surfaces in plan at the sides of the stage to increase acoustic projection away from the stage towards the audience.

For the Turku concert hall, it is required that an array of reflectors is suspended above the stage that influence orchestra balance, project sound towards the audience and to generate reflections that facilitate the listening conditions amongst the musicians. Moreover, these reflectors must be mounted so that their height and inclination angle can be varied to efficiently adjust the ST1 value. As indicated above, for homogeneous coverage, in order to avoid shadow-zones and in order to slightly attenuate the reflection strength, a slight convex curvature of all overhead ceiling reflectors is recommended.

The following values of ST1 are required:

- Mean ST1 over the stage of between -15dB and -12dB;
- The mean value of the ST1 should be variable by at least ±1.5dB by adjusting the reflectors hanging over the stage and by other variable acoustics features in the vicinity of the stage;
- ST1 for the strings and soloist position to be above the mean level: ST1 ≥ ST1mean;
- ST1 for the woodwinds and other instruments in the centre of the stage to be close to the mean level: ST1mean ± 1dB
- ST1 for the percussion and brass to be equal to or less than the mean level: ST1 ≤ ST1mean;
- Required height variability: between 7.5m and 16m for an array of over-stage acoustic reflectors;
- Required angle variability: between 0° (horizontal) and 15° vertical inclination, with the edge towards the main audience raised.