DESIGN OF THE NOKIA CONCERT HALL TALLINN WITH RESPECT TO VARIABLE ACOUSTICS

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1 INTRODUCTION

The Nokia Concert Hall in Tallinn, Estonia has been designed as a multi-purpose entertainment venue with the intention of hosting numerous performance types, both with and without sound reinforcement, to a high standard. This aspiration has been made possible through the use of an active acoustics system. The interior design of the hall has been undertaken to complement the capabilities of both the active acoustics system and the installed sound reinforcement system. The understanding of the design parameters required for the acoustics of unamplified music has been the subject of much ongoing and detailed work since the early 1900's[1]. The requirements for the design parameters associated with amplified music are subject to a more recently published body of work, and the design requirements for a hall to accommodate both unamplified and amplified performance with the use of an active acoustics system is currently an emergent sector of understanding. This paper presents some of the design principles and solutions in the specific example of the Nokia Concert Hall.

2 ACOUSTIC CRITERIA FOR THE VENUE

The Hall is intended to accommodate choral, symphony, jazz, pop and rock music, opera, musical theatre and ballet. The hall also has facilities for cinema and conferences.

The requirement for the hall to accommodate uses ranging from choral music to cinema screening illustrates the wide range of acoustic parameters demanded. The ability to provide this range of uses in the same hall requires a range of reverberation times that, with the use of passive acoustic solutions would require significant architectural engineering to achieve.

The amplified uses require a low reverberation time (RT), good direct sound coverage and minimum sound colouration. The unamplified uses require a range of higher RT times and associated lateral reflections, providing early decay and strength.

Criteria for halls of this type have been discussed with reference to the relevant musical genre in published text[2].

The hall's passive mid-frequency RT has been set at 1.0 second and the active acoustic system raises the mid-band up to 2.5 seconds. The lower RT time is intended to provide appropriate conditions for amplified sound whilst the additional reflected sound that is required for unamplified use is provided by the active acoustic system.

The intended use of the hall for theatre and operatic performances requires the inclusion of a stage house and proscenium configuration. The requirement for the hall to host unamplified orchestral performances results in the additional requirement for a stage shell.

3 PHYSICAL ATTRIBUTES OF THE ROOM

3.1 Hall

The hall is shown in both section and plan in Figure 1. The hall seats a total of 1,829 people, 1029 in the stalls, 492 in the first balcony and 308 in the second balcony. The length of the hall is 31.3m and the height to the ceiling in the main stalls is 16m. The hall is rectangular in shape and the width is 29.8m between the side walls.

The distance from the stage edge to the furthest seat in the hall is 34m (D)[3]. Table 1 below shows how this compares with similar capacity venues[3].

Hall Type	Reference	Capacity (N)	D (m)	V/N (m^3)
Concert Hall – Shoe Box	Nokia Concert Hall - Tallinn	1829	34	6.7
Concert Hall - Shoe Box	Grosser Musikvereinssaal - Vienna	1680	40.2	8.9
Concert Hall – Vineyard	Berlin Philharmonie	2218	30	9.0
Opera House - Proscenium	Teatro di San Carlo - Naples	1414	36.3	9.8
Theatre - Proscenium	Royal Shakespeare Theatre - Stratford	1459	28	4.3

Table 1: Comparison of Hall Types

An advantage of the compact design of the hall is a good direct sound level. An interesting feature of this layout is that the balconies have a longer overhang and a lower ceiling height than the accepted ideals for concert halls using only passive acoustic design principles, however the balcony overhangs are in line with the findings of Barron on theatre design with respect to improved intelligibility[4].

The compact design results in an auditorium volume of 12,300m^3 providing a volume per person of approx 6.7m^3. This is significantly lower than that of the most highly rated classical concert halls and is compares more closely with similar capacity theatres as shown in the Table 1 above. The inherently low RT is further controlled by the placement of sound absorbing surfaces throughout the auditorium hall on both perimeter wall surfaces and ceiling surfaces.

3.2 Stage House and Proscenium

The stage floor is 20m wide by 13m deep providing a maximum stage area of 260m^2. The height of the fly tower grid is 26m. This provides a large stage area capable for both full orchestral and theatrical productions[4].

The height of the proscenium is 10m above the stage floor, its width is 20m.

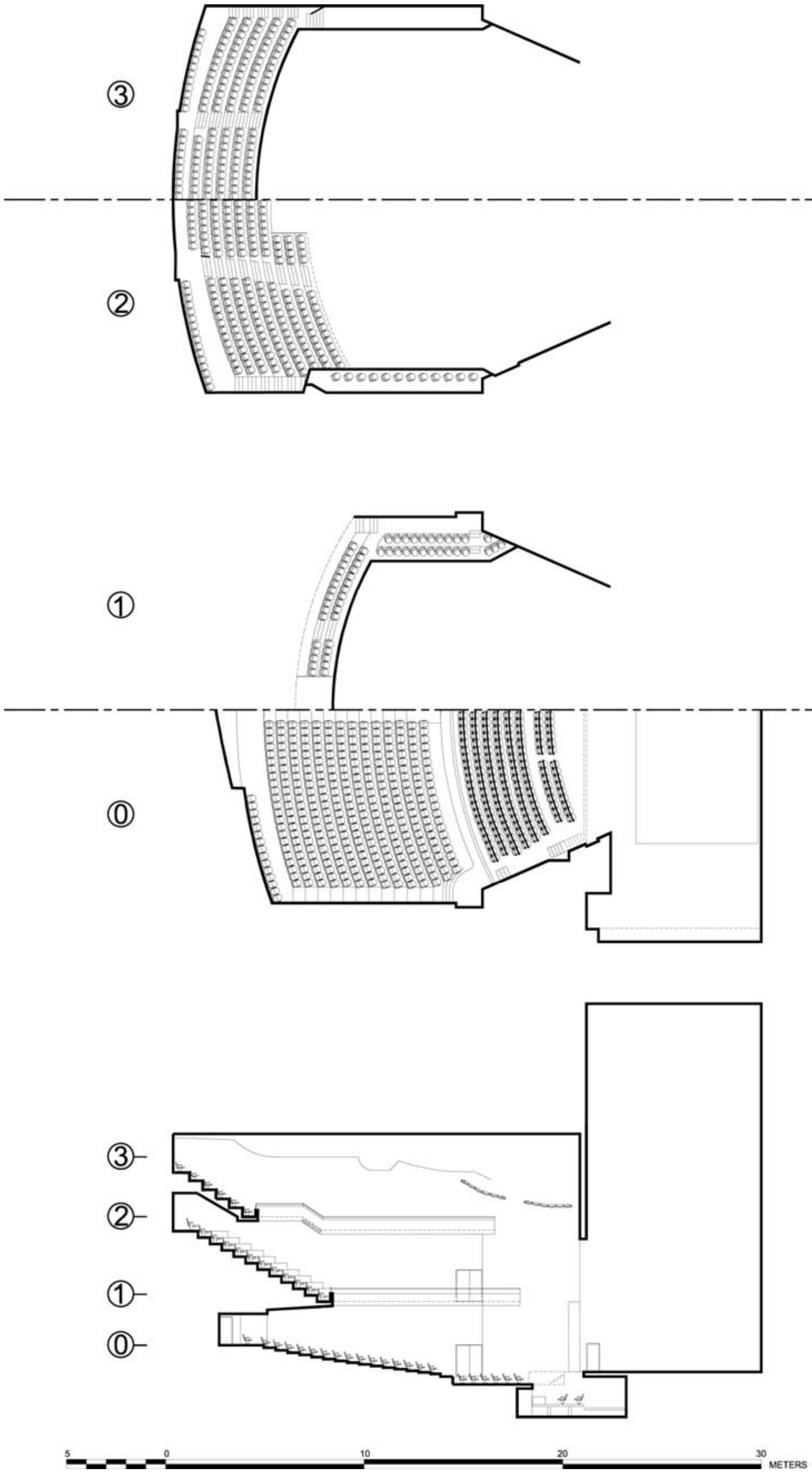

Figure 1: Plan and Section of the Hall

4 ACTIVE ACOUSTICS SYSTEM

4.1 Constellation Design Principles

Constellation combines active acoustics technology with the space's physical architecture to produce natural sounding acoustics with the aural qualities of the best performance spaces. Constellation is powered by the VRAS™ algorithm patented by Dr. Mark Poletti of the University of Auckland in 1993[5]. Meyer Sound has exclusive commercial rights to this technology. In addition, the technology can be used as an audio show control system, allowing sound effects and music to be panned throughout the room, both vertically and laterally to produce multichannel sound-scapes, with or without reverberation and spatial effects provided by the Constellation processors.

System reverberation processing operates under two basic principles:

- The apparent absorption of the venue is reduced through multi-channel gain.
- The apparent cubic volume of the venue is increased via the multi-channel coupled reverberator.

Other design principles:

- Early reflection processing promotes intimacy and connection between performers and audience and has been shown to increase the apparent source width of the performers.
- The system is linear in the frequency, gain and time domains.
- VRAS technology implements a 16-channel unitary processor per acoustic zone.
- The quantities, selection, and placement of Constellation microphones and loudspeakers are determined by the acoustical and architectural requirements of the venue.
- The system uses the same microphones in the stage area to generate early reflections and reverberation, and the same set of loudspeakers to deliver both.
- The system is able to tailor the direct to reverberant level of the performer to the audience and compensate for non-uniform venue acoustics.
- Systems may include under-balcony coverage and Constellation design principles ensure that loudspeaker localization does not occur.
- Constellation stage systems replace large mechanical shells and use a separate set of loudspeakers to cover that space.
- The system creates no pitch shifting because it is time stable and as such can be measured by any professional audio measurement tools.

4.2 Nokia Concert Hall Constellation Equipment

Microphones and loudspeakers are distributed throughout the auditorium and stage in accordance with the principles set out by Polleti[5,6]. There are a total of 189 4 inch 18Volt self powered (Stella-4) loudspeakers, of these, 47 are used under Balcony 1, and 84 under Balcony 2, which has less headroom. Each under balcony is designated as an acoustic zone with a dedicated VRAS processor and 12 boundary layer microphones.

The following equipment is used: 189 x 4 inch 18Volt self powered loudspeakers (Stella-4C); 22 x 8 inch18Volt self powered loudspeakers (Stella-8C); 17 x Dual 5 inch LF + 1 inch HF self powered loudspeakers (UPM-1P); 12 x 8 inch LF + 2 inch HF self powered loudspeakers (UP Junior); 22 x Dual 4 inch LF + 1 inch HF 48V self powered loudspeakers (UP-4XP); 12 x Dual 10 inch self powered subwoofers (UMS-1P); 56 x Omni-directional condenser microphones (auditorium); 16 x Cardioid condenser microphones (stage). The equipment layout is shown in Figure 2 below;

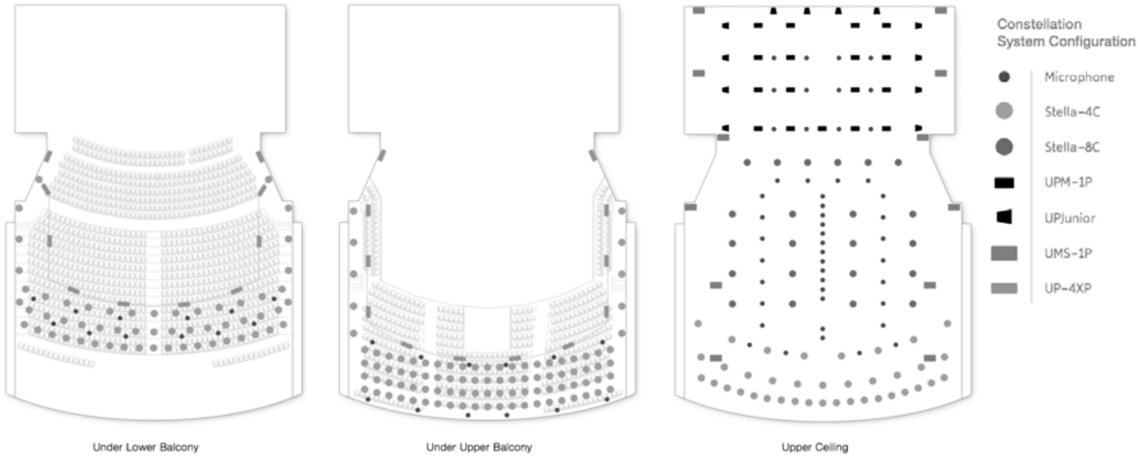

Figure 2: Constellation Equipment Layout

The auditorium is divided into four acoustic zones: house left, house right, lower balcony, and upper balcony. The stage is the fifth zone. Each zone has its own dedicated MS-VRAS processor to create sets of early reflections and late reverberation with properties that are adjusted in software during the system tuning. The system also includes a master MS-Constellation processor and five MX-CEXP expansion processors that supply additional inputs and outputs. A Lemur touch screen controller provides preset recall. Presets can also be controlled from a web browser, allowing control via iPhone or similar wireless devices.

4.3 Constellation Design Considerations

Reverberation zones are defined both by the geometry of the venue and the amount of power gain and reverberation time increase required. Each zone operates as it's own system with independent loudspeakers, up to 16 microphones and a dedicated VRAS processor. Early Reflections are generated from the 16 cardioid stage mics and distributed and time-aligned across multiple zones as required. Loudspeakers are separated from each other by at least a de-correlation distance at their lowest operating frequency. Loudspeakers and microphones are separated from each other by a distance proportional to the mid-band reverberation radius of the unassisted hall.

22 UP-4XP loudspeakers in the balcony fronts and either side of the proscenium provide the main source of lateral energy. In addition, 22 Stella 4 loudspeakers mounted in the lateral walls cover the edges of the room. Because these are located much closer to listeners they run at low power and are spaced such that a listener standing close is not able to localize individual units.

4.4 Stage House

The stage house contains: 17 overhead UPM-1P loudspeakers; 12 lateral UP Junior loudspeakers; 4 UMS subwoofers and 16 cardioid mics. The microphones and overhead loudspeakers are housed on fly-bars that allow them to be moved into various positions as required. The system is adaptable to a number of uses and able to pick-up the stage sound and propagate into the hall removing the need for physical overhead reflectors or stage shell. One person can deploy the stage system in 10 minutes by lowering the appropriate fly bars. The lateral UP Junior loudspeakers are permanently hung on the ends of the same bars, thus ensuring vertical and horizontal spacing between loudspeakers and microphones remains constant as the system is moved up or down to accommodate different stage configurations. This helps maintain system stability.

The 16 cardioid microphones above the stage operate within the reverberation radius (RR), and are typically 5-6m above the stage floor. This ensures sound is returned to the performers within 35ms, and the audience soon after. The 32 omnidirectional microphones over the auditorium (16 per zone) are placed outside the RR and capture reverberant energy only.

5 SOUND REINFORCEMENT SYSTEM

5.1 Hall

The hall is equipped with a Meyer sound reinforcement system that is used for all amplified events. Frequently, for musical theatre and other amplified music the system is used in conjunction with the Constellation system set with a short RT time to give added depth, warmth and immersion to the listening experience. Combining the two systems has been a major success for the venue, and this application has proven popular in other Constellation equipped venues.

Equipment includes: 20 x Dual 10 inch LF + Dual 3 inch HF active line array loudspeakers (MICA); 10 x Dual 8 inch LF+ 3 inch HF active line array loudspeakers (M'elodie); 19 x Dual 5 inch + Triple .75 inch HF active line array loudspeakers (M1D); 2 x Single 12 inch LF + 3 inch HF active loudspeakers (UPA-1P); 4 x Single 15 inch LF + 3 inch HF active loudspeakers (USM-100P); 6 x Dual 18 inch active subwoofers (700-HP) and 2 Galileo digital loudspeaker management systems.

6 HALL DESIGN CONSIDERATIONS

6.1 Overhead Canopy

The location of the physical overhead canopy that connects the proscenium stage to the auditorium is subject to considerations of both the passive and active acoustic components of the hall. The canopy provides a location for Constellation elements as well as providing an acoustically reflective surface. The acoustic energy provided by the canopy is required to distribute sound energy into the hall, but needs to be controlled in order to allow the Constellation stage canopy to provide the reflections required across the stage area for the musicians. Barron has shown that musicians tend to have a preference for a high ceiling above the stage and this also helps to provide even balance of sound across the stage[7]. The canopy height in the hall is set such that diffuse reflections from the canopy on the stage arrive in the range of 35ms and later, this allows the Constellation system to provide the early reflections that are important to musicians on stage and allows the adjustment of their level and time delay. The diffusing capability of the panels has been set in line with design parameters given by Cox[8]. The use of the stage system behind the proscenium allows the Constellation settings to be adjusted for the provision of a balanced stage sound and control of on-stage loudness.

6.2 Stage Front Side Walls

The consideration for first reflections from the side walls of the auditorium is a result of both the requirement for lateral energy in the seating areas which contributes to various parameters such as Strength[3] and the requirement to provide a suitable nearfield control of the sound emitted from the side and rear of the main loudspeaker arrays. A selection of low frequency absorbers and reflective panels is used on the front side wall to provide absorption local to the loudspeaker arrays and reflective surfaces immediately adjacent to the side of stage.

6.3 Auditorium Side Walls

The presence of lateral reflections is essential for the experience of the spatial impression[9] in a hall. The associated parameter of spaciousness is one of the key parameters that distinguishes the quality of good sounding halls[3]. Lateral reflections from side walls in the plane of the audience are subject to attenuation due to grazing incidence over the audience itself[10]. The provision of lateral reflections from higher surfaces can minimize the effect of audience attenuation and provide more consistent lateral energy over the seating area[10]. The provision of acoustically absorbent surfaces at low level in the hall is designed in conjunction with the provision of Constellation units at higher level and in the balcony fronts to provide good coverage of lateral energy over the seating area.

7 USE IN PRACTICE

7.1 Tuning The System

Following the design and installation, all adjustments and presets for the system were made within CueStation software that allows control of the system from a number of wireless client computers simultaneously. The system was calibrated and voiced to allow the RT to be raised incrementally from 1s (unassisted) – 2.3s (choral) without significant double sloping beyond that desired for clarity.

The system is designed to support a reverberant level in the room of 105 dB, allowing for linear operation even for a large symphony orchestra. The calibration process ensures the system remains linear throughout it's frequency and gain range.

The VRAS algorithm uses multiple independent microphones and loudspeaker channels to establish its gain, and couples this to the VRAS multichannel reverberator. The system is able to achieve both power and reverberant gain independently and the advantage is that results are not based on gain alone. This provides flexibility in achieving settings that have the same reverberation time but with different amounts of clarity[11].

Constellation facilitates adjustment of the following acoustic parameters: Reverberance (RT, EDT); Intimacy (initial time gap); Loudness (G); Clarity (C80); and Warmth (bass ratio and low frequency strength). The subjective tuning of the system has been performed by John Pellowe using expertise gained over 20 years recording classical music in some of the world's finest concert halls for the Decca Record Co. This experience has helped ensure the success of the project and "natural sound of the hall".

The subjective tuning process includes: Balancing levels of overhead and lateral energy (both stage and auditorium); Setting levels, density and attenuation of Early Reflections; Setting RT and strength for the stage, L+R auditorium and under balcony zones for the various user presets.

The under balcony systems are set for somewhat shorter reverberation times than the main auditorium as this better matches the visual environment. (Care must be taken to retain credibility between what the listener hears and sees.) The exception to this is where the system is used for special effects, when the aim might be the complete opposite.

7.2 Use In Performances

The flexibility of the user interface allows the settings of the system to be recalled and manipulated in realtime. The premise of the system is not that it is used in the same manner as "architecture" either on or off, present or absent, but that it comprises a flexible creative tool.

This assumes that the static state of the room acoustics are adequate to have controlled any acoustic anomalies and set an appropriate base for the addition of further acoustic energy into the space. This allows the experienced engineer the freedom to manipulate the acoustic character of the room from piece to piece, in much the same way that a sound engineer would adjust equalization, gain and other settings during a performance.

Figure 3 below shows a range of reverberation presets within the system.

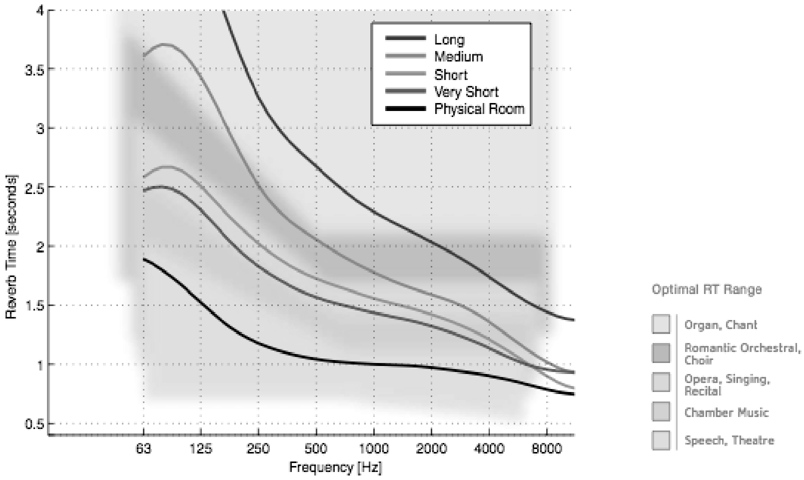

Figure 3: Reverberation Presets within the Constellation System

The ability to vary the parameters in real time also allows the possibility of the engineer significantly degrading the acoustic quality of the hall due to inappropriate setting of numerous parameters.

A debate has long been continuing into the “natural” sound of concert halls and performance venues. As recently as 2009 the removal of a “sound-enhancement system” has been hailed as a triumph for the “natural sound” of a venue[12]. In the case of the Nokia Concert Hall in Tallinn the continued development of technology combined with the careful design and sensitive commissioning of the system has produced subjectively pleasing results. The ability of the system to store numerous configurations and facilitate further adjustment of numerous parameters has also provided the opportunity to continue fine tuning the acoustic parameters of the hall to achieve excellent results.

7.3 Audience Experience

Audience envelopment is an essential part of the concert going experience. Constellation systems are designed to ensure listeners are in the same acoustic environment as the performers, providing strong response to audience reactions and applause, and providing optimized acoustics for off stage music.

7.4 Four way communication

The system is designed to optimize the four-way communication necessary for a venue to be successful:

Performer–Performer; Performer–Audience; Audience–Audience; Audience–Performer.

The presence of the system is intended to be transparent although the effect of the system is clearly quantifiable allowing the venue to host a range of events with the ability to increase the subjectively important parameters individually and in real time as required for numerous performance types.

Collaboration between design, installation and commissioning specialists is essential for the optimum execution of such projects. And the ultimate success of the project is based on the experienced tuning of the system in a room which provides a clean acoustic canvass upon which to paint with a correctly located and installed active acoustic system.

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