Acoustic design of the Ukaria Cultural Centre Concert Hall

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ABSTRACT

The recently-opened Ukaria Concert Hall (formerly Ngeringa Concert Hall) is an intimate chamber music recital space. The acoustic design of the hall faced the challenge of achieving good acoustics for chamber music within an overall-concave architectural room form, while providing comparable acoustic quality to historical European precedent venues. A key component of the room design was the shaping of the room surfaces to reduce focussing, provide high clarity and provide a strong sense of immersion as per a traditional rectangular hall. Key design features include the provision of additional lateral reflection paths above the audience area and a highly-diffusive reciprocal-frame ceiling. The design of sound scattering surfaces in the room was done using Boundary Element Modelling (BEM) to create room elements that were inherently part of the room aesthetic but also were functional acoustically. The resulting hall has high subjective reverberance, clarity and immersion despite its relatively-small size and seating capacity and has been acclaimed by both musicians and audiences.

1. INTRODUCTION

The Ukaria Cultural Centre is located at the Ngeringa winery near Mt Barker, SA and replaces a “tin shed” that was previously used as the venue for the Ngeringa Arts concert series that has been held at the winery since the late 1990s. The founder of the concert series, arts philanthropist Ulrike Klein, is one of the major sponsors of the Australian String Quartet and has been leading fundraising efforts to buy a matched set of Guadagnini instruments for the ASQ’s use. In 2013, Ngeringa Arts decided to replace the existing venue at the winery with a purpose-built venue designed to host the Ngeringa Arts chamber music series, as well as provide exhibition space and a new cellar door for the Ngeringa winery. Although opening as the Ngeringa Cultural Centre, the concert hall has since been renamed the Ukaria Cultural Centre to avoid confusion with the adjacent Ngeringa winery.

2. ACOUSTIC BRIEF AND DESIGN TARGETS

The brief from the client was for a 150 seat space purpose-designed for chamber music for small ensembles up to ~10 musicians, providing the “best acoustic possible”, and referring to classic European halls as precedents for the room acoustic, in particular Wigmore Hall in London and the classic “jewel box” palace ballrooms/anterooms e.g. the Eroicasaal in the Lobkowitz Palace in Vienna (the location of the premiere of Beethoven’s *Eroica* symphony) and the Music Room at the Esterhaza palace at Fertőd in Hungary (the home of Haydn’s court orchestra), as well as contemporary spaces such as the Salon at the Melbourne Recital Centre.

These spaces are generally characterised by a rectangular plan form, and use of rich decoration that provides extensive acoustic diffusion, with a reverberation time in the vicinity of 1.5 s.

In response to the brief, the following objective acoustic design targets were set for the Ngeringa concert hall:

Table 1: Design parameters developed for Ngeringa Concert Hall in response to the client brief:

Parameter	Value (occupied, average of 500 Hz and 1 kHz)
Early Decay Time, *EDT* *(s)*	1.3-1.6 s (80-100% of RT)
Reverberation Time, *RT* (s)	1.6 s ± 0.1 s
Musical Clarity, C_{80} (dB)	1-3 dB
Lateral Energy Fraction, LF_{80}	0.2-0.3

No criteria were developed for loudness (G) due to the small size of the venue which means that adequate loudness would be achieved for small music ensembles without any need to specifically focus on this aspect of design.

3. ARCHITECTURAL CONCEPT

The architectural concept for the Ukaria Cultural Centre involved a strong architectural concept of having the architecture of the concert hall respond to the site – in particular, a desire to include a glazed wall behind the stage in order to provide views across the grounds of the winery towards the summit of Mt Barker (including a she-oak tree that gives its name to the entire site; *Ngeringa* means "she-oak" in the local Peramangk language). The materiality of the space was also informed by the rural setting, with a desire to use sustainable and locally-available materials such as rammed earth and sustainably-sourced timber.

Unfortunately, the initial architectural concept (Figure 1) was unfavourable acoustically in that the overall room shape was near-circular with a conical ceiling (from 4.3m at the base to 6.8 m overall room height), absorptive curtains separating the concert hall from adjacent gallery/exhibition spaces and "sawtooth" side walls which would result in uneven reflection coverage of the audience area (due to focussing in plan and from the ceiling as well as the inefficient reflection patterns from the sawtooth side walls), short reverberation (only predicted 0.8 s occupied), poor spatial impression (very frontal room sound with little envelopment or spaciousness, LF < 0.20) and poor tone quality (especially harshness from over-strong overhead reflections).

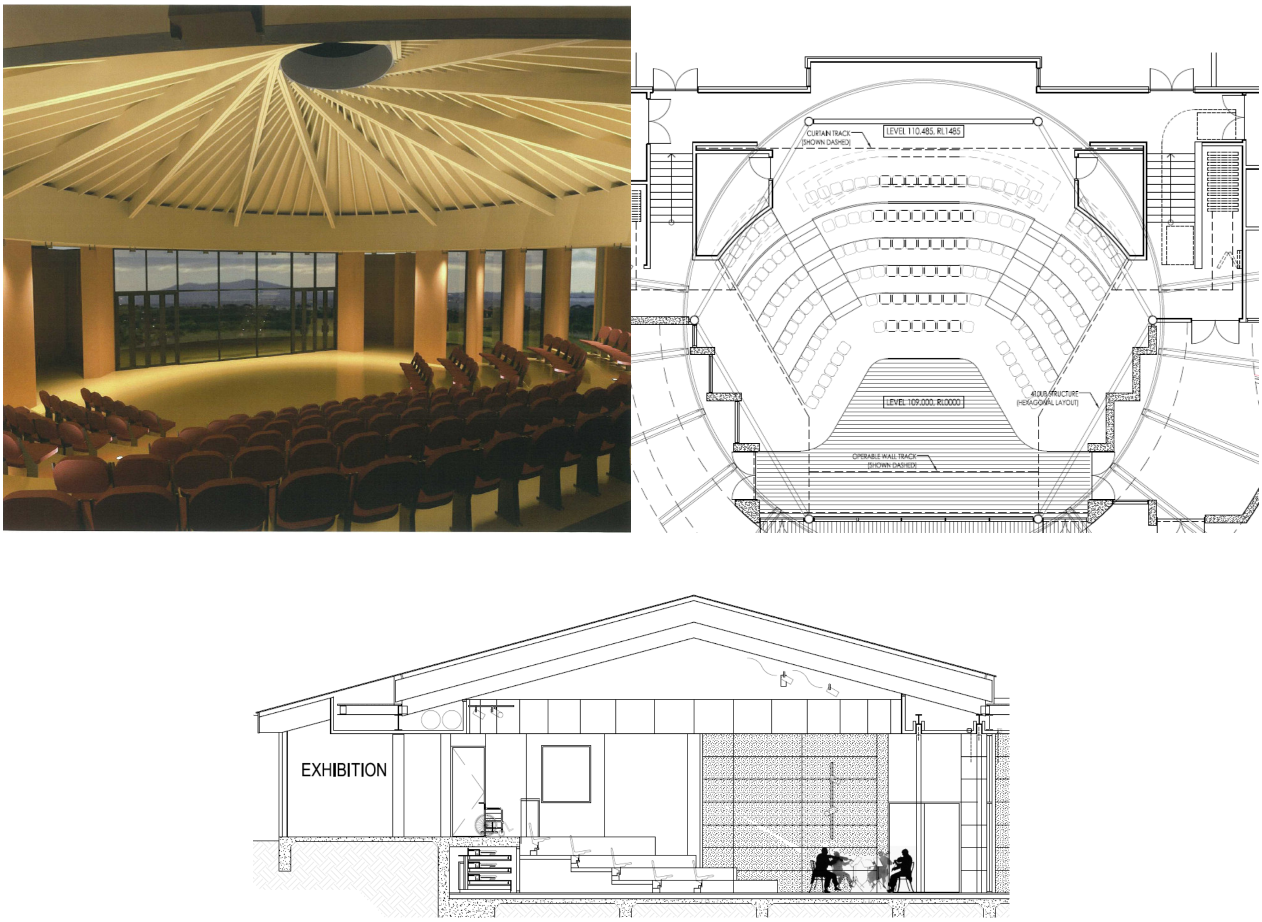

Figure 1 Render, plan and section of original Concert Hall design

4. ROOM GEOMETRY DEVELOPMENT

Initial design process focused on addressing shortcomings of the initial design, in particular addressing the following areas:

- Lack of reverberance (by increasing room volume and eliminating sound-absorptive surfaces)
- Improving poor early energy (by reshaping the room plan form for more-efficient reflection to audience)
- Rectifying poor tone quality (by adding sound-scattering finishes, modifying the domed ceiling to reduce focusing)

- Addressing poor spatial impression (by adding additional surfaces to provide early and late lateral reflections to improve the subjective spaciousness and immersion)

4.1 Room Plan Form

The “sawtooth” side wall geometry initially resulted in poor reflection coverage to the centre of the room (with each successive edge of the walls shielding much of the next “step” from view from the stage). This was rectified by changing to a fan-shaped “sending zone” adjacent to stage to improve the early reflections to the central audience, as shown in the *Odeon* scatter plots in Figure 2.

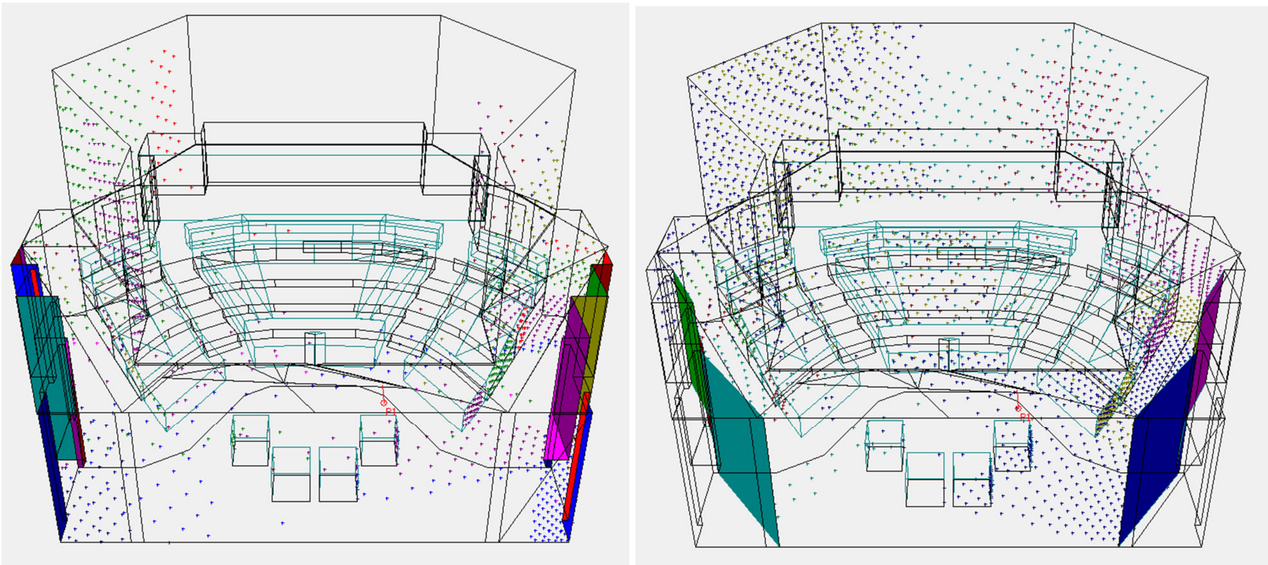

Figure 2 Reflection patterns from original (left) and revised (right) stage zone walls, showing improved reflection coverage to central seating area.

This resulted in an overall-hexagonal plan form, with the fan-shaped “source zone” providing strong lateral reflections to central seats, while the reverse-fan “audience zone” sends lateral reflections to rear seats. The overall room shape also helps to reduce the risk of false localisation that can occur in a small rectangular hall where the side wall reflections are very strong due to the low hall width (Barron 2010).

4.2 Upper Room Geometry

Initial listening tests (via an auralisation demonstration in Arup’s *SoundLab*) indicated that the room’s spatial impression was subjectively very frontal, with little source broadening or immersion. This was a consequence of the reflection sequence, which was dominated by the direct sound and at most one or two significant side wall reflections. Although the side-wall changes discussed in Section 4.1 improved the spaciousness (source-broadening) aspect, there was still a need to improve the “3D” aspects of the room spatial response via incorporation of raised reflection paths other than the ceiling reflection. Ideally, these reflections would occur in the 50 ms to 100 ms range to provide spatial cues without being distinctly audible as echoes.

Additional reflection paths were incorporated via a series of stepped “bulkheads” added to the side walls, in effect creating a series of soffits with varying height (and hence reflection delay) to act as 2^{nd}-order reflecting surfaces.

The side walls, a perimeter soffit around the front walls of the concert hall and a stepped soffit in the upper wall above provide strong lateral reflections that progressively “step up” the side walls of the hall, creating a strong spatial impression for the early sound and also increasing the subjective height of the auditorium. The reflection patterns from the front side walls are shown via ray-tracing in Figure 3.

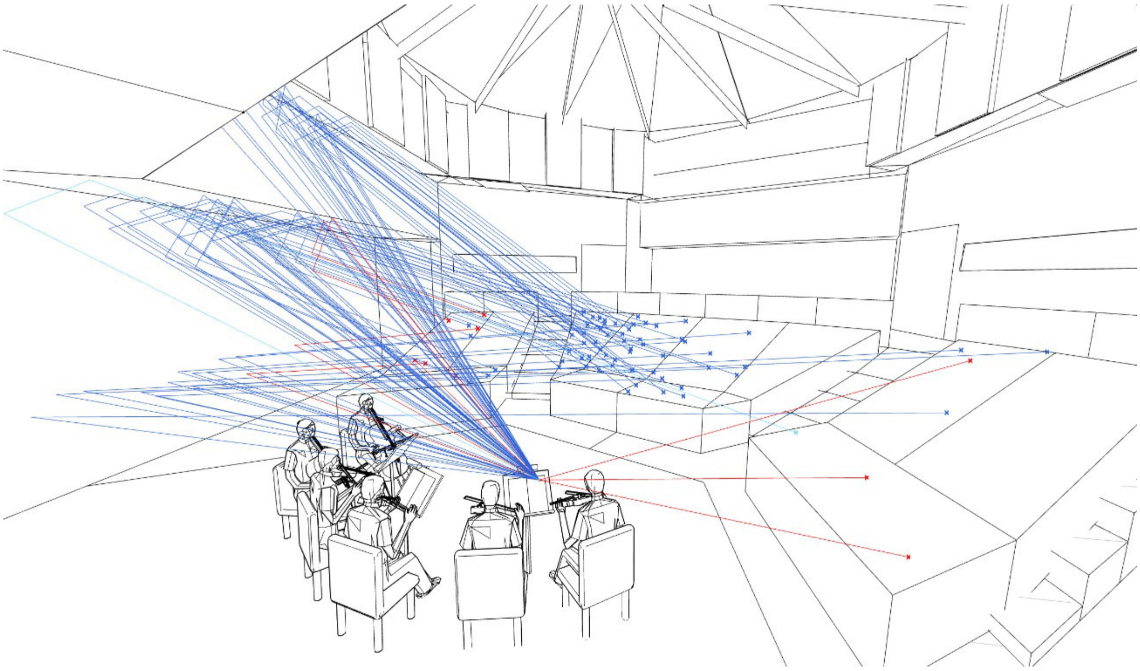

Figure 3 Ray-tracing showing 1st and 2nd order reflections from front side walls and “bulkhead” soffits

An additional “step” in the front wall (above stage) provided 2nd-order “support” reflections for musicians on stage, as shown in Figure 4.

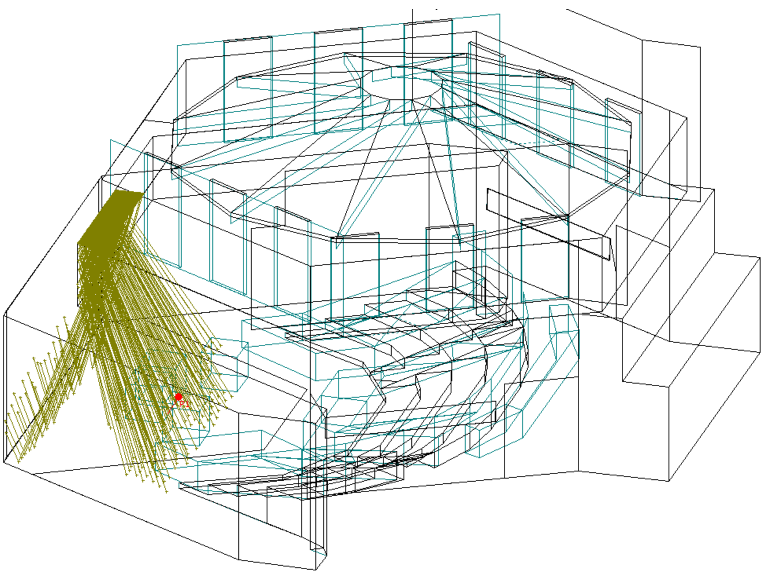

Figure 4 Reflections from “support bulkhead” on front wall

The front room geometry successfully improved the spaciousness of the early sound, however additional improvement to the overall sense of immersion (i.e. spaciousness of the late sound field) was still desired. This was achieved by two interventions: adding “bulkheads” on the rear wall to provide delayed raised reflections from behind the audience members, and by making the upper room volume heavily diffusive. The reflection pattern from the rear wall shaping is shown in Figure 5.

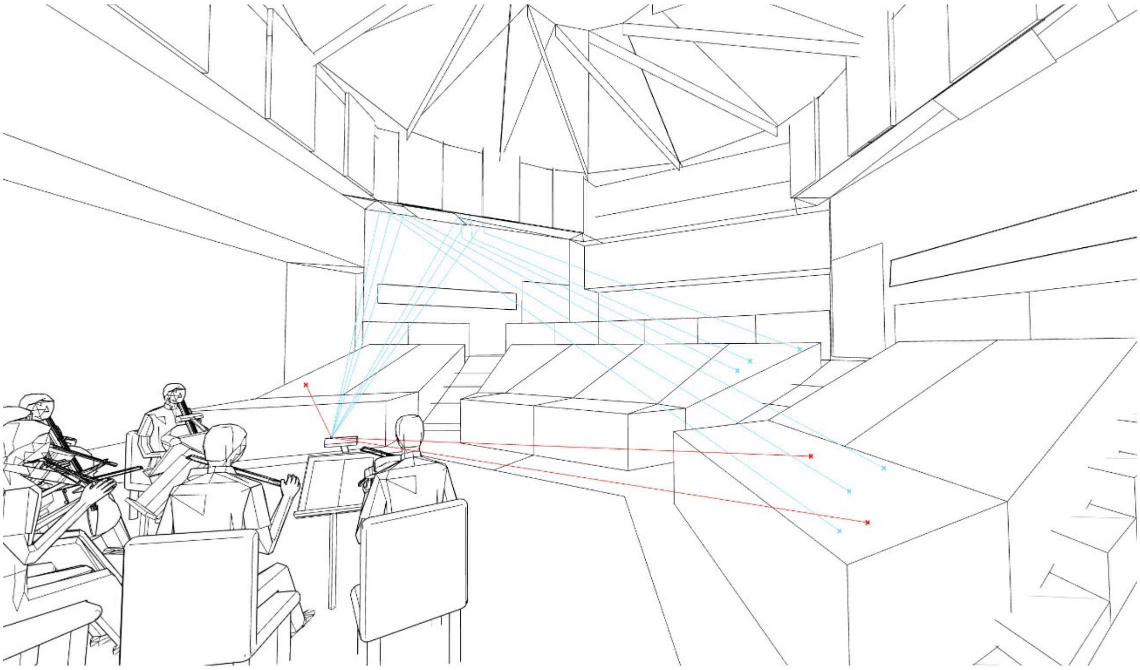

Figure 5 2nd Order Reflections from Rear Bulkheads providing "rear lateral" reflections to the audience area

The subjective effect of the rear room shaping is to simulate the listener being in an acoustically-larger space and to provide a considerable subjective impression of immersion despite the relatively small room size (~2100 m³).

4.3 Roof Geometry

The roof geometry of the concert hall was originally a truncated cone shape which would result in strong focusing of sound onto the audience area, which was causing tone quality issues as well as decreasing the reverberance (by "grounding" the ceiling reflection onto the absorptive audience plane after only one reflection and hence "starving" the reverberant field of energy). This exacerbated the lack of room volume due to its relatively-low ceiling height (average ~5.5 m).

During the initial design stages, the possibility of changing the roof profile to a flat roof was explored; although this resulted in a noticeable acoustic improvement (and was registered as such by the client and architect during critical listening auralisation workshops in the *SoundLab*), the aesthetic desire was for the conical ceiling (in particular the spiraling reciprocal-frame pattern of ceiling beams with a central oculus), and hence the acoustic design had to reduce or eliminate the negative effects of a concave ceiling while preserving the architectural design qualities.

Focussing from the ceiling was addressed by a combination of:

- Raising the ceiling height from 4.3 m (base)/6.8 m(top) to 9.8 m (base)/ 11.3 m (top) to provide sufficient reverberance for the desired 1.6 s RT – i.e. an increase in the overall room height of 4.5 m
- Flattening the ceiling (i.e. decreasing the slope of the cone); in conjunction with the changed ceiling height this reduced the strength of focusing at the audience plane.
- Making the ceiling strongly diffusive (refer Section 5).

4.4 Comparison of Room Improvements

Figure 6 shows 3D "rose" plots of the spatial distribution of the sound field in the final model for a mid-audience seat, showing strong early lateral reflections (pink) and very even spatial distribution of reflections up to 80 ms (green) and very even spatial distribution of the late reverberant sound (blue). This registers subjectively as a strong sense of spaciousness and immersion despite the relatively small size of the room.

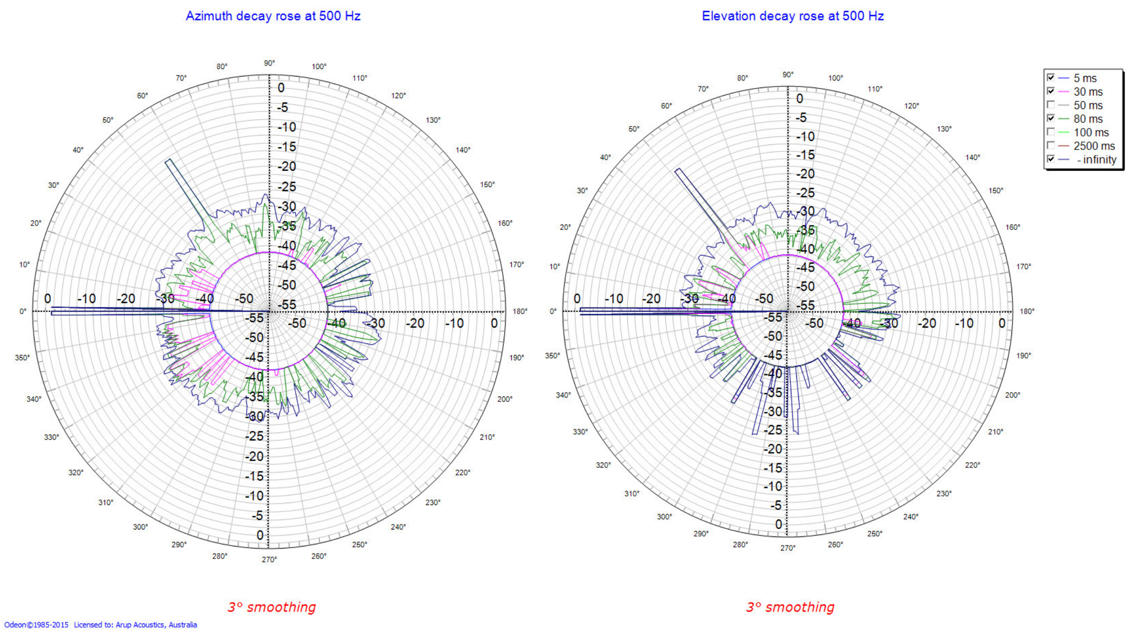

Figure 6: Spatial Plot of Sound Field for mid-stalls seat

5. DESIGN OF SOUND SCATTERING FINISHES

The Ukaria Concert Hall offered a rare opportunity for an extremely-close collaboration between architect and acoustician in the development of the sound scattering finishes for the hall, resulting in the sound scattering finishes becoming part of the inherent architecture of the hall rather than an "add-on".

In responding to the architectural brief and the site, the sound scattering finishes allowed an unusual scope for creativity and "artistic" design.

The overall concept for the sound scattering finishes was focussed on three levels of diffusion:

- Heavy scattering to the upper walls and ceiling (effective at ~250 Hz and upwards) to:
    - Mix the reverberant sound field
    - Achieve even reflection coverage from the ceiling / avoiding focussing
    - Improve the tone quality of overhead reflections
- Medium scattering to the side walls and "bulkhead" soffits (effective from ~ 1 kHz upwards) to:
    - "Blend" early reflections across the audience area
    - Improve tone quality by "softening" strong lateral reflections
    - Avoid potential echoes back to stage from soffit 2nd order reflections
- Light scattering for the glazed walls behind stage (effective from ~3 kHz upwards)

The design frequency of 1 kHz for the sidewall and soffit scattering was adopted based on previous experience and the discussion in Griesinger (2010), who suggests that phase coherence between the harmonics of the direct sound above 700 Hz is important for subjective engagement and a sense of "immediacy". This theory has also been supported by Beranek (2013).

Griesinger states that the basilar membrane analyses complex tones within each critical band based on the phase coherence of the harmonics above ~700 Hz, with constructive and destructive interference between harmonics resulting in an amplitude-modulated signal (similar to a comb filter). The ability of the ear to detect these modulations is a key parameter for conveying information regarding the music including localisation, a sense of aural distance and tonal quality. The presence of strong early reflections in this frequency range "scrambles" the harmonic of the direct sound and reduces the strength of the modulations, making the sound subjectively more "distant" and reducing engagement (and, potentially, perceived tonal quality/timbre). Hence high frequency diffusion is beneficial in reducing the strength of the reflected sound and improving the immediacy and engagement of the direct sound.

The designed scattering finishes were modelled using the *Reflex* software (AFMG 2011), which is a commercially-available 2D boundary element modelling (BEM) diffusion modelling package.

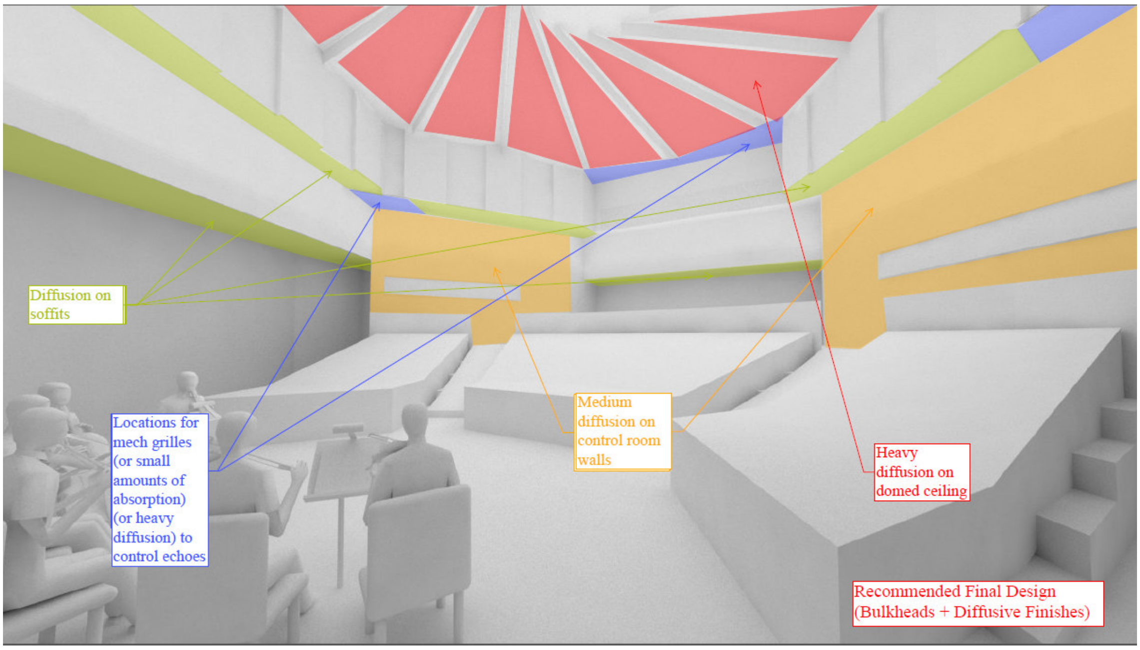

Figure 7 Diffusion/scattering design for Ukaria Concert Room

The glazed stage walls posed a challenge in implementing scattering; some scattering was achieved by using oversized expressed glazing frames to provide some irregularity to the glazed surfaces. The requirement for views through the glazing prevented the use of a transparent diffuser material in front of the glass (e.g. a diffusion profile in Perspex) which (although successfully implemented acoustically on other projects e.g. the Queensland Symphony Orchestra's rehearsal hall within the ABC Brisbane building) would distort the visual image unacceptably.

5.1 Side Walls

5.1.1 Stage Wall

The stage wall (platform right side) is an "interior" wall separating the concert hall from the foyer and is a structural wall constructed of rammed-earth. (The other stage walls are glazed). A sound scattering finish was desired for this wall with mainly "horizontal" scattering to blend the reflection coverage from this wall.

Several options were developed, including the use of an irregular timber batten screen in front of the rammed earth wall, and casting a diffusion profile into the rammed earth. The selected option was a "wavy wall" profile cast into the rammed earth, which provides very even spatial coverage (close to the idealised Lambert cosine directivity) and is an effective scattering surface above 1 kHz as shown in Figure 8.

Figure 8 Side Wall Diffusion Image and Spatial Response (1 kHz)

5.1.2 Control Room Wall

The scattering profile for the control room walls behind the audience seating areas was inspired by a piano keyboard, and consisted of a quasi-random sequence of four different “blocks” separated by constant-width spacers, each with a different depth groove (60mm/45mm/20mm/10mm) routed into the block.

Because the control room walls do not reflect directly onto the audience (except for the seats immediately adjacent to these walls), there was more scope to be “aesthetic” with these walls and hence the scattering profile was not as acoustically-optimised as for other surfaces.

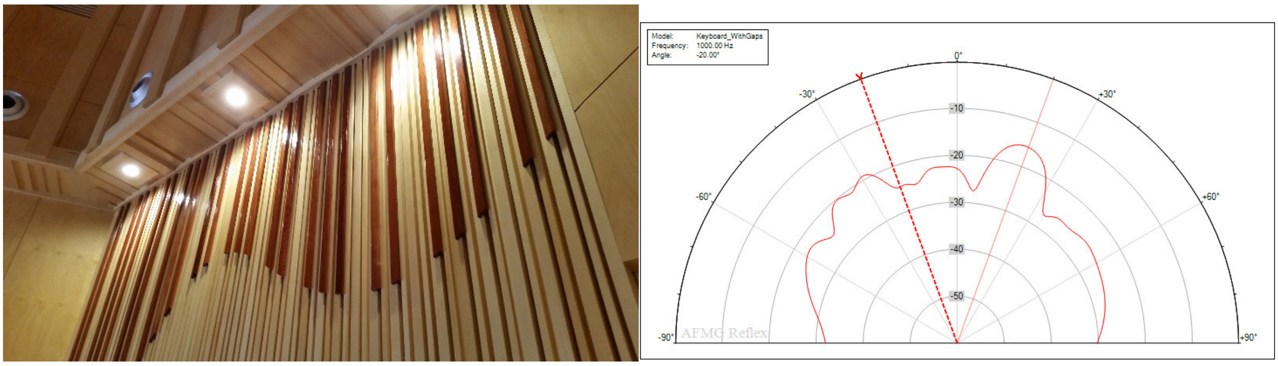

Figure 9 “Keyboard” diffusion finish for control room windows and spatial response (1 kHz)

5.2 Soffits

The soffit diffusion design was also intended to maximise the horizontal diffusion to improve reflection coverage over a wider audience area, as well as to disperse potential echoes away from the source position. Due to the small width of the reflecting surface, the diffusion profile was only required to strongly scatter from 2 kHz upwards.

Again, several options were developed, with the selected option being based on the Fibbonaci number sequence implemented in a 10 mm module, which was truncated to a maximum sequence depth of 80 mm (by taking the element height modulo 80 mm) and then mirrored to obtain a repeating sequence of 18 elements that were repeated as needed to cover the soffits.

Figure 10 Soffit Diffusion image and Spatial Response (2 kHz)

5.3 Ceiling Scattering

The ceiling profile was perhaps the most constrained area in terms of architectural integration. The agreed acoustic/architectural concept was for each of the near-triangular ceiling panels intermediate between the spiralling reciprocal frame roof beams to be subdivided into a “honeycomb” type tracery of dividers, with infill panels within each subdivision that could be varied in depth to provide scattering. The architectural desire was for the panels to be generally “shallower” at the centre of the room so that the dividers between the cells were more-prominent at the sides of the room and reduced towards the centre; giving an effect similar to the tracery of vaulting in medieval architecture.

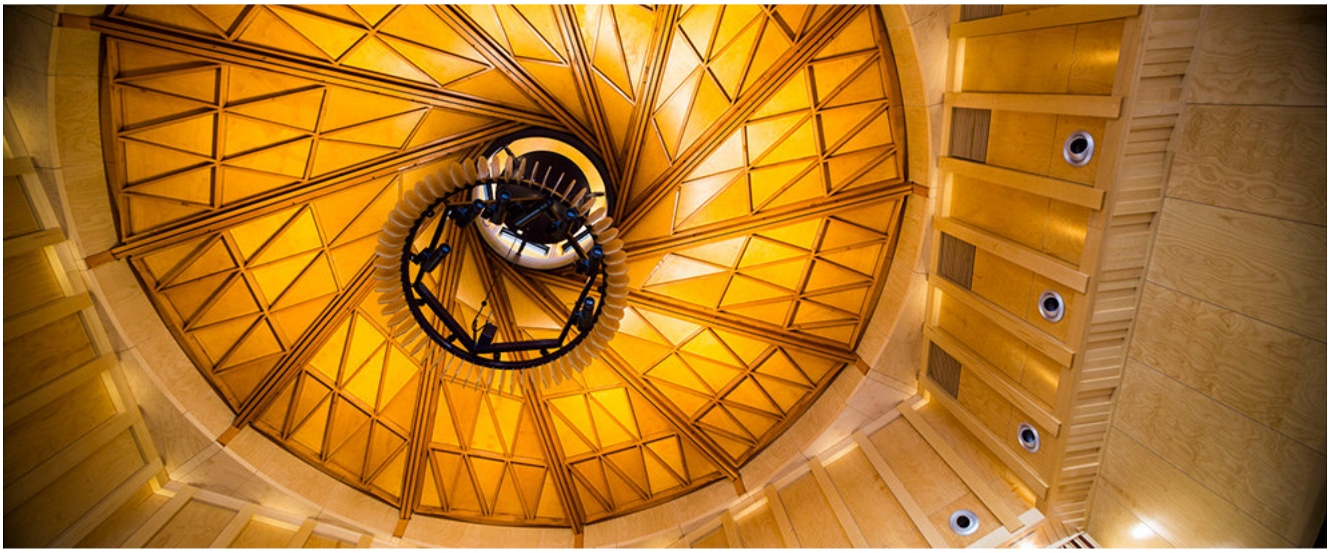

Figure 11 Finished ceiling of Ukaria Concert Room

The acoustic design for the ceiling considered various options including QRD and PRD diffusers; the final design included varying depths of the infill panels based on an inverted Fibonacci sequence.

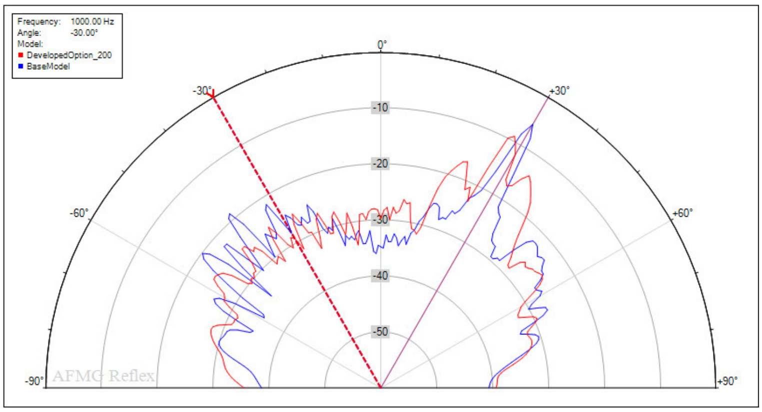

Figure 12 Scattering performance of developed ceiling (red) compared to ceiling w/ no infill panels (blue)

The scattering design broadens the reflection pattern from the ceiling to reduce the strength of focusing as well as avoiding the “back-scatter” that would occur at high frequencies from a ceiling with no infill panels.

6. CONSTRUCTION AND COMMISSIONING

During construction, the client decided to add an additional 70 seats to the hall (adding a second retractable seating bank at the upper level in the former exhibition space), increasing the overall hall capacity to 220 seats. However, it was too late to incorporate any design changes to the hall to offset the additional seating.

As a result, the achieved room reverberance was reduced to a measured unoccupied RT of 1.35 s (no occupied measurements have been conducted as yet), however the other measured acoustic parameters are all within the briefed range. In particular, the EDT was very high relative to RT: 1.30 s which is 95-100% of RT at mid-frequency. The frequency spectrum of the reverberance showed a bass rise at 63 Hz, but a dip at 125 Hz which is likely to be due to the relatively-lightweight retractable seating decking. As part of the ongoing tuning of the hall, modifications to the retractable seats to reduce their absorption at 125 Hz are planned to be investigated.

Clarity was within the recommended range with unoccupied clarity C_{80} 1.4 dB at mid-frequency. Lateral energy was not directly measured during the commissioning which only used omnidirectional and SoundField microphones; the predicted LF_{80} of the final hall design is 0.23 at mid-frequency.

A voicing concert was held in the hall in August 2015 with piano quartet and string quartet repertoire, played by Kristian Chong and the section principals of the Adelaide Symphony Orchestra, followed by the opening concerts on the weekend of 29/30 August 2015 with performances by the Australian String Quartet, Marshall McGuire, Paul Dean and performers from the Australian National Academy of Music, as shown in Figure 13.

Figure 13 Australian String Quartet performing at the opening concert.

7. CONCLUSIONS

The Concert Hall at the Ukaria Cultural Centre has been a rare opportunity to design a venue specifically for small chamber ensembles where the acoustic quality of the room is of prime importance. The close cooperation between the acoustic and architectural design has resulted in a space that is visually and acoustically stunning.

The subjective impressions (from performers and audience members) has been extremely favourable. In particular, the hall has very high perceived reverberance, high clarity and intimacy and beautiful tone quality. The spatial impression is of a hall much larger than the physical size of the hall. The reduced RT does not appear to have impacted significantly on the perceived quality of the hall (noting that for chamber music the appropriate RT for different repertoire is somewhat a matter of taste).

Critical reaction has also been very favourable, with the initial review in *The Australian* stating:

It is a marvel and sound-wise quite the best venue this reviewer has encountered for small chamber ensembles… The air felt alive with sound, and the timbres of instruments came across with extraordinary clarity. The effect was to put a lens up close to each performance, which in turn seemed to inspire the players to give their best (Strahle 2015)

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