Lateral reflections in the Sydney Town Hall; preservation of room acoustics in a historically significant venue

Matthew Ottley (1)

(1) Marshall Day Acoustics, Sydney, Australia

ABSTRACT

Sydney Town Hall was constructed in the late 19th Century and is of heritage significance. The main hall, known as Centennial Hall, is a traditional 'shoebox' hall and features one of the largest pipe organs in the world, the 1890 'Grand Organ'. The acoustics of the space are held in high regard and the space was the home of the Sydney Symphony Orchestra prior to construction of the Sydney Opera House.

In the 1970's two side boxes (small rooms within the space) were installed at ground level in Centennial Hall in order to narrow the hall and provide increased lateral reflections from musicians on the stage to audiences in the Eastern Gallery (the seating section at rear of the hall on first floor level). In 2018 a proposal was explored to remove the two side boxes, primarily in order to increase seating capacity of the venue. This paper details the acoustic investigation carried out to determine the likely effect the removal of these boxes will have on the acoustics of the space, particularly with regards to reflections via the boxes to the Eastern Gallery. The assessment included measurement of the 3D reflection sequence from various stage positions to various seating positions, as well as 3D acoustic modelling of the venue, with and without the side boxes.

The proposal raises questions regarding the value and protections available to the acoustics of rooms with heritage significance.

1 INTRODUCTION

Sydney Town Hall is owned and operated by the City of Sydney. The main venue, Centennial Hall is a 2,000 seat traditional shoebox hall with four row deep side galleries (Northern and Southern Galleries) and a seven row deep rear gallery (Eastern Gallery). The Hall features one of the largest pipe organs in the world, the 1890 'Grand Organ'.

The maximum dimensions of the space are in the order of 50m long, 25m wide and 19m high. The dimensions are similar to two of the most acoustically revered shoebox halls in the world, namely the Grosse Musikvereinssaal at 29 m long, 19 m wide and 19 m high (Musikverein n.d.) as well as the Concertgebouw at 44 m long, 28 m wide and 18 m high (Amsterdam Info n.d.).

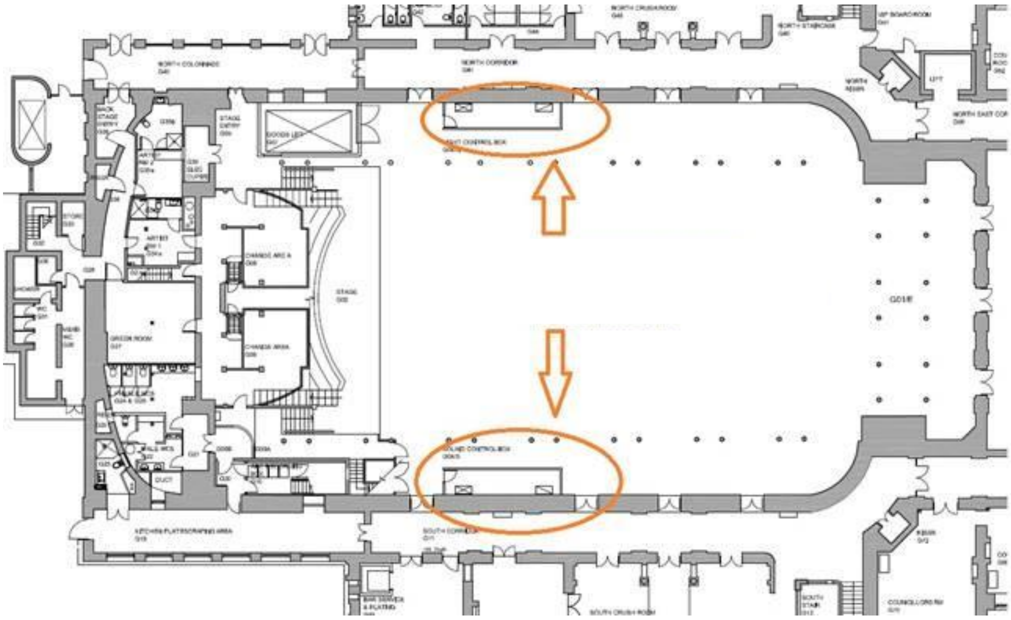
The acoustics of the space are held in high regard and the space was the home of the Sydney Symphony Orchestra prior to construction of the Sydney Opera House. As Emma Dunch, CEO of the Sydney Symphony Orchestra, noted on their return performance to the venue "We are thrilled to be coming back and it has a world class acoustic for a symphony orchestra. As good a hall as you will hear anywhere around the globe" (Dunch, 2019).

The hall comprises original finishes throughout, including:

- Floor: Timber (some carpet to first floor balconies)
- Stage: Timber
- Ceiling: Ornate plaster
- Walls: Ornate plaster & masonry

- Seating: Upholstered fixed seating in first floor, lightly upholstered loose seating to ground (approx. 50% in place during testing)

Two side boxes, small enclosed rooms of timber frame construction built within the auditorium, adjacent the side walls, were installed in the 1970's at ground level, just forward of the stage. The acoustic consultant directing this work was Peter R Knowland. From conversations with Mr Knowland his intent was to narrow the hall and provide increased reflections from musicians on the stage to the Eastern Gallery (the seating section at rear of the hall on first floor level). The box on the southern side provided space for outside broadcast facilities, whilst the box on the northern side was a lighting control room.



Source (supplied by City of Sydney, 2017)
Figure 1: Side box locations

Source (Author, 2018)
Figure 2: Side box below balcony

The use of the boxes for both outside broadcast and lighting is now no longer needed. The boxes consume floor space near the stage, which could be used for additional seating, and also impede sightlines from some areas behind the boxes. The use of the venue has also changed since the 1970's, with conferences, cocktail and dining events and amplified musical performance now making up a larger portion of the venue's program. The City of Sydney have been exploring the possibility of removing the two side boxes, primarily in order to increase seating capacity of the venue. The City sought investigations to determine what effect the removal of these boxes would have on the acoustics of the space, particularly with regards to sound reflections via the boxes to the Eastern Gallery.

2 ASSESSMENT METHODOLOGY

The standard metrics for describing acoustic parameters in a performance space are set out in International Standard ISO 3382-1:2009 *Acoustics -- Measurement of room acoustic parameters -- Part 1: Performance spaces*. A table of the main parameters are set out in Annex A (informative) of the standard, reproduced below.

Table 1: Acoustic quantities group according to listener aspects (reproduced from ISO 3382-1)

Subjective listener aspect	Acoustic quantity	Single number frequency averaging [a] Hz	Just noticeable difference (JND)	Typical range [b]
Subjective level of sound	Sound strength, G, in decibels	500 to 1 000	1 dB	−2 dB; +10 dB
Perceived reverberance	Early decay time (EDT) in seconds	500 to 1 000	Rel. 5 %	1,0 s; 3,0 s
Perceived clarity of sound	Clarity, C_{80}, in decibels	500 to 1 000	1 dB	−5 dB; +5 dB
	Definition, D_{50}	500 to 1 000	0,05	0,3; 0,7
	Centre time, T_S, in milliseconds	500 to 1 000	10 ms	60 ms; 260 ms
Apparent source width (ASW)	Early lateral energy fraction, J_{LF} or J_{LFC}	125 to 1 000	0,05	0,05; 0,35
Listener envelopment (LEV)	Late lateral sound level, L_J, in decibels	125 to 1 000	Not known	−14 dB; +1 dB

[a] The single number frequency averaging denotes the arithmetical average for the octave bands, except for L_J which shall be energy averaged [see (A.17)].

[b] Frequency-averaged values in single positions in non-occupied concert and multi-purpose halls up to 25 000 m^3.

It is worth noting that the three metrics provided in relation to perceived clarity of sound (C_{80}, D_{50}, Ts) are generally correlated, i.e. an improvement in clarity in any one of these metrics will normally be reflected with a corresponding improvement in the other two metrics. For this reason the following analysis focuses on C_{80}, which is most closely related to musical clarity.

The hypothesis put forward was that the primary acoustic function of the side boxes was to provide additional early reflections to the Eastern Gallery. These reflections would be first order reflections, i.e. the sound would reflect only once, from the box, and then be received by the listener in the gallery. Where a significant degree of additional support is provided to the Eastern Gallery by these reflections it would be expected that the clarity (C_{80} metric) be increased in the presence of the boxes. There may also be an increase in the apparent source width (L_F or J_{LF} metric), depending on the geometric relationship of the source, reflector and receiver.

In order to evaluate the acoustic effect of the boxes, acoustic measurements and modelling were carried out. Benchmarking measurements in the existing space were conducted in order to directly investigate currently experienced levels of C_{80} and J_{LF} as well as ascertain the presence of strong identifiable reflections from the side boxes. 3D computer models were also constructed of the hall for direct comparison of predicted C_{80} and J_{LF} in the gallery with and without the side boxes.

3 BENCHMARKING MEASUREMENTS

In order to establish the existing acoustic performance of the hall a series of benchmarking measurements were carried out using the IRIS 3D Acoustic Impulse Response System (Marshall Day Acoustics, n.d.). The IRIS system produces both 3D visual plots of reflections at the receiver as well as numerical measurements in order to quantify and explore a room’s acoustic response.

Measurements were carried out at 16 receiver locations, at approximately 1.2m above ground height. Three different source locations were tested as follows:

- Source A: on existing stage (1.5m height above stage), with dodecahedral test speaker
- Source B: at stage height representing small stage extension (at height representing 1.5m height above stage, although no stage extension was installed), with dodecahedral test speaker
- Source C: at stage height representing full stage extension (at height representing 1.5m height above stage, although no stage extension was installed), with dodecahedral test speaker

The source and receiver locations are shown in Figures 3 (Ground Floor) and 4 (Upper floor).

GROUND FLOOR

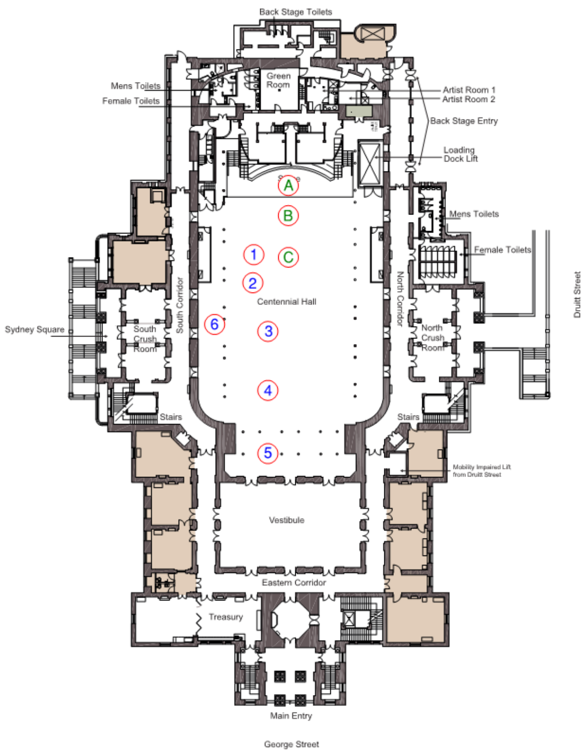


Figure 3: Source (A-C) and Receiver Locations (1-6) on Ground Floor

FIRST FLOOR (CENTENNIAL HALL GALLERY HALL)

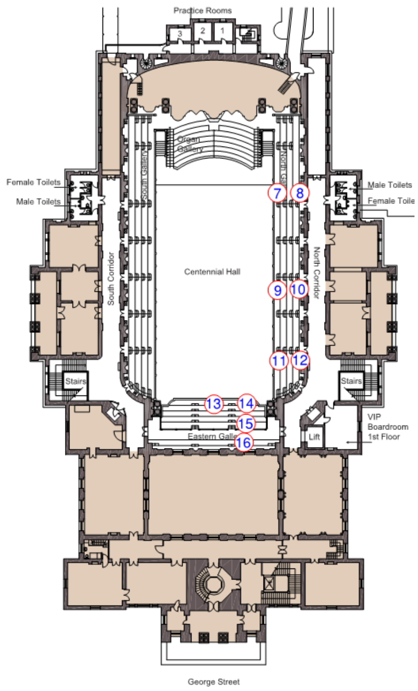


Figure 4: Receiver Locations (7-16) in Gallery / Balcony, First Floor

Table 2 provides a comparison of results at 16 discreet receiver locations for 3 source locations (Early Decay Time EDT, Clarity C80 and Lateral Energy Fraction LF). Note that the table shows mid-frequency values of the measurements only (average of 500 and 1000Hz) enabling direct comparison to ISO descriptors.

Table 2: Measurement results, mid frequency, all receiver locations

	Source A			Source B			Source C		
Receiver	EDT (s)	C_{80} (dB)	LF	EDT (s)	C_{80} (dB)	LF	EDT (s)	C_{80} (dB)	LF
R1	2.9	-0.7	0.19	2.9	0.4	0.27	2.2	6.5	0.07
R2	3.2	-1.2	0.21	3.0	-1.6	0.25	3.1	2.5	0.12
R3	3.2	-4.6	0.16	3.1	-4.7	0.16	3.0	-4.3	0.19
R4	3.1	-5.5	0.24	3.1	-5.2	0.32	3.1	-5.3	0.39
R5	3.1	-4.3	0.25	3.2	-4.8	0.30	2.9	-4.1	0.26
R6	3.2	-3.6	0.31	3.2	-3.6	0.31	2.9	-2.4	0.51
R7	3.0	-0.5	0.06	2.7	-0.5	0.06	3.1	-2.9	0.10
R8	2.8	-1.6	0.08	2.7	-1.9	0.07	3.1	-2.6	0.10
R9	3.1	-4.9	0.16	3.1	-3.9	0.11	3.0	-2.8	0.09
R10	3.0	-4.2	0.08	3.2	-3.8	0.15	3.0	-3.0	0.10
R11	3.1	-6.1	0.14	3.1	-5.9	0.15	3.0	-5.1	0.15
R12	3.0	-6.3	0.19	3.1	-5.3	0.17	3.1	-5.0	0.14
R13	2.8	-3.1	0.08	3.1	-4.7	0.16	2.9	-4.6	0.15
R14	3.0	-3.5	0.12	3.0	-4.7	0.17	3.1	-4.0	0.18
R15	3.0	-2.5	0.10	3.1	-4.2	0.17	3.1	-3.6	0.11
R16	3.0	-2.3	0.14	3.0	-3.7	0.14	3.1	-4.6	0.18

It could be expected that any clarity provided by the side boxes would be strongest using a source at Location A, which is behind the boxes, and that conversely clarity increases for a source at Location C would be minimal as the angle of reflection would be too acute to reach the Eastern Gallery. We would therefore expect to see an increase the measured C_{80} values for Source A relative to Source C. The relevant results are reproduced in Table 3.

Table 3: Difference in measured clarity for Eastern Balcony for Sources A & C

Receiver in Eastern Gallery	C_{80} for Source A (dB)	C_{80} for Source C (dB)	Increase in C_{80} for Source A (dB)
13	-3.1	-4.6	1.5
14	-3.5	-4.0	0.5
15	-2.5	-3.6	1.1
16	-2.3	-4.6	2.3

For C_{80} a change in clarity of 1dB is a Just Noticeable Difference. The above results suggest that a perceivable increase in clarity may be experienced at some locations in the Eastern Gallery when the sound source is at location A compared to location C. However the stage extension was not installed during testing so Source A would be expected to have some additional clarity due to stage reflections (Source C was above acoustically absorbent seating). Taking this into account the difference in C_{80} is likely to be less than 1dB for at least three of the four test locations in the Eastern Balcony. The difference in C_{80} between Sources B and C for locations in the Eastern Gallery was less than 1dB in all cases.

Examination of the 3D IRIS plots for receivers in the Eastern Gallery did not identify significantly stronger reflections from the direction of the side boxes.

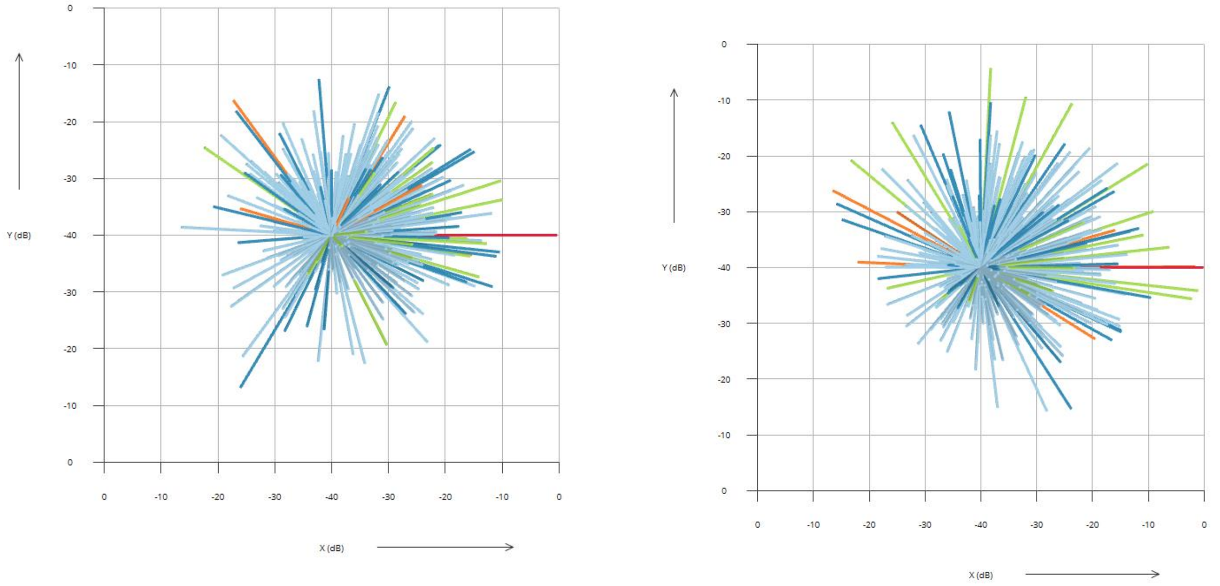


Figure 4: IRIS reflection plots at Receiver 16 for Source Location C (left) and A (right). X-axis is along length of the room, with Y-axis across the room

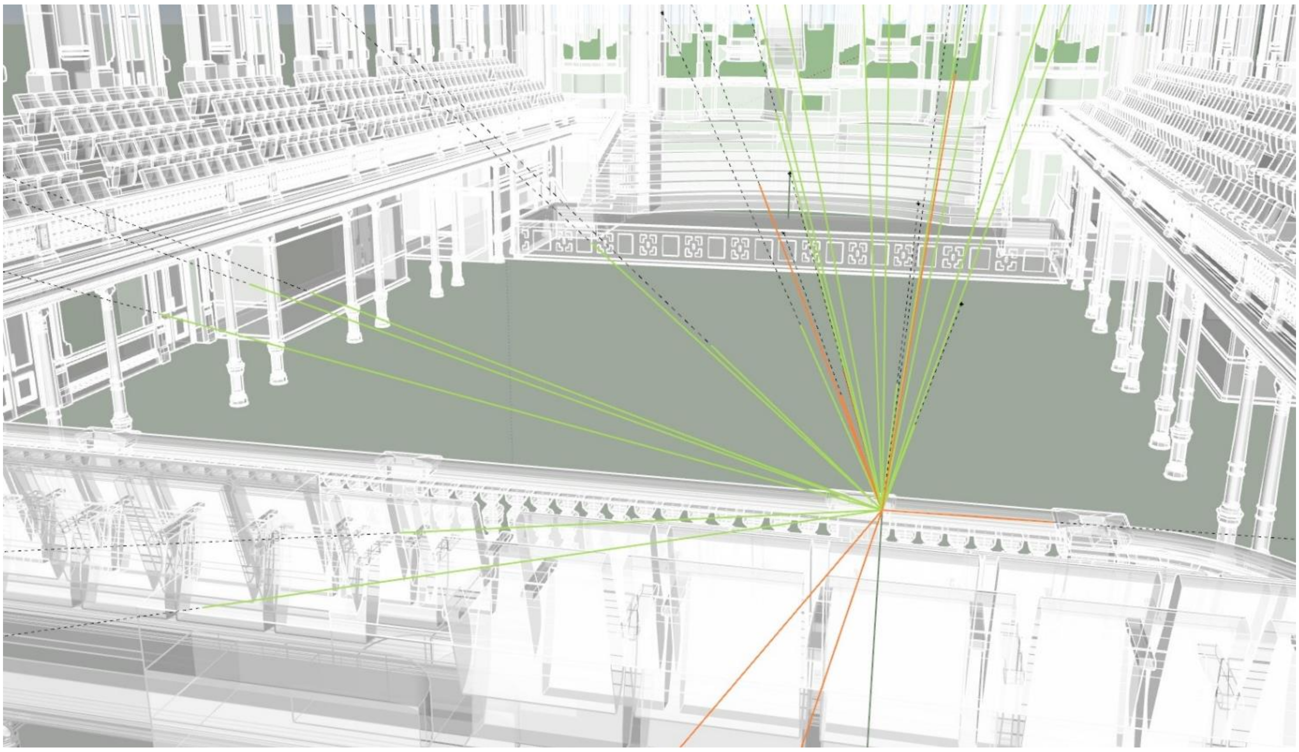


Figure 5: IRIS reflection plot for 0 to 80 ms at Receiver 16 for Source Location A, 3D view.

4 COMPUTER MODELLING

3D computer noise models of the room were prepared and assessed using Odeon acoustic prediction software (Odeon A/S n.d.).

The main purpose of the analysis was to model a direct comparison with and without the side boxes in order to determine their acoustic affect.

Comparison of modelling results, with and without side boxes is shown in Table 4 for Source A. Differences that exceed the Just Noticeable Difference (JND) condition are shown **underlined**.

Table 4: Model results with and without side boxes, mid-frequency, for Source A. Differences that exceed the Just Noticeable Difference (JND) condition are shown **underlined**

	Model with box		**Model no box**		**Difference**	
Receiver	**C_{80} (dB)**	**LF**	**C_{80} (dB)**	**LF**	**C_{80} (dB)**	**LF**
1	-3.5	0.30	-3.1	0.24	0.4	**-0.06**
2	-5.3	0.21	-5.8	0.20	-0.5	-0.01
3	-5.0	0.25	-6.0	0.22	-1.0	-0.03
4	-5.3	0.22	-5.7	0.18	-0.4	-0.05
5	-4.1	0.29	-3.3	0.30	0.8	0.01
6	-6.3	0.23	-5.1	0.19	**1.2**	-0.04
7	-0.9	0.10	-1.5	0.10	-0.6	0.00
8	-1.6	0.35	-1.4	0.36	0.2	0.00
9	-4.8	0.20	-4.6	0.20	0.2	0.01
10	-4.3	0.20	-3.8	0.21	0.6	0.01
11	-5.4	0.21	-5.7	0.21	-0.3	0.00
12	-4.8	0.16	-4.6	0.13	0.2	-0.03
13	-4.6	0.16	-4.4	0.16	0.3	-0.01
14	-4.8	0.20	-5.2	0.20	-0.4	0.01
15	-4.5	0.22	-5.2	0.21	-0.7	-0.01
16	-3.8	0.27	-4.7	0.30	-0.9	0.02

Comparison of modelling results, with and without side boxes is shown in Table 5 for Source B. Differences that exceed the Just Noticeable Difference (JND) condition are shown **underlined**.

Table 5: Model results with and without side boxes, mid-frequency, for Source B. Differences that exceed the Just Noticeable Difference (JND) condition are shown **underlined**

	Model with box		**Model no box**		**Difference**	
Receiver	**C_{80} (dB)**	**LF**	**C_{80} (dB)**	**LF**	**C_{80} (dB)**	**LF**
1	-0.9	0.30	-1.6	0.16	-0.7	**-0.14**
2	-2.8	0.30	-3.9	0.19	**-1.2**	**-0.11**
3	-5.5	0.21	-5.0	0.26	0.5	**0.06**
4	-4.6	0.26	-4.7	0.27	-0.1	0.01
5	-2.5	0.24	-2.7	0.27	-0.2	0.03
6	-4.1	0.25	-4.0	0.19	0.1	**-0.06**
7	-1.8	0.12	-1.5	0.12	0.3	0.00
8	-1.7	0.34	-1.2	0.33	0.5	0.00
9	-4.2	0.19	-4.0	0.19	0.2	0.00
10	-3.2	0.16	-3.3	0.15	-0.1	0.00
11	-4.4	0.23	-4.4	0.21	0.0	-0.01
12	-4.1	0.17	-3.7	0.17	0.4	0.00
13	-3.8	0.16	-4.0	0.15	-0.3	-0.01
14	-4.4	0.18	-5.4	0.18	-1.0	0.00
15	-3.9	0.23	-4.0	0.26	-0.2	0.04
16	-3.9	0.31	-3.9	0.30	0.0	-0.01

Comparison of modelling results, with and without side boxes is shown in Table 6 for Source C. Differences that exceed the Just Noticeable Difference (JND) condition are shown **underlined**.

Table 6: Model results with and without side boxes, mid-frequency, for Source C. Differences that exceed the Just Noticeable Difference (JND) condition are shown **underlined**

	Model with box		Model no box		Difference	
Receiver	**C_{80} (dB)**	**LF**	**C_{80} (dB)**	**LF**	**C_{80} (dB)**	**LF**
1	0.1	0.27	-0.5	0.12	-0.6	**-0.15**
2	-1.2	0.25	-1.1	0.16	0.0	**-0.09**
3	-3.5	0.23	-3.3	0.23	0.2	0.00
4	-3.8	0.23	-3.7	0.23	0.0	0.00
5	-0.7	0.25	-1.2	0.31	-0.5	**0.06**
6	-2.0	0.24	-2.1	0.17	0.0	**-0.07**
7	-2.4	0.13	-2.1	0.12	0.3	-0.01
8	-2.3	0.28	-2.5	0.28	-0.2	0.00
9	-2.5	0.15	-2.3	0.14	0.2	0.00
10	-3.0	0.31	-2.5	0.30	0.5	-0.01
11	-4.8	0.22	-4.1	0.21	0.8	-0.01
12	-3.8	0.24	-3.1	0.26	0.7	0.01
13	-4.1	0.15	-3.7	0.15	0.4	0.00
14	-5.0	0.21	-4.7	0.18	0.3	-0.03
15	-3.3	0.18	-2.8	0.20	0.5	0.02
16	-1.4	0.28	-1.2	0.28	0.2	0.00

The results modelled using ODEON software show that there would be no perceptible difference to either clarity (C_{80}) or apparent source width (LF) for receivers in the Eastern Gallery with and without the side boxes.

In the computer model the coverage provided by the side boxes as reflectors was explored. The coverage of reflections (shown as green and red crosses) are shown in Figure 5, for a sound source at Source Location A (centre of main stage). Note that the reflectors do not provide (any) significant reflections to the Eastern Gallery. This is due to the geometry of the room, i.e. the source on the stage is too high to be strongly supported, and reflections can be trapped by the underside of the North and South Galleries.

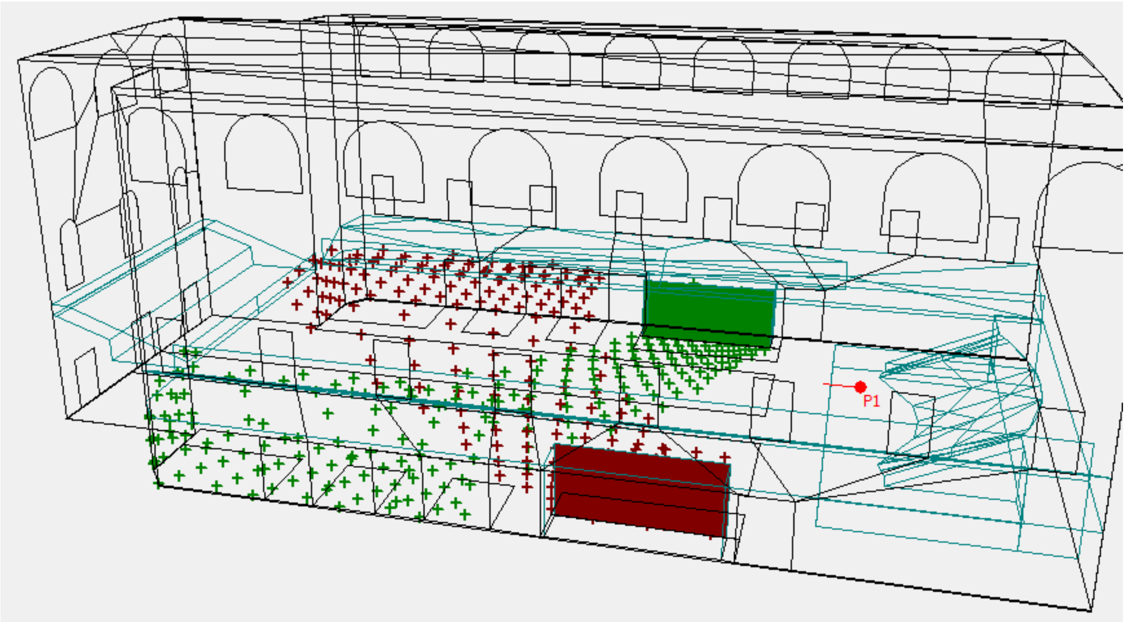


Figure 5: Reflector coverage for Source A

Further exploration of the reflector coverage shows that for some source locations the side boxes can provide reflections to the Eastern Gallery. This is shown in Figure 6 for an alternative source located low (in height) on the stage and set toward the edge of the stage area. This would only be of benefit to a small number of sources on stage (and not for sources on the stage risers), and the density of reflections to the Eastern Gallery remains low. This indicates the benefits from the reflectors would be minimal.

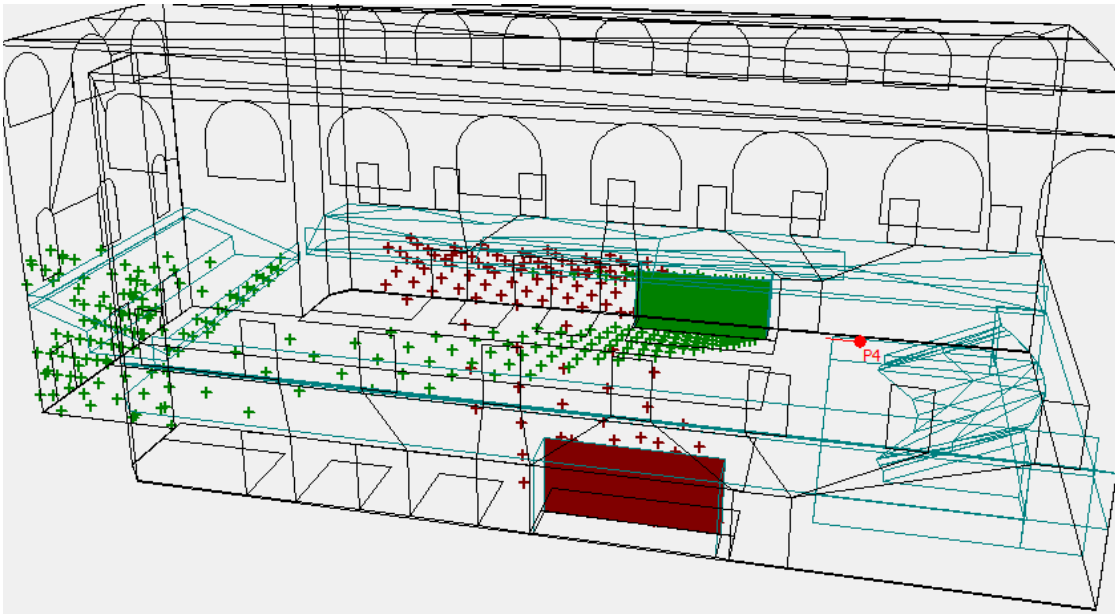


Figure 6: Reflector coverage for a source low down on the right hand side of the stage

Examining the effect of the reflectors in areas other than the Eastern Gallery it is clear the most significant effects from the side boxes are to the ground level (stalls) receivers.

The boxes provide some listening positions on the ground, near and immediately behind the boxes, with a ‘narrowing’ of the hall and stronger early reflections. However the effect for the zone behind these seats, towards the read of the stalls, is that the boxes provide a ‘shadow zone’ where sound from the side walls is not reflected.

An illustration of the effect can be seen in Figure 7 and Figure 8, which show apparent source width (early lateral energy fraction LF) with and without the boxes. A strong increase in LF is shown on the floor area just behind the boxes in Figure 7, with an uneven response along the length of the hall floor. With the boxes removed the response along the length of the hall is more uniform.

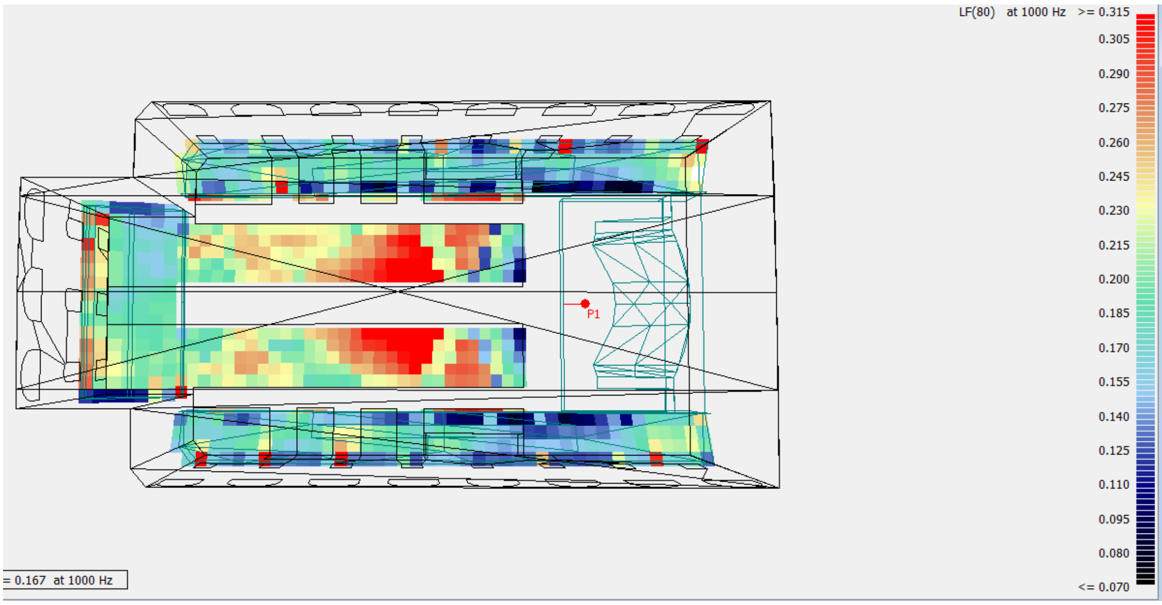


Figure 7: Lateral Fraction (LF) map with boxes in place

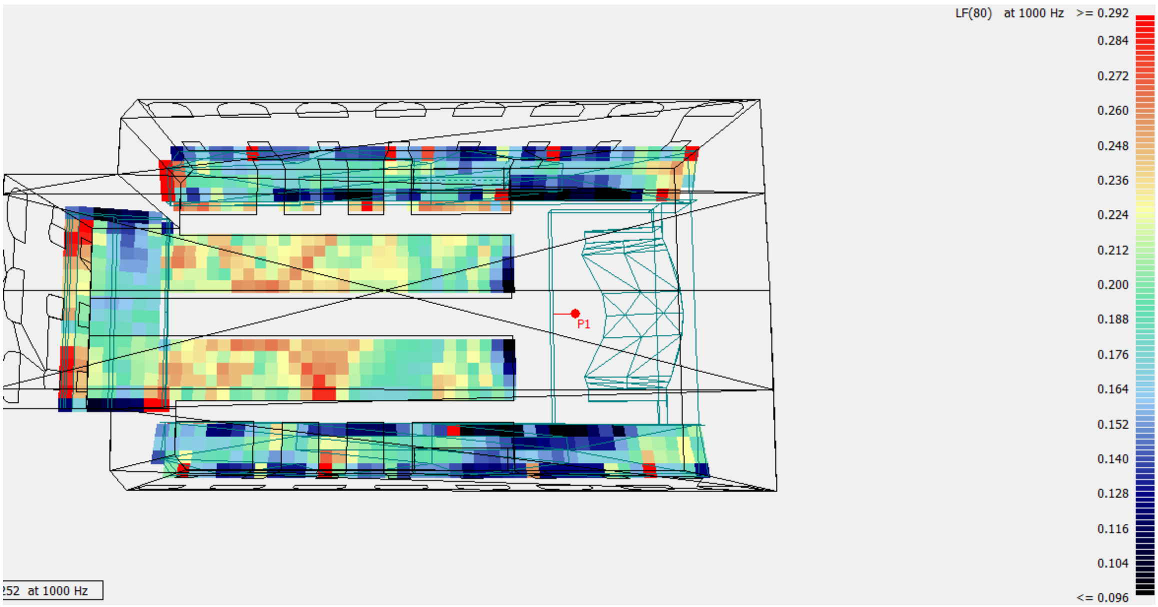


Figure 8: Lateral Fraction (LF) map with boxes removed

5 ANALYSIS OF RESULTS

The measurement results in the existing hall found that the side boxes do not provide significant additional early reflections to the Eastern Gallery.

The 3D computer modelling of the space showed that the side boxes may provide some marginal increases in reflections to the Eastern Gallery for a limited number of source positions on the stage, particularly those low and towards the front of the stage. The removal of the boxes is however unlikely to make a perceptible difference to receivers in the Eastern Gallery.

The 3D modelling did show that removal of the boxes would change the acoustic response for some seats on the floor of the hall. The acoustic response for these seats would overall be more uniform with the boxes removed.

The modelling also confirmed that the overall reverberation time of the room would not change significantly if the boxes are removed. This is due to the relatively small surface area of the boxes (relative to the total room surface) and the low degree of acoustic absorption that they provide.

The results do identify that the removal of the side boxes could produce some minor perceptible changes in the acoustic response of the room for unamplified music performance, depending on the receiver location as well as source location. Whether these minor changes are positive or negative is somewhat subjective.

In October 2019 the author discussed these findings with Peter Knowland, the original acoustician involved with the installation of the boxes. He stated that in conjunction with the installation of the side boxes the height of the front of the stage was to be lowered. A series of trial concerts were conducted with the lower stage installed however the stage was reinstated at its original height some time later. The 3D modelling did suggest that with a lower stage height some additional reflections would be provided to the Eastern Gallery. Given the stage height has since reverted to its higher original level, and there is no indication that it will be reduced, the acoustic impact of such a scenario is moot.

6 DECISIONS IN A HISTORICAL CONTEXT

When the acoustic benefit to changes in a building are largely subjective the consultant and/or custodian of the space is faced with making a value judgement on how to proceed. Where a space has historic significance the decision is made more difficult. In the conservation of historically significant spaces the focus tends to be on the visual elements of the space, with acoustic values often forgotten and/or unquantified (O'Connor 2008 and Karabiber 2013), even though in some spaces the acoustical perception is as essential and sometimes more important than visual perception (Karabiber 2013). The retention of the original acoustics of the space may also need to be balanced against the contemporary needs of a space, which may require different acoustic conditions (Berardi 2015).

In order to preserve valuable acoustics in historic venues further work will need to be done by the heritage conservation community so that the full value of historic spaces, including acoustics, is conserved. A number of initiatives are underway around the world to create acoustic archives of such spaces, including the CAHRISMA project in focused on the 16th century mosques by architect Sinan (Karabiber 2013) and the ERATO project which is focused on ancient theatre acoustics (Haddad 2008).

One important driver behind this work is the need to safeguard the historic acoustic characteristics of the spaces in case any of these acoustically interesting spaces are destroyed or damaged (Brezina 2013). The 2011 Christchurch earthquakes have been a timely reminder of the value of such work. The Christchurch Town Hall, regarded as the "birthplace of modern-day concert hall acoustics", was originally slated for demolition following the earthquake damage but public pressure saw the Council committing to rebuilding (Radich 2019). The value that the community placed on the venue and its acoustics, as well as the extensive acoustic archive of the space were required in order to preserve the complex.

7 CONCLUSIONS

In the case of Centennial Hall the weight of historical value of the hall in its current configuration was lessened as the boxes were not original to the hall's construction, being installed only around 40 years ago. Nevertheless a generation of concertgoers have only experienced the venue with the boxes in place. Any changes, even where minor and of subjective benefit, may have an impact of the experience of the space for some visitors.

The current usage of the space is also a context for the City of Sydney to consider the changes. The side boxes were installed at a time when the predominant use of the hall was for unamplified music performance. In the intervening time period, and with construction of the Sydney Opera House, the use of the space has changed, with amplified speech, amplified music performance and functions now significantly outnumbering acoustic music performances. Removal of the boxes would allow for additional seating and flexibility.

Ultimately the recommendation to the City of Sydney was that the boxes could be removed whilst maintaining the excellent acoustics of the space, notwithstanding that the acoustics in some areas of the venue would be slightly altered.

ACKNOWLEDGEMENTS

I would like to acknowledge the City of Sydney for permitting the publication of the data in this paper. I take the opportunity to commend them as a custodian of this historic venue for expending the time and resources to properly examine the acoustic impacts of the proposed changes to the building. I thank my Marshall Day Acoustics colleagues, including Peter Exton and Nicholas Lynar, who assisted in the project. I would also like to thank Peter Knowland, who has contributed to acousticians and acoustics in Australia for over 50 years, for his insight into the original works. Whilst the City of Sydney are custodians of the Town Hall building it is constructed on the lands of the Gadigal people of the Eora Nation, who are the custodians of the land on which it stands. I acknowledge the Gadigal and pay my respect to their Elders, both past and present. I am humbled by their grace.

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