THE ESPLANADE IN MEDICINE HAT, CANADA: FROM PLENUM TO FLYTOWER

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1 INTRODUCTION

The Esplanade Arts and Heritage Centre opened in October 2005. It is located in the Canadian province of Alberta and was built in celebration of the provincial centennial. Throughout its creation, the project faced political, economic and acoustical challenges – formidable on occasion – that had to be overcome. This paper will, of course, concentrate on the latter but, inevitably, one often influences the other. Of particular interest are the noise control design of the Heating Ventilation & Air Conditioning (HVAC) displacement system plenum and the behaviour of computer modelling in the presence of partially open surfaces such as an orchestra shell ceiling.

2 DESIGN

2.1 Project Description

The Esplanade houses a museum, an art gallery, a 150 seat studio theatre and the 700 seat theatre discussed here.

The 700 seat, single balcony theatre is located in the north-east corner of the building and is surrounded on three sides by a 50 mm acoustic joint. To simplify construction, a corridor between the north façade of the building and the audience chamber was left unisolated. Carpet on the corridor floor controls noise from footfall. The room is designed for music and theatre, both community based and professional.

The walls of the audience chamber are sealed, bush hammered concrete. The balcony facia and the walls surrounding the side wall boxes have a sand blasted wood finish: 300 x 25 mm boards of varying depths arranged in a random, vertically orientated pattern, mounted on a 32 mm gypsum board substrate. Adjustable acoustic curtains are provided on the side and back walls.

The orchestra pit seats approximately 30 musicians. The stage is equipped with a custom designed orchestra shell, with finishes to match the box walls and balcony facia. When not in use, the shell is stored on the upstage wall and in the fly-tower.

2.2 Design Team

Owner:	The City of Medicine Hat
Architect:	Diamond Schmitt Architects Inc.
Acoustician:	Aercoustics Engineering Ltd
Sound System:	Engineering Harmonics
Theatre Consultant:	Fisher Dachs Associates
Mechanical & Electrical Engineer:	Crossey Engineering Ltd.
Structural Engineer:	Halcrow Yolles Engineering

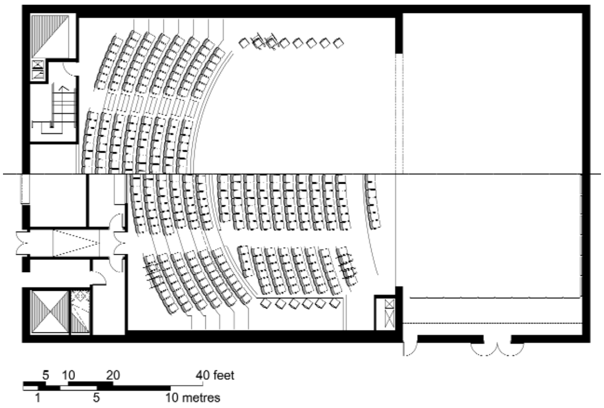

Figure 1 Composite Plan

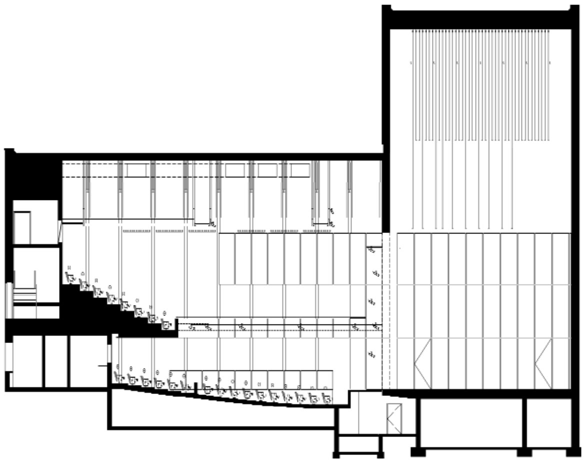

Figure 2 Longitudinal Section

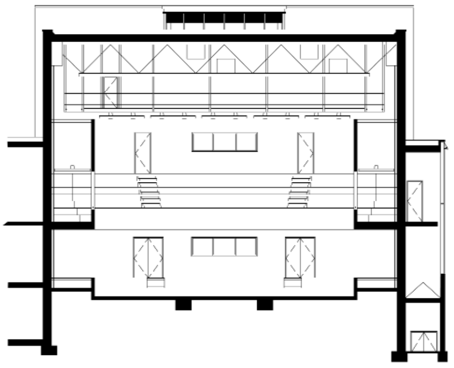

Figure 3 Transverse Section

2.3 Room Parameters

Table 1

Number of Seats	700	
Volume	5,450 m^3	
Proscenium Height	10.6 m	
Proscenium Width	15.5 m	
Ambient Noise	PNC 10	
	Concert Mode	Theatre Mode
Reverberation Time (s)	2.2^{+}	1.0
Early Decay Time (s)	2.2	0.9
Clarity (dB)	1.1	6.55
Strength (dB)	4.7	n/a
50 ms Distinctness (%)	32	73

+ all data in the 1 kHz Octave Band

3 HVAC PLENUM

Quite early on in the design, it was decided to ventilate the room by means of a displacement system. These systems have become quite popular in North America of late, but there is precious little published data to inform noise control design decisions. The system for Medicine Hat is similar to many others. The floors of the stalls and balcony levels are perforated with a series of 150 mm diameter holes. A room below the stalls and the ceiling space underneath the balcony act as their respective plena. In both cases, ductwork inside the plenum helps to provide an even distribution of air. The air flows through the openings at a velocity of 0.5 m/s (100 fpm) and is returned through ducts located high above the audience.

As mentioned, although private studies have been carried out, there is little, if any, information in the literature to guide design. Industry standard calculations such as ASHRAE[1] do have calculation procedures for plena but not of the kind considered here. For example, the ASHRAE routine assumes that air is supplied through a duct connected to the side of the box. In a typical displacement system for a performing arts centre, the air is supplied through ductwork *inside* the box. So, how does one calculate the noise attenuation of a typical displacement system plenum?

3.1 Plenum Calculation Procedure

The first steps are obvious. First, calculate the attenuation in the ductwork in the normal fashion. Then, treat the plenum as a room and use the appropriate sound power to sound pressure conversion. After that however, one faces a dilemma: how to calculate the attenuation of sound as it moves from the plenum into the auditorium. Does each sound source, i.e. each diffuser in the floor, contribute the same amount of energy? It depends on the listener's location. Sitting in the stalls, a listener has a clear line of sight to only a handful diffusers. Looking down from the catwalk however, a listener can see almost all of the diffusers, albeit partially blocked in each case by the seat. Surely these are contributing to the total sound field. A familiar pattern of analysis emerges: a concept of direct and reverberant fields – or perhaps more accurately "near" and reverberant fields.

For the near field, the calculation model is of a partially blocked pipe. For the reverberant field the procedure is similar to a noise intrusion calculation from one room to another, where the Transmission Loss (TL) of the common partition is calculated as an area ratio combining the concrete floor and the partially blocked pipe.

None of these calculations however, were required for The Esplanade project. The design goal for the room was Preferred Noise Criterion (PNC) 15 which, fortunately, was satisfied by attenuation upstream of the stalls and balcony plena. The experience prompted concern of course and initiated a series of measurements which are presented here. The immediate concern was with our next major project: Canada's first opera house, the Four Seasons Centre for the Performing Arts (FSCPA). The first set of measurements was performed at the nearby Mississauga Living Arts Centre (MLAC). More recently, measurements have been performed at the completed Esplanade and FSCPA buildings. Details of the three systems are presented below.

Table 2

Building	City	Volume (m^3)	Type of Diffuser	Plenum lining
The Esplanade	Medicine Hat	5,450	Mushroom	None
MLAC	Mississauga	approx. 13,000	Seat pedestal	100 mm
FSCPA	Toronto	14,000	Seat pedestal	50 mm

3.2 Plenum Measurements

3.2.1 Near Field

The so-called near field measurements were performed as follows: a white or pink noise source was placed on top of one of the distribution ducts in the plenum, typically about 400 to 500 mm from the hole under test. A single measurement was performed on the source, i.e. on the plenum side of the hole, approximately 75 to 100 mm from the opening. Care was taken not to occlude the hole. A series of measurements was then performed in the auditorium, two of which are published here: (i) near the diffuser at floor level and (ii) in the seat immediately above, at ear level. These are shown in Figure 4 and Figure 5 respectively.

In Figure 4, we see clear signs of pipe resonances. In Figure 5, i.e. at the same source location, only this time at ear level in the seat immediately above, the pipe resonances are still evident but so are the higher frequency barrier effects of the chairs. Measurements were performed in occupied seats.

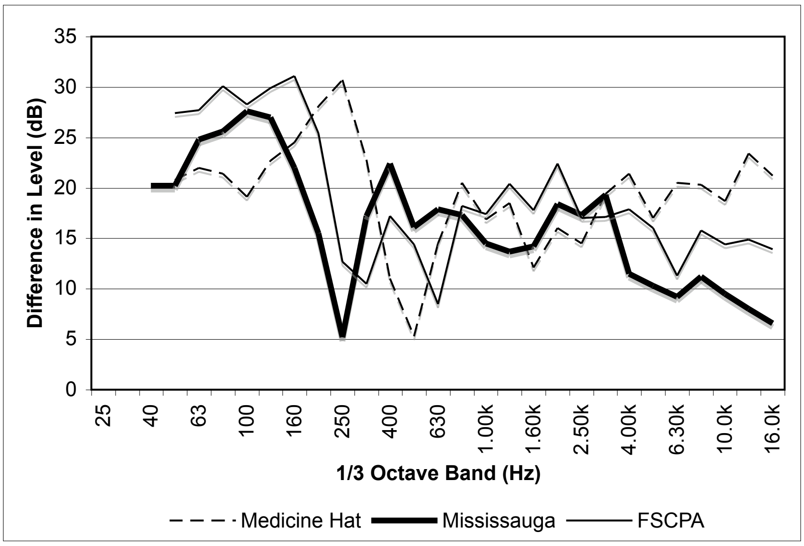

Figure 4 Measured attenuation from the underside of a slab hole to the diffuser at the floor level immediately above.

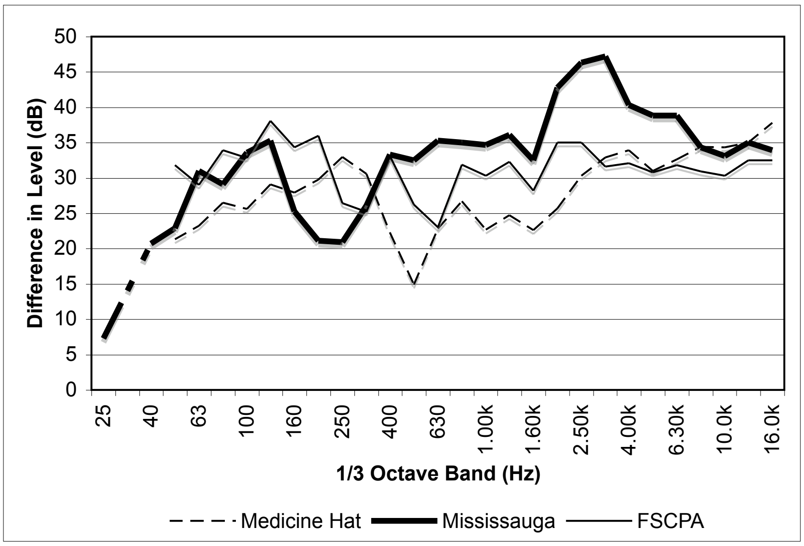

Figure 5 Measured attenuation from the underside of a slab hole to ear level in the seat above.

3.2.2 Reverberant Field

Reverberant field measurements were performed as one might perform an in-situ measurement of a wall or floor. The white or pink noise source was placed on the floor of the plenum. Six or more reverberant field measurements were performed in the plenum, then in the auditorium above. The results are shown Figure 6.

Also shown in Figure 6 are the results of the calculation procedure described in Section 3.1, above. Using the MLAC near field measurements at the diffuser (seen in Figure 4), an area ratio Noise Reduction (NR) calculation was performed. (In North American parlance, NR refers to the Transmission Loss (TL) of a given building component plus the affect of the receiver room.) The calculation (shown with X's) indicates good agreement with the measurements except at low

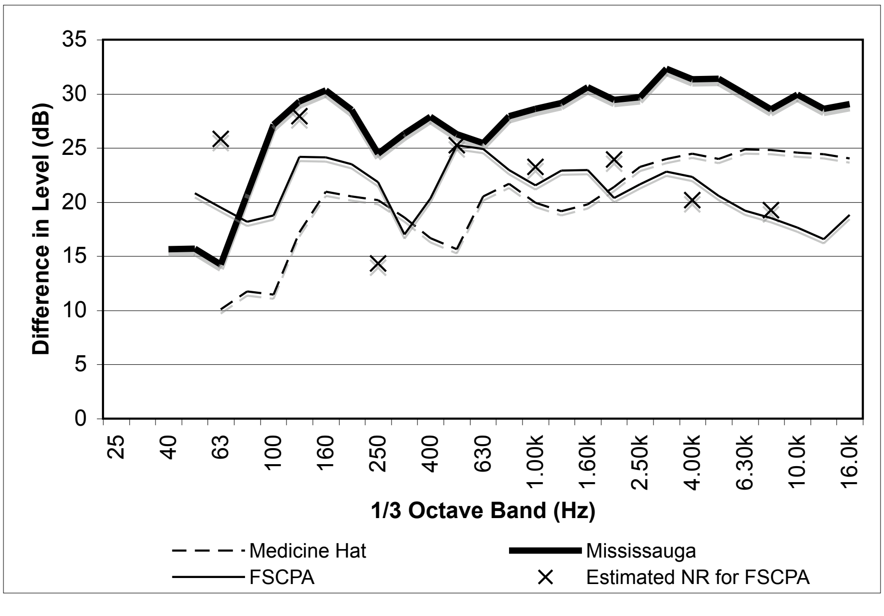

Figure 6 Measured attenuation from the plenum to the stalls level.

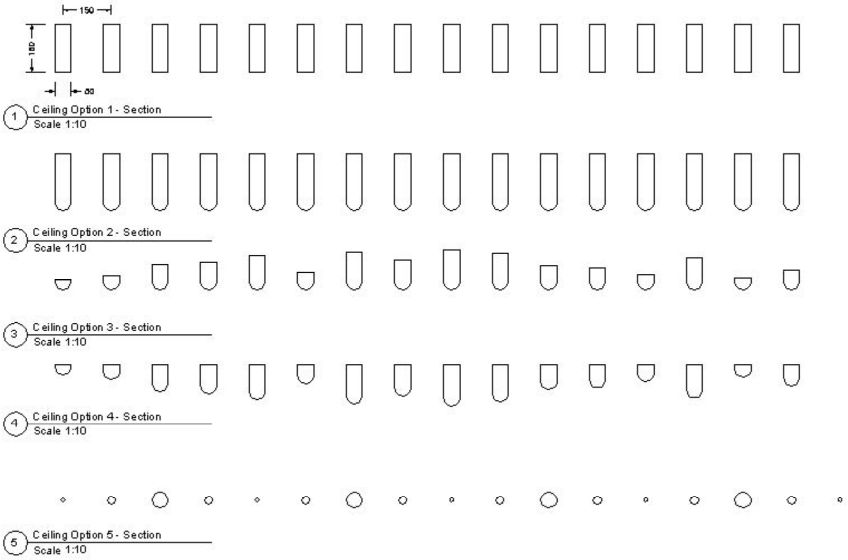

Figure 7 Some of the designs considered for the acoustically transparent ceiling.

frequencies, where attenuation is somewhat over-estimated.

4 THE CEILING

One of the more interesting challenges of the design stemmed from the architect's keen desire for visual intimacy, manifest in a low "acoustically transparent" ceiling. A 1:20 scale model was built and a number of ceiling scenarios were tested. Some of these are shown in Figure 7. In order to investigate scattering, effects at grazing incidence and other high frequency behaviour, parts of the ceiling were tested in a 1:5 scale "anechoic" model. The final solution, evident in Figure 8 was a ceiling more than 85% open, made up of 25 mm diameter wooden dowels.

Scale model experiments were also performed on the orchestra shell ceiling in an effort to optimise the size of the panels and the openings between the panels. A view of the orchestra shell is shown in Figure 9.

All of the 1:20 scale model measurements were augmented with the post-processing algorithm developed by Grillon[2]. This routine, executed in MatLab, extends both the frequency and dynamic ranges of acquired signals.

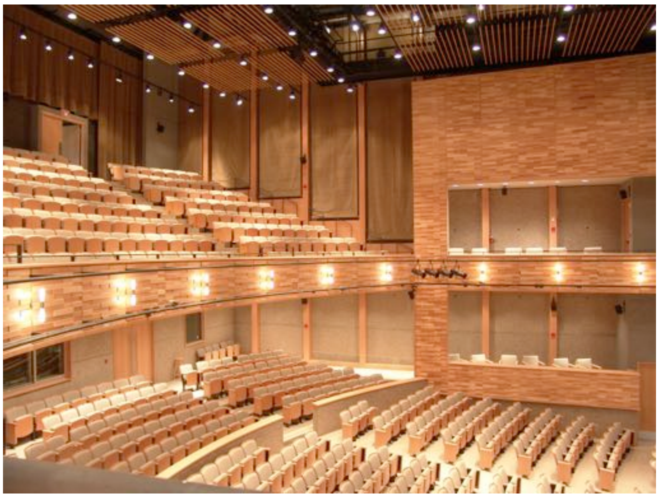

Figure 8 The audience chamber showing the transparent ceiling, acoustical banners and wall finishes. (Photo by Michael Leckman)

5 THE FLY-TOWER

Figure 9 View of the stage with the orchestra shell in place.

The scale model mentioned above was not planned for in this project. The desire for a "transparent" ceiling, something a computer cannot model accurately, made the scale model a necessity. This proved fortuitous because the computer model also had trouble dealing with the fly-tower. Through a number of trials and experiments, it consistently overestimated the effect of soft goods stored in the fly-tower above the (partially open) orchestra shell ceiling. Typical results are shown in Figure 10 and Figure 11.

The problem, we suspect, is not with the software (an otherwise reliable commercial product) but with a fundamental computer modelling algorithm. In a computer model, the test for whether sound travels through an opening in the orchestra shell ceiling is whether or not a line intersects a plane. The line of course is infinitesimally narrow. It has an effective wavelength of zero. Thus, one might expect a computer model to overestimate the amount of sound passing through a partially open surface such as the orchestra shell ceiling. The scale model, of course, includes natural wave affects and, at least in this instance, provides a more accurate prediction.

This is rather interesting because in this project, the scale model was something of a second thought. It was originally used for *relative* comparisons of different ceiling designs. Not a lot of effort was put into the *absolute* calibration of the model. Much more effort was focussed on the computer model. Nonetheless, in the end, the scale model proved more accurate.

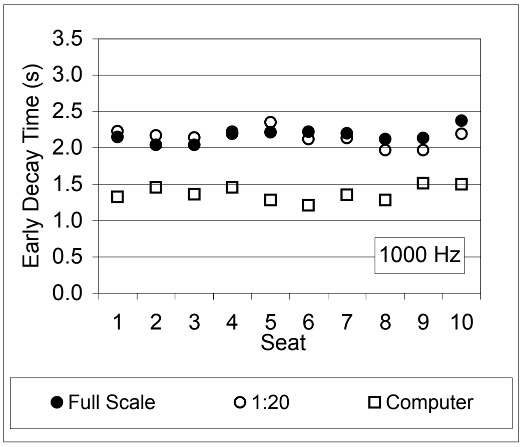

Figure 10 Predicted and measured Early Decay Times. Seats 1 to 6 are in the stalls, 7 to 10 in the balcony.

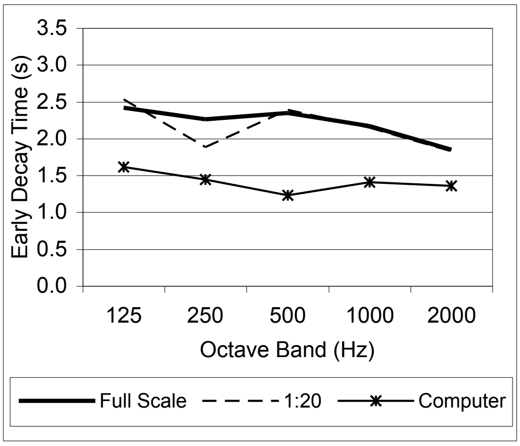

Figure 11 Predicted and measured Early Decay Times. The computer model over-estimates the affect of curtains in the tower.

6 CONCLUSION

The Esplanade albeit a small room at 700 seats, proved a challenging project. The combined goals of architectural excellence and the practicalities of performance can often seem at odds with acoustical concerns. This is the source of the challenge and it is a welcome one. It his hoped that the presentation of these issues in this paper, especially the issues associated with the plenum, will prompt further discussion.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

1. American Society of Heating, Refrigerating and Air Conditioning Engineers (AHSRAE), Sound and Vibration Control, 2003 ASHRAE Handbook, pp. 47.1-47.5 (2003).
2. V. Grillon, Auralisation dans les Maquettes: Traitement des Response Impulsionelles, Ph. D. Thesis, Universite du Maine (1995).