Parametric Analysis of Acoustical Requirements for Lateral Reflections: Melbourne Recital Hall Case Study

Design and Modeling Methods and Methodologies

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This paper is an investigation of the Melbourne Recital Centre as a case study to define the parameters necessary for good acoustical quality as it relates to the Binaural Quality Index and determining the intimacy of the hall by its initial time delay gap. The Melbourne Recital Centre, designed by Ashton Raggatt McDougall Architects, is a significant case study, as its design was driven by the acoustic requirements of reflection and diffusion through Odeon Acoustical Software. It achieves the same acoustical quality of older, ornately designed shoebox concert halls, from the perspective of contemporary design and fabrication tools and techniques. The sleek design of the Melbourne Recital Centre successfully reflects sound waves in low, mid, and high frequencies due to corresponding wall panel differentiation in the corresponding scales, as engineered by Arup Acoustics.

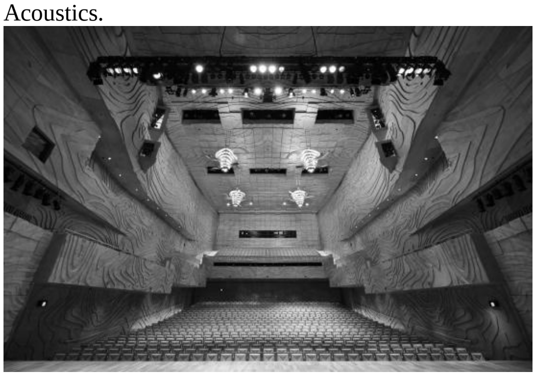


Figure 1: Melbourne Recital Centre and Melbourne Theatre Company buildings by ARM (Photo: John Gollings)

The analysis of Melbourne Recital Centre consisted of visual analysis of photographs and orthographic drawings of the concert hall. After which, the Melbourne Recital Centre could be modeled in Autodesk Inventor with specific dimensions parametrically controlled. Modeling of the Melbourne Recital Centre was for two purposes: to first understand acoustical mechanisms of the hall, and to parametrize certain dimensions and test the effects of changes on certain parameters. In its simplest expression, a parameter could simply be the dimension of a line controlled by the parametric software; it is a distinguishing factor that can be variable either numerically, geometrically, or algorithmically.

Modeling of the Melbourne Recital Hall is achieved through extrusions in both plan and section. In both directions, outlines of the elements were drawn in sketches; in sectional elements, parameters are controlled in the planar directions, while planar elements are controlled sectionally. From the sketches, constraints and driven dimensions must be carefully considered, in order to force the sketches to respond to parameter changes as desired. The sketches were then extruded to differing dimensions, which are not parametric dimensions, although they do differ between extrusions.

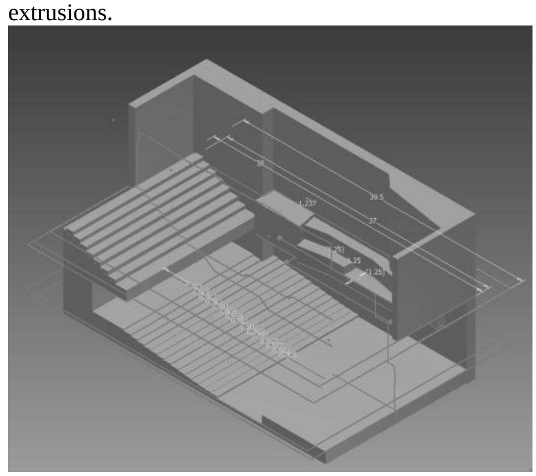


Figure 2: Screenshot of Autodesk Inventor model of Melbourne Recital Centre with visible parameterized dimensions

These parameters are significant, because it is these dimensions that control the amount of protrusion in to the original “shoebox” shape, i.e. balconies, side walls and panels. In particular, these sets of parameters reflect specific ratios between the amount of protrusions between the balconies. Increasing or decreasing these parameters should affect the ratio of Surface Area to Volume of the space, another important acoustic performance parameter. The hypothesis of this paper is to investigate the assumption that a higher Surface Area to Volume ratio would indicate more protrusions into the classic “shoebox” concert hall shape, therefore affecting lateral reflections, ultimately influencing BQI and ITDG. Additionally, these specific ratios of the depth of protrusions could affect lateral reflections, and therefore BQI and ITDG. Testing the lateral reflections would require two additional elements; the accurate measurement of Surface Area, and connection to the stress analysis tool results, explained below. Achieving an accurate measurement of Surface Area is problematic due to the nature of the model construction; because all of the elements of the hall were modeled in "parts", due to the variations in parameters, there is much Surface Area that is overlapping or redundant. An overall measurement of Surface Area would produce a much higher value than occurs in reality due to this phenomenon. Therefore, the main challenge in calculating surface area would be how to only take into account visible surfaces.

The Binaural Quality Index is one of the most accurate predictions of a hall's acoustical quality, especially for shoebox halls. The BQI measures the difference in lateral reflections as it reaches a listener's ears; the more difference between one's ears, the better the perceived acoustical quality. The BQI only takes into account lateral reflections; sound waves from directly ahead of a person, such as those direct sound waves from a stage, do not affect BQI.

The Initial Time Delay Gap is examined when determining the acoustical intimacy of a space. A recital hall is considered to be intimate when one listens to music in a large space but experiences as if in a smaller room. ITDG is the interval between the arrival of direct sound and the first reflection at listener. The smaller the ITDG, the more intimate the space. For intimate recital halls, it is necessary to aim for time delays for first reflections of 20 milliseconds or less.

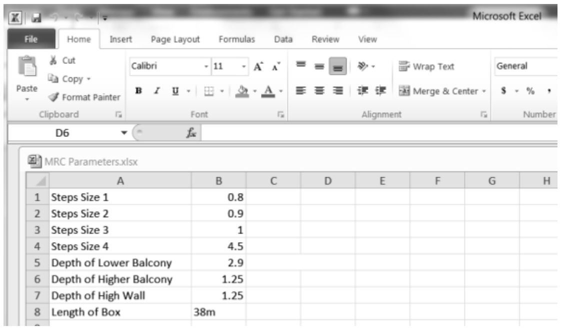
Wall depth, soffit, and balcony dimensions were recorded in an Excel chart, with the numerical values analyzed and transformed into algorithms based on dependent relationships between the architectural elements. The benefit of using a program such as Autodesk Inventor is the ability to use secondary programs such as Excel to analyze and create formulaic relationships between data; this forms the basis of the research needed to generate a design process for alternative forms. By setting one of the balcony depths as a base value, the other values of balcony depths could be re-written as equations in terms of the base balcony depth, thus setting up proportional relationships between the depth values. This base value could then be modified, with the other depth values updating correspondingly. Furthermore, these algorithms could be changed to reflect different proportions. Additionally, the Excel file contains dimensions relating to overall volume calculations. Once a method for measuring Surface Area has been calculated, these values can then be integrated into the Excel file as well.

It is hypothesized by using the force analysis tools in Inventor, the magnitudes of both indexes can be visualized. Part of the research involves generating new surfaces using existing parameters of Melbourne Recital Centre, such as a spherical network that could be used as a concert hall interior surface. By applying these parameters derived from the Melbourne Recital Centre case study, optimized for lateral reflections, BQI, and ITDG, one can analyze the sound wave reflections off these created surfaces and predict hypothetical acoustical quality. In separate part files, three spheres were created, and then given the three parameters corresponding to the lateral wall protrusions. These spheres then take on the proportional ratios of the balconies, as determined by the algorithms in the Excel file.

Ray tracing of lateral reflections was done in Inventor. A sound source point was created at the center of the edge of the stage and linked to particular points on the wall surfaces in a 3D sketch. In this case, the spherical surfaces. A plane normal to the point on the curved surface and a plane through the source point, the point on the surface, and a third point was created in order to produce a work axis through the intersection of those two planes. The angle of reflection and thus the angle of incidence was found by measuring the angle of the line from the source point to the point on the surface to the work axis. This process was repeated for each spherical surface.

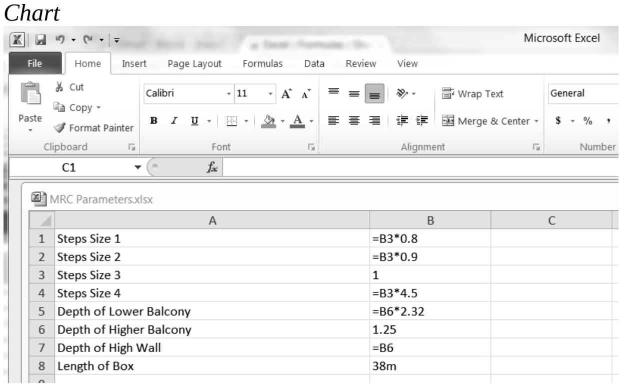
In order to graphically visualize the sound pressure of the ITDG, the analysis tool was tested by using the Remote Force option. The ITDG Limit line was created by creating a line perpendicular to the reflection and extended to intersect with the line of incidence. Any point along the line of incidence before the point where this line intersects with the ITDG limit line is along the ITDG. Coordinate points along the ITDG and approximate magnitude of sound generated by an orchestra (pascals converted into pounds per square foot) were input into the Remote Force Analysis tool. A vector is produced under this tool which represents the magnitude and direction of the force. In this case, the sound pressure is the force being represented. Because the ITDG is dependent of the sound source and listener position, the surface representing the chair was tested. The vector was positioned in the direction of the chair surface and ran an analysis. All three spheres were tested. The visual results produced by the analysis tool showed that the sound pressure was insignificant on that chair surface. Thus, the ITDG was too long. If the ITDG was in the preferable range of 12 to 25 milliseconds, hypothetically, the sound pressure would arrive on the surface and show up visually by the analysis tool. In theory, the analysis tool could produce graphically visual results; however, the scale of the magnitude of force (sound pressure) that was being tested versus the scale of the magnitude of forces Inventor (i.e. tension and compression) was created to measure, the results do not seem visually significant. If there was a way to change the scale, perhaps the visual results would vary.

It was hypothesized that the sphere surfaces, having extreme curvature, thus a wider angle of reflection, would create a longer ITDG, proving that these surfaces would not be preferable for an intimate hall. For an intimate recital hall, ITDG should ideally range from 12 to 25 milliseconds. Although the depth of the spheres share the same parameters of the balconies of the Melbourne Recital Centre, the angle of curvature produces significantly results in terms of striving for intimacy. If the balconies of the MRC were tested in the same way, hypothetically, the results would show the sound pressure on the chair surface because the recital hall is considered to be intimate, as well as the curvature of the balconies and side walls are not as extreme as the produced spheres.



	A	B
1	Steps Size 1	0.8
2	Steps Size 2	0.9
3	Steps Size 3	1
4	Steps Size 4	4.5
5	Depth of Lower Balcony	2.9
6	Depth of Higher Balcony	1.25
7	Depth of High Wall	1.25
8	Length of Box	38m

Figure 3: Screenshot of Excel Parameter Chart



	A	B
1	Steps Size 1	=B3*0.8
2	Steps Size 2	=B3*0.9
3	Steps Size 3	1
4	Steps Size 4	=B3*4.5
5	Depth of Lower Balcony	=B6*2.32
6	Depth of Higher Balcony	1.25
7	Depth of High Wall	=B6
8	Length of Box	38m

Figure 4: Screenshot of Excel Parameters with embedded algorithms

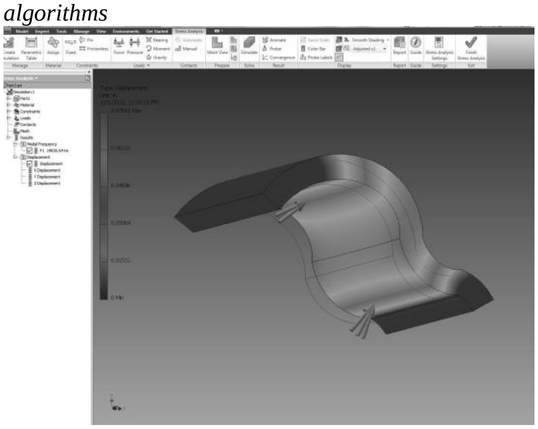


Figure 5: Screenshot of Autodesk Inventor force analysis tool

This evaluation of the Melbourne Recital Centre creates an opportunity to generate rules and algorithms applicable to the design of concert halls that strive for intimacy and optimized acoustical quality. This overall process can be repeated in other categories of design as well, in which certain ratios and relationships are vital to the performance of other architectural systems. A benefit of this process is that it can be done relatively quickly and inexpensively. This is a mechanical and manual way of testing the acoustics on a portion of a surface. The leading industry software, Odeon Acoustical software, is a highly complex software designed to measure many acoustical qualities in many different kinds of environments, from train stations and airport terminals to restaurants, concert halls, and even outdoor spaces. Odeon is capable of importing 3D models, or one can model surfaces in Odeon itself. Additionally, Odeon can incorporate the absorption data of surface materials.

Compared to the Odeon Acoustical Software, the leading software program in the industry to test acoustics, this can be done by a student for free using Autodesk's free three year trial for students, and the Microsoft Office Suite included on most computers. A university license for Odeon Acoustical Software for one seat starts at over 5,000 euros, with basic commerical packages jumping to over 14,000 euros for one seat..

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Room Acoustics | Noise Prediction Software | Sound Absorption | Acoustic Modeling | Loudspeaker Cluster | BRIR. Web. 27 Sept. 2011. <http://www.odeon.dk/>.