THE APPLICATION OF NURBS TO ACOUSTICAL SCIENCE

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1 Introduction

Non-Uniform Rational B-Splines or NURBS are a mathematical construct developed by the Italian automotive industry in the 1960s. A NURB is to a 3D shape what a B-Spline is to a 2D curve. Once the purview of multi-nationals with large mainframe computers, for the past 15 or so years they can be found on personal computers in software platforms such as Rhino, among others. The impact of NURBS on architecture can be seen in the increasingly challenging geometries such the Guangzhou Opera House [1] and the wonderful new Philharmonie de Paris [2]. The rectilinear geometry paradigm that has dominated architecture since the beginning of the last century is beginning to wane. Acousticians were complicit in the rectilinear discipline because over that time if one wanted to do a reflection calculation, either by hand or computer, one had to cast reflections off a flat surface. The result was that the wonderful curves and domes used by architects in ages past have no longer been seen in recent buildings. NURBS can restore that exciting expression of geometry and, indeed, already have.

2 History

It is the author's observation that if one looks at the history of science or technologies such as our own, the important ideas of the day tend to focus on what could be measured or predicted at the time. For a good part of the 20th century, the concept of Reverberation Time ruled. That was because until the 70s or 80s, before the dawn of accessible computer power, that's all that one could measure or confidently predict.

Before NURBs were introduced to acoustics, geometries that focus sound were generally thought to be acoustically troublesome. This despite evidence to the contrary, such as barrel vaulted naves in churches and cathedrals. There are successful concert venues with barrel-vaulted ceilings, notably London's Wigmore Hall [3] and sections of rooms that benefit from domed ceilings, e.g. the balcony of Vancouver's Orpheum.

One of the most celebrated domes is in St. Paul's Cathedral, London. Please see Figure 1. There are two foci as the sound collected in the dome propagates towards the congregation below. By the time it gets there it is arriving at the listeners as lateral energy, which as we know, is an important ingredient for good acoustics.

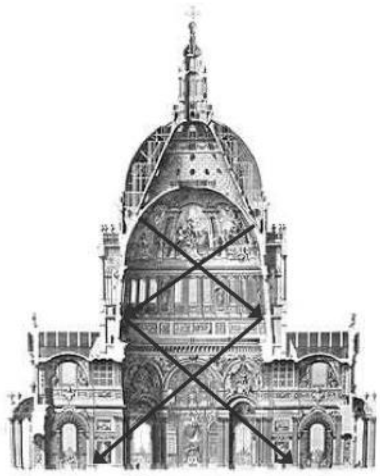

Figure 1: Focusing created by the dome in St. Paul's leads to beneficial lateral reflections directed towards the congregation

2.1 Experiment

Using the flexibility of NURB based design; a simple computer based experiment was performed. There are three important forms of focusing geometries: circular, hyperbolic and elliptical. The latter is the most interesting for acoustic reflector design. There are two foci in an ellipse and one can use that to advantage, as shown in Figure 2.

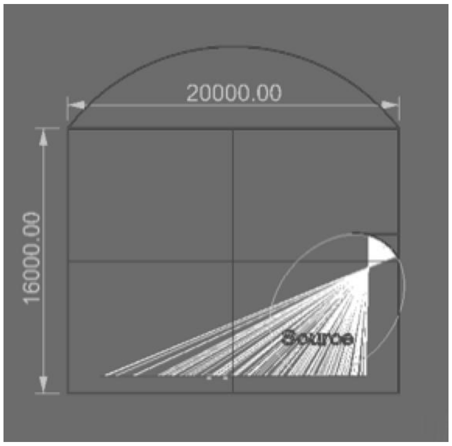

Figure 2: A focusing soffit reflector. The source on stage is at one of the reflector's foci and the focus of the reflected sound is at the other, high above the listeners' heads.

In this experiment the source on stage is at one of the ellipse's foci and the focus of the reflected sound is at the other. Three things to note: (i) The curved soffit reflector provides beneficial lateral reflections to the listeners. But, unlike side wall reflections, the soffit reflections come from above and thus are not subject to low frequency grazing

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incidence attenuation; (ii) the focus of the reflected sound is high above the listeners' heads; (iii) beyond the reflected sound focus the soffit reflector turns into a scatterer of sound, which has been optimised for uniform distribution of sound on the seating plain and to avoid "splash" to the wall beside.

3 Case studies

3.1 Queen Elizabeth Theatre, Vancouver

The author and his colleagues learned about the importance of instantaneous visual feedback from computer software during the renovation design of Vancouver's Queen Elizabeth Theatre [4]. This was, acoustically, a very difficult renovation because the owner's representative insisted on a seat count of 2800. This meant leaving the remnants of an acoustically lamentable, very wide post-war room and then trying to solve the problem. It was solved with green building software known as Ekotek, a package intended for light not sound, This allowed the design team, for example, to design balcony front reflectors hanging – in a mathematical sense in 3-D nowhere land – to be optimised to within less than a degree. But all this design power could only be rendered in flat surfaces. That was when the author and his colleagues started developing similar visual optimisations on curved surfaces, i.e. using NURBS.

3.2 Von Kuster Hall, London Ontario

Following the work on the Queen Elizabeth Theatre, the design of which was limited to rectilinear solutions, the hope of the author was to graduate the iterative acoustic design optimisations from flat surfaces to curved surfaces, thus, hopefully, expanding the architects' design palette. The budget for von Kuster Hall could not accommodate side wall balconies. Knowing how important soffit reflections are, as explained in Section 0, an unoccupied shelf was put in, as shown in Figure 3. Iterative visual optimisation of the soffit's geometry was done with a plug-in created by the author and his colleagues called the NURB Room Acoustics Tool, or NRAT [5]. NRAT is essentially a ray tracer that can reflect sound off curved surfaces.

3.3 Confederation centre, Charlottetown PEI

NRAT was also employed in the renovation design of the Confederation Centre in Charlottetown. A number of NURB based designs were proposed, including one using the principles explained in Section 0. In the end, the architects decided to use their own design.

4 Automated design optimisation

The design iterations for von Kuster Hall and the Confederation Centre were done "by hand". That is, after each iteration, the NRAT operator would change the geometry of the reflector in Rhino then run NRAT to find out the results. This took time, at most only 12 optimisation designs could be generated and tested in a day. It was decided to employ computer optimisation routines borrowed from the aerospace industry [6]. The optimisation tool is called SOAR. Where perhaps a dozen optimisation iterations could be done in a day, SOAR can do thousands.

Figure 3: von Kuster Hall, University of Western Ontario. What looks like a side wall balcony is an unoccupied "shelf" used to generate beneficial lateral soffit reflections.

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