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PRESENTS

A new software tool to facilitate NURB based geometries in acoustic design

by John O'Keefe, Payam Ashtiani and David Grant

ABSTRACT

Non-rational uniform B-splines (NURBs) are liberating acoustic design. Geometrical acoustics is no longer limited to flat surfaces. For decades, curved surfaces in computer models had to be broken down into a series of contiguous flat surfaces; a procedure prone to inaccuracy. With NURBs this is no longer the case. A new software tool has been developed by the authors, called NRAT, intended to facilitate acoustic design in NURB based geometries. Two parameters have been developed to quantify the efficiency of reflectors as they are being designed. They are called Reflector Efficiency (RFE) and Receiver Coverage (RCC). The two are quoted together, much like a blood pressure reading might be. The two parameters are required for reasons that became apparent to the authors as the NRAT tool was being developed. A small reflector, perhaps one that might be part of an array, may have a very high percentage of its surface area effectively casting reflections to the audience (perhaps 85%) but those reflections may only cover a small proportion of the audience area (say, 12%). Conversely, a large reflector, for example the side wall of a shoe box shaped concert hall, may only have a small area casting reflections to the audience – in our experience, in the range of 6%. But this small zone efficiently casts reflections across the expanse of the audience, sometimes as much as 90% or more. The quantification of the two RFE/RCC scenarios presented above would be, respectively, "85 over 12" and "6 over 90". Two case studies of Non-rational uniform B-splines (NURBs) in acoustic design are presented.

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A new software tool to facilitate NURB based geometries in acoustic design

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ABSTRACT

Non-rational uniform B-splines (NURBs) are liberating acoustic design. Geometrical acoustics is no longer limited to flat surfaces. For decades, curved surfaces in computer models had to be broken down into a series of contiguous flat surfaces; a procedure prone to inaccuracy. With NURBs this is no longer the case. A new software tool has been developed by the authors, called NRAT, intended to facilitate acoustic design in NURB based geometries. Two parameters have been developed to quantify the efficiency of reflectors as they are being designed. They are called Reflector Efficiency (RFE) and Receiver Coverage (RCC). The two are quoted together, much like a blood pressure reading might be. The two parameters are required for reasons that became apparent to the authors as the NRAT tool was being developed. A small reflector, perhaps one that might be part of an array, may have a very high percentage of its surface area effectively casting reflections to the audience (perhaps 85%) but those reflections may only cover a small proportion of the audience area (say, 12%). Conversely, a large reflector, for example the side wall of a shoe box shaped concert hall, may only have a small area casting reflections to the audience – in our experience, in the range of 6%. But this small zone efficiently casts reflections across the expanse of the audience, sometimes as much as 90% or more. The quantification of the two RFE/RCC scenarios presented above would be, respectively, "85 over 12" and "6 over 90". Two case studies are presented.

1 INTRODUCTION

Non-rational uniform B-splines (NURBs) are essentially a three dimensional version of a two dimensional B-spline. They are now being used in a wide range of industries. From buildings to widgets to cars, software based on NURBs is freeing up design and manufacture. Indeed, one of the first applications of NURBs was in the automotive industry. More recently, NURBs are entering the world of acoustic design. Guangzhou Opera House[1] and the new Paris Concert Hall[2], to name just two, relied heavily on NURB based design.

One of the main advantages that NURBs give to acoustical designers is that reflection calculations are no longer limited to flat planes. Thus, if one wants to determine the reflections off a curved surface, one can actually use the curved surface. It is no longer necessary to break that surface down into a series of flat surfaces.

One of the more popular NURB based design software packages is Rhino. Because Rhino is easily programmable, it has spawned a mini-industry of so-called “plug-in” applications. In a recent project, the Queen Elizabeth Theatre renovation[3], the authors learned about the power of computer based iterative design in 3-D space. The power is in the immediate visual response, rather than numeric parameters that take much longer to calculate. Some of the reflectors in the Queen Elizabeth Theatre were designed to an accuracy of a degree or less. With that, we were able to overcome the challenges of a very wide room and provide good spatial sound. But, in doing that, we had to deal with only flat surfaces. A limitation that, inevitably, translated into the architectural expression of the building.

2 NRAT

We sought to overcome that limitation and eventually developed our own plug-in for Rhino. It’s called the NURB Room Acoustics Tool, or NRAT. It is a ray tracer much like any other but with the advantage that we can now calculate reflections off curves, domes or any geometry one might think up. NRAT is, for the most part, a visual tool used during design to optimise a given reflector or array of reflectors. It operates in two modes that could be loosely called static and dynamic. In the latter, the designer can watch where reflections are cast as he or she adjusts the shape or position of a reflector, and do so in close to real time.

2.1 Reflector Efficiency

As mentioned, the visual feedback provided during computer based design is very important. Despite this, it is still useful to have some form of numeric quantification to determine if one design iteration is better than another. To this end, the authors have developed a simple parameter called Reflector Efficiency (RFE). It’s a simple ratio of the area of a reflector that is actually reflecting sound to the total area.

$$RFE = \frac{S_{reflect}}{S_{total}} \tag{1}$$

where: $S_{reflect}$ is the area of the reflector that is successfully casting reflections to the receiving plane (i.e. the audience).
S_{total} is the total area of the reflector.

Having worked with this for a while though, we found that it didn’t quite quantify the entire picture. For example, a small reflector may have an RFE close to 100% but only cover a small area of the receiving plane. Conversely, a very large reflector, like a ceiling or side wall could have a very low RFE but cover the entire receiving plane. We created a new parameter and a method of expressing the information. It’s called Receiver Coverage (RCC)

$$RCC = \frac{A_{receive}}{A_{total}} \tag{2}$$

where: $A_{receive}$ is the area of the receiving plane that actually receives reflections
A_{total} is the total area of the receiving plane.

We combine the two in an expression similar to a quantification of blood pressure. The small reflector might have an RFE/RCC of "85 over 12" while the ceiling or wall may have one of "6 over 90".

3 CASE STUDIES

3.1 von Kuster Hall

von Kuster Hall is an existing room in the Faculty of Music, University of Western Ontario. It is 250 seat recital hall, well liked by both students and faculty. It is both reverberant and loud, with a measured Early Decay Time (EDT) of 1.4 seconds and Strength(G) of 16 dB. Unfortunately, it is contained inside the campus's least efficient building. The building, along with the recital hall, will be demolished and replaced with a new building. Our commission was to ensure that the new von Kuster Hall had acoustics that were as good or better than the existing room.

One of the improvements that has been incorporated into the design is what we are calling the side wall soffit reflectors. Although there will be no side wall balcony in the room, the benefits of 2^{nd} order reflections off a side wall balcony soffit are well known. In a shoebox shaped hall such as this one, soffit reflections offer the advantage of lateral reflections that are not subject to low frequency grazing incidence attenuation. Lateral reflections directly off the side wall are subject to grazing incidence attenuation and thus, it is thought, lead to a reduction in warmth.

With the power of NURBs, Rhino and NRAT at our disposal, it was thought that we could optimise the soffit reflectors by creating either concave or convex surfaces. In the end, ironically, it turns out that, at least at the front of the room, a flat surface makes for a more efficient reflector.

An image of the final reflector design is shown in Figure 1. The sound source is downstage centre, where a soloist would probably perform. Lines indicating the sound rays are not shown because they confuse the clarity of the visual information. Rather, we use dots to indicate the points for reflection and reception. NRAT can currently calculate up to 5^{th} order reflections. Each order can be displayed individually or collectively with the others. In Figure 1, the image is limited to 2^{nd} order reflections. On the side wall, note the reflection points on the wall and the soffit reflector. On the receiver plane, note the white and red receiver points. White represents a reflection arriving within 35 ms or less, red between 35 and 50 ms. The RFE/RCC quotient for this design is approximately 55 over 45. Obviously, one would want to get the RCC component as close to 100% as possible (i.e. full coverage of the audience) but note that this is only one of two reflectors and the room is symmetrical about its centre axis. When the two reflectors are combined, we come fairly close to total coverage.

In an effort to achieve 100% RFE, i.e. a reflector that is casting useful reflections across its entire surface, the back third of the soffit reflector was tilted down and slightly twisted. The intent was to get sound to the receiving plane through a third order reflection off the back wall. The result is shown in Figure 2.

This demonstrates the value of a RFE/RCC quotient because, even though we now have many more reflections off the soffit reflector, suggesting a better RFE (i.e. reflector efficiency is higher), the RCC (receiver efficiency) has barely changed. The previous quotient was 55 over 45, this new iteration is approximately 85 over 48.

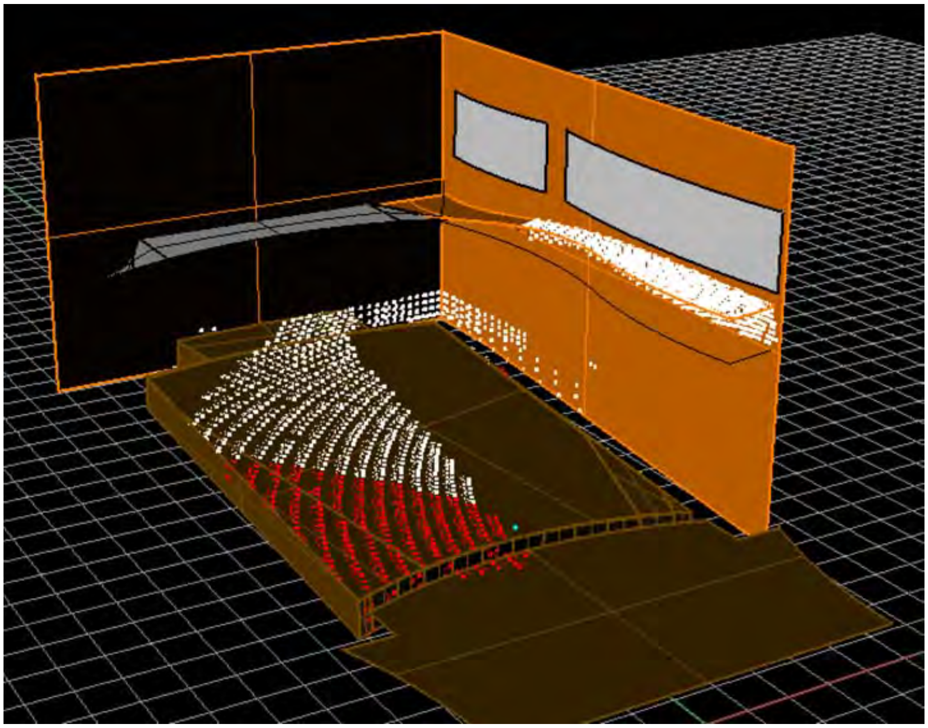

Figure 1: 2nd order reflection and receiving points for the von Kuster Hall soffit reflector design. On the receiving plane (the audience) the white dots indicate reflections arriving within the first 35 ms. The red dots represent reflections arriving between 35 and 50 ms.

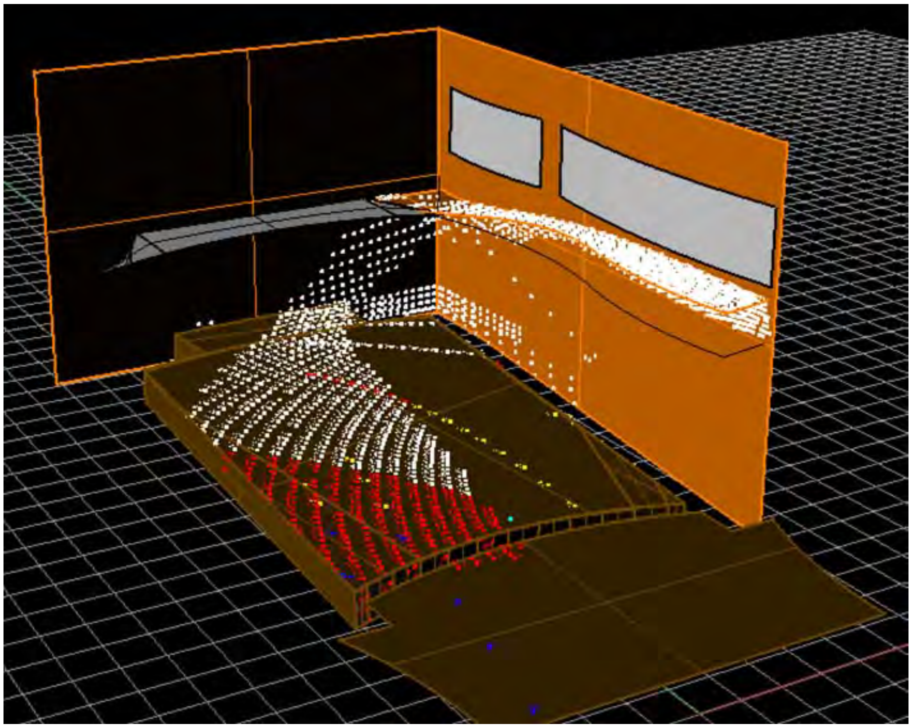

Figure 2: 2nd and 3rd order reflection and receiving points for the von Kuster Hall soffit reflector design.

3.2 Confederation Centre

The Confederation Centre for the Arts in Charlottetown, Prince Edward Island opened in 1964 to celebrate the centenary of the Charlottetown Conference that lead to Canada's confederation three years later in 1867. It was designed by essentially the same architectural and acoustic team that did the Queen Elizabeth Theatre in Vancouver[3]. It is very much of its age acoustically. It is very wide with a subsequent lack of spatial sound. Our task was the same as the one for the Queen Elizabeth Theatre: make a wide room sound narrow. And to do so without losing too much of the 1960s architectural heritage that the Islanders have slowly befriended.

Three design concepts for lateral reflectors have been considered so far, two of which will be presented here. Neither one of the three could have been reliably studied without NURB based analysis.

The first was inspired by a "back of the envelope" sketch by one of the architects. A curved intersection between the side walls and the ceiling. In hindsight, it would be similar to the problematic curved surface that challenged us at Vancouver's Orpheum in 1995[4]. But unlike then, we now have a reasonably reliable tool to predict the performance of those curved surfaces.

An array of curved reflectors was developed. The reflection pattern for one of those reflectors is shown in Figure 3. Note that despite its problematic concave design, we can now confidently locate the focus of the curve high above the audience members' heads. Beyond that focal point the concave surface is no longer focussing but scattering. The entire array is shown in Figure 4.

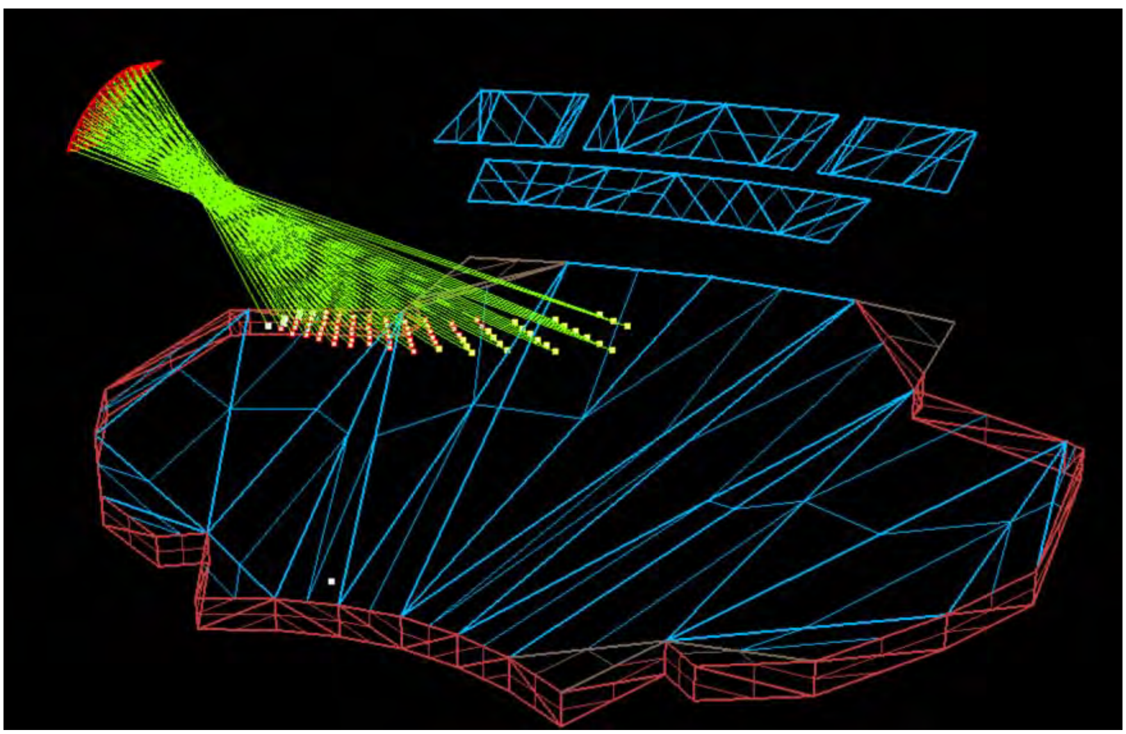

Figure 3: 1st order ray study of a concave lateral reflector in the Confederation Centre.

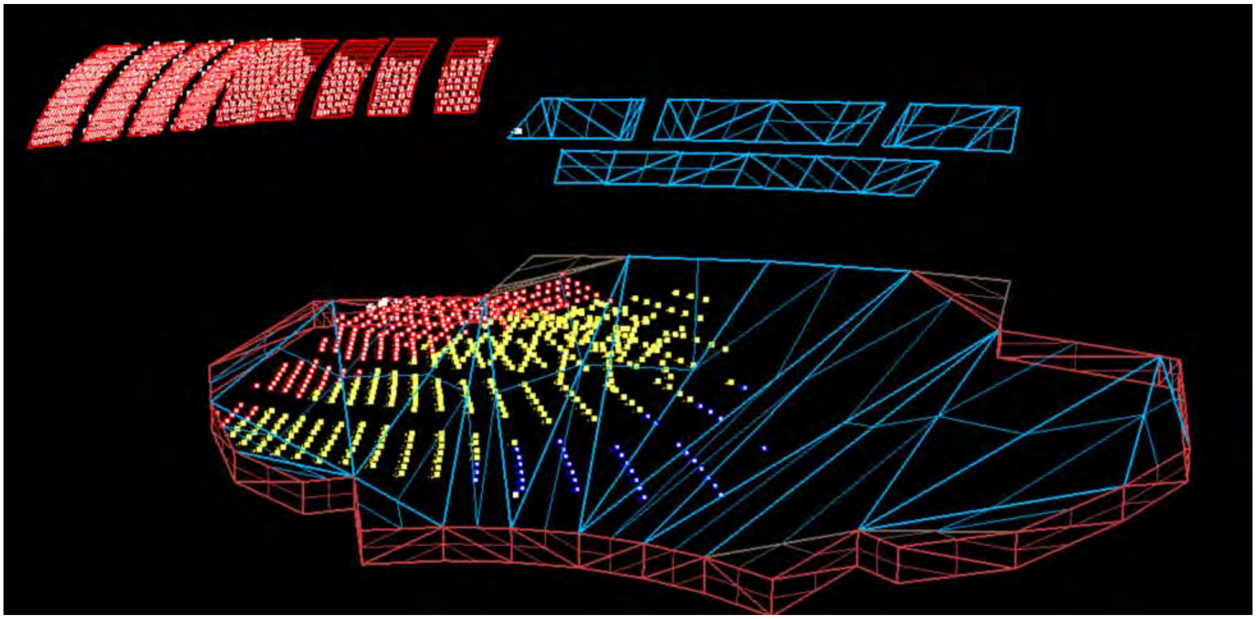

Figure 4: 1st order ray study for the entire (concave) lateral reflector array in the Confederation Centre.

The second iteration was also proposed by the architect. The intention was to preserve the sculptural impression of the Alexander Calder like reflectors in front of the proscenium arch. Please see Figure 5. These, of course, are reminiscent of the reflectors/sculptures that Calder did with the same acousticians (Bolt Beranek and Newman) in Aula Magna in 1953.

Figure 5: Reflectors above the proscenium arch. (Photo by Sarah Mackel)

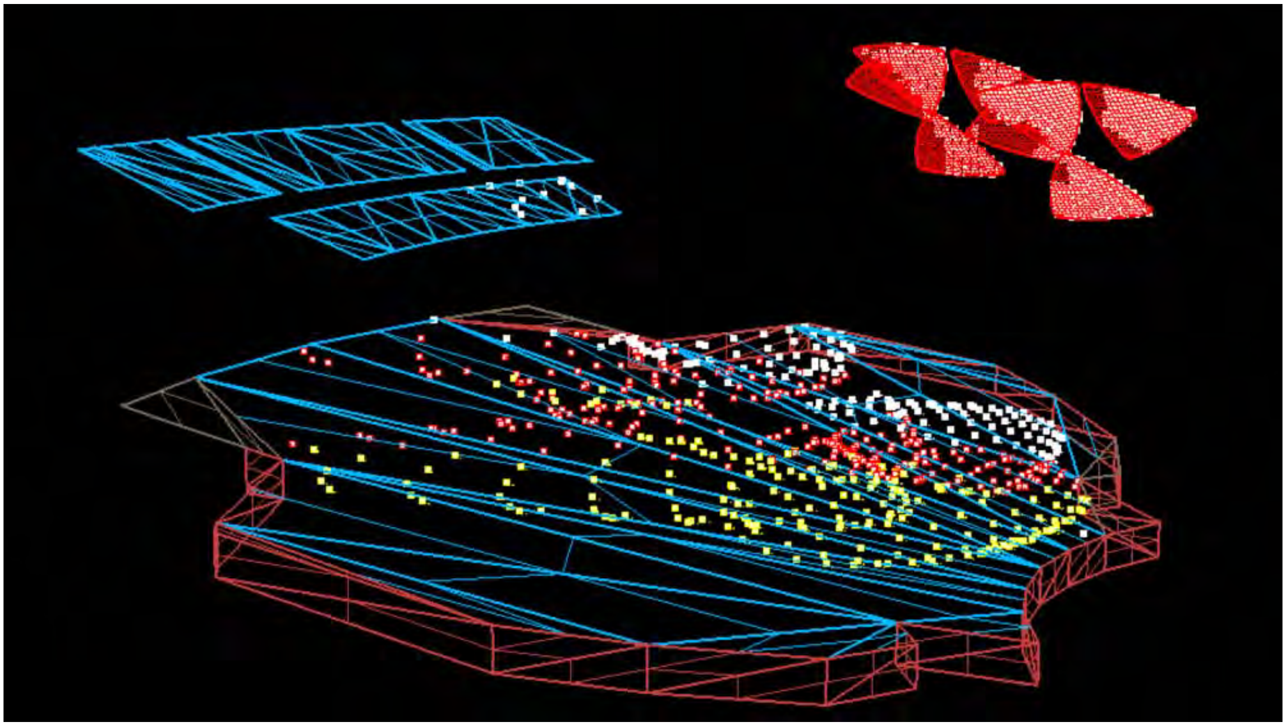

Figure 6: 1st order reflection and receiving points for the convex reflectors at the Confederation Centre.

In the 1960s these reflectors were positioned to provide frontal energy. We now know, of course, that a lateral placement would have been better. So the design exercise was to relocate them – or rather replace them with new, cleaner versions – to the side walls. The results are shown in Figure 6. The Calder like reflectors are shown in the top right hand corner. We see both efficient use of the reflectors and good coverage of the receiving plane. For the orchestra level seating, the RFE/RCC quotient is in the range of 75 over 65. Remember again that the room is symmetrical and this study only represents reflectors from one side. One could expect entire coverage of the audience area with this design.

FUTURE WORK

The NRAT tool continues to develop. An automated computer based optimiser has been created and has been presented at this conference[5]. We will also be incorporating a novel approach to early/late energy ratio calculations. Using NRAT we can easily determine the early energy off curved surfaces. Determining the late, diffuse field in a NURB environment is not so easy. Rather than this, we are using Revised Theory[6] to quantify the late energy in the calculation.

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