

# Adrian James Acoustics

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## CONSULTANCY SPOTLIGHT

***The Norwich Forum – The acoustics of a library for the 21<sup>st</sup> century.***

***Adrian James MIOA***

The acoustic design of auditoria and studios is generally quite straightforward. The acoustic aims and criteria are reasonably well-understood (or at least we like to think so). A substantial budget is

set aside for sound insulation, acoustic elements and finishes; indeed there is some relief when we do not insist that every surface should be covered in quadratic residue diffusers, 100-year-old sycamore panelling or fibreglass wedges, and general rejoicing when we admit that the whole building does not need to be mounted on springs. A pleasantly large budget is set aside for extremely expensive loudspeakers, and a much smaller budget is set aside for our fees. Efforts to re-allocate funds between these budgets are generally doomed to failure, but fun.

In concert halls, the architect is prepared to listen politely to us because these are buildings where acoustics are considered to be important. Enlightened architects may even consult us before the concept design is (they hope) set in stone. In general the most difficult task is explaining to the client that he can not have a 2,000 seat auditorium with the acoustics of both the Barbican Theatre and the Amsterdam Concertgebouw simply by drawing a few curtains. While our colleagues in environmental acoustics suffer agonies at the hands of bemused planning inspectors and irascible judges, our most difficult problem recently was when, an hour before the first performance in a new concert hall, one of the legs fell off the piano and the resulting collapse left a hole in the stage and an instrument which, by the end of a spirited performance of Rachmaninov's second piano concerto, was sounding rather the worse for wear. Fortunately so were the local music critics, or perhaps they were too busy writing weighty opinions about the acoustics to listen to the music.

In fact, auditorium acoustics is generally quite fun, and we like to stick to it. Every now and again, however, we come across a building for an apparently much more mundane use, but of such unusual concept and acoustic complexity that we feel that we simply have to stick our oar in. The Millennium Forum in Norwich was such a building.

## ***History***

As its name implies, the Forum enjoys a central location (albeit in Norwich rather than Rome) between the City's finest church, the Theatre Royal, the Assembly House, the City Hall, the police station and the fire station. The last of these is particularly relevant because the Forum is on the site of the central library, which was completely destroyed by fire in 1994. Not unnaturally therefore when building schemes for the millennium started being discussed, a replacement for the library was at the heart of the scheme.

As usual for what have become designated "Landmark Buildings", a well-known architectural firm from London was appointed, in this case Michael Hopkins and

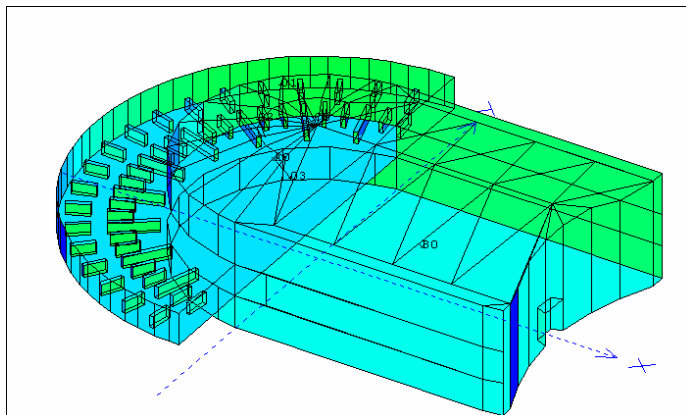


Partners, causing great irritation to some more local architects who had done quite a lot of groundwork (when will architects ever learn not to do unpaid work?). Oddly enough, although we attended countless meetings at his offices and on site, we never met Michael Hopkins himself. However, he cast his shadow over the project on those occasions when his excellent deputy, Mike Taylor, would begin a meeting with the announcement the great man had reviewed the latest developments of the design and disapproved of the effect that cluttering up the building with lifts, staircases, furniture and tenants' shopfronts would have on the nice empty space that his vision had created, and could we therefore reverse all of the decisions taken at the previous meeting? Irritatingly enough, he generally turned out to be right and fortunately, the transformation of several acres of glass roof into perforated steel for acoustic purposes escaped this treatment.

### ***The building concept***

It is always interesting to go back through the files of a project. In writing this article I have found a press release stating that "The Forum's design has attracted widespread public support for its unique horseshoe shape". Did market researchers, I wonder, ask a statistically significant number of geometrically qualified shoppers whether they supported a forum with a unique horseshoe shape, as opposed to a less unique toroidal form or perhaps a plain mundane ellipse? In the original Forum, philosophical ancient Romans might have launched into a discussion of whether a horseshoe shape could be unique being shaped, inevitably, like a horseshoe. In Norwich, sadly, replies would probably have been shorter.

None the less, the description of a horseshoe shape is accurate, and its uniqueness lies not so much in its shape as in its dimensions, being some 70 m long, 50 m wide and 17 m high. And, unlike most horseshoes, it is built largely of glass. The accommodation is around the perimeter of the horseshoe on ground, first and second floor levels,



with the whole of the third storey of the horseshoe allocated to plant, and two storeys of car park underneath the building. The volume enclosed by the horseshoe is a huge, full-height, glass-roofed atrium, (rather confusingly also called the Forum) acting as an entrance hall to all of these facilities, and providing a home for a variety of informal catering outlets.. The whole project was costed at £63 million of which half was provided by the Millennium Commission.

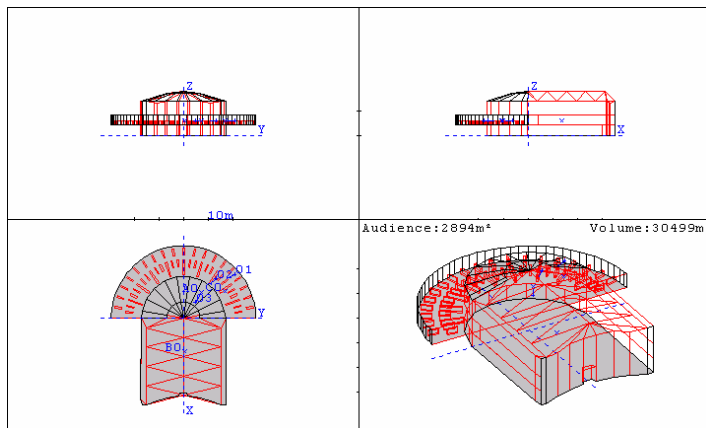
When we joined the project (just before the completion of RIBA stage D, the outline design stage) the accommodation was to include a lending and reference library with specialist collections, staff and study areas, training, meeting and staff rooms; a 200-seat multimedia auditorium; a "Heritage Visitor Attraction"; the city's tourist information centre; and a number of small commercial / retail units ; and of course the Forum itself. The Heritage Visitor Attraction was designed separately and is not covered in this article. During the design period the multimedia auditorium was eventually replaced with a television studio (although not until after we had provided a rather satisfying acoustic design which worked within the less than ideal semicircular space) and part of the Forum was let to Pizza Express. The remaining

acoustically interesting aspects were the Forum and library; the sound insulation of the naturally-ventilated building envelope; the provision of sound insulating airpaths through partitions ; attenuation of some unusually large extract fans ; and design of broadcasting studios which came into the scheme at a later date.

### **Acoustics of the Atrium**

The acoustic challenge that had originally caught our attention was that the library was to be open-plan to the Forum, which was to be finished almost exclusively in glass, metal and concrete, with tiled floors, a glazed roof and a huge curved glazed screen forming the front wall. All of these finishes have of course the considerable advantages of architectural simplicity and incombustibility, which given the fate of the previous library appealed to the Client and to the fire brigade. The principal disadvantage was a predicted mid-frequency reverberation time of about 5 seconds, increasing substantially at low frequencies, in a volume of some 30,000 m<sup>3</sup>. Imagine a volume three times that of the Royal Festival Hall, with the only acoustic absorption being some bookshelves and thin carpet at one end, and you may conceive the magnitude of the problem.

Apart from the well-known problems of an over-reverberant Atrium space, we had the problem that at first floor level the library was effectively part of this space, with only a 1.8 m high glass screen between the two. The Forum and first floor libraries therefore had to be considered as a single acoustic volume. The Forum was designed to be a busy public space with restaurants, coffee bars and informal entertainment taking place while the library was in use. This was a fundamental precept of the design, to leave behind the image of a library as a hushed, intimidating and exclusive environment and instead to make it part of a busy, exciting space where people would want to come. In this respect the building has been remarkably successful. At the design stage however we were faced with the problem of a reference library open to a very noisy environment, with the paradox that the more successful the concept proved to be, the busier and noisier it would become.



This looked like an interesting challenge to which the techniques that we use for large auditorium design would be well-suited, as the atrium and library are linked reverberant spaces where statistical calculations based on Sabine theory would not apply. We therefore created a *CATT-Acoustic* model of the whole space (Figure 1)

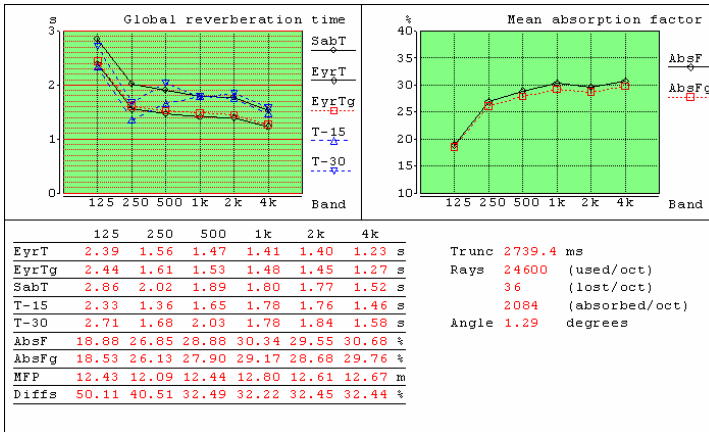
and investigated the propagation of sound throughout the space with sources at various locations in the Atrium.

There is not a great deal of published guidance on the acoustics of libraries. BS8233 suggests 50 dB LAeq,T (where T is an unspecified period) as being “reasonable” and 40 dB LAeq,T as being “good”. Measurements in other libraries confirmed that these were acceptable activity levels in lending / staff areas and in reference / study areas respectively. The *CATT* model, using source levels measured in similar spaces, led

us to expect levels approaching 65 dB LAeq,T dB(A) on a busy day throughout the open-plan areas of the library.

We had been appointed to the project only shortly before the Stage D (outline design) reports were due to be submitted and by this time there was very little scope for changes to the concept and layout of the building. We made all of the predictable suggestions – a full-height glazed wall between the library and the Forum, suspended ceilings, suspended acoustic absorbers, carpet, earplug-dispensing machines at the library entrances – and they were equally predictably rejected as out of keeping with the appearance of the building. More radical suggestions such as the use of concealed resonant absorbers (as used in the acoustically very similar Musee D’Orsay in Paris) were seriously considered but rejected as too expensive and difficult to cast into the concrete.

Fortunately, both the client and the architect were persuaded of the severity of the problem and we therefore reached a compromise between the visual and acoustic requirements. Some 40% of the roof was changed from glass to perforated metal with a mineral wool infill, walls at the highest level between the Forum and the plantroom were clad in similar perforated metal panels, and carpet was introduced to the walkways at first floor level.



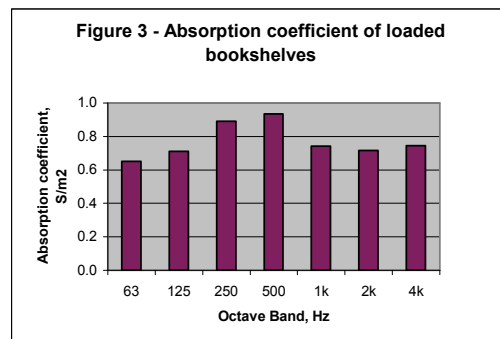
The resulting caustic, while far from ideal, at least gave some hope of being manageable. The reverberation times T-15 and T-30, calculated from the CATT-Acoustic computer model, were below 3 seconds at 125 Hz and below 2 seconds at higher frequencies. (Figure 2). The discrepancy between these values and the classical Sabine and

Eyring RTs was not due to any lack of diffusion in the model, but due to the fact that all of the absorption is at high level so that the statistical assumptions on which Sabine and Eyring’s theories are based do not apply. The decay curves (both predicted and, later measured) are far from straight lines and the acoustics naturally vary with position in the space.

### Acoustics of the library spaces

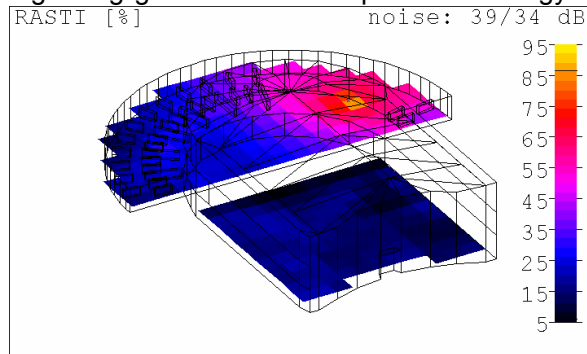
Once out of the main Forum volume, the main library spaces are single-storey in height, but have exposed concrete ceiling soffits to provide thermal inertia for energy efficiency. This, combined with the large floor areas, meant that in the original design the only acoustic absorption would come from thin carpet (not very absorbent at low frequencies) and from the books, bookshelves and furnishings, which were an unknown quantity.

We measured the acoustic absorption of



loaded bookshelves in different layouts and geometries and found the results in Figure 3 to be generally applicable.

For additional absorption in the horizontal plane, special bookshelf units were designed with acoustically absorbent top surfaces.. Given the area of bookshelves in the library, we considered this to be sufficient for most cases. The Client however wished to maintain the flexibility of having large areas of floor without bookshelves, in the event of large areas of the building being given over to computer technology in future. We therefore designed perforated wooden panels with acoustically absorbent carbon-impregnated foam for use in the wall finishes around the perimeter of the library and the results provide acceptable local acoustic conditions even in the absence of books – not a consideration that would normally be required in a traditional library.



At an early stage of our involvement we expressed concern that there were no areas set aside for quiet study, as reference areas were on the first floor and open-plan both to other areas of the library and to the Atrium. We suggested that a “quiet area” on the second floor should be made available. The second floor is largely given over to the business library and other specialised areas and is considerably quieter than other floors. At the time of writing we have no useful indication of whether there is a significant demand from users for such a “quiet area”.

### ***The voice alarm / public address system***

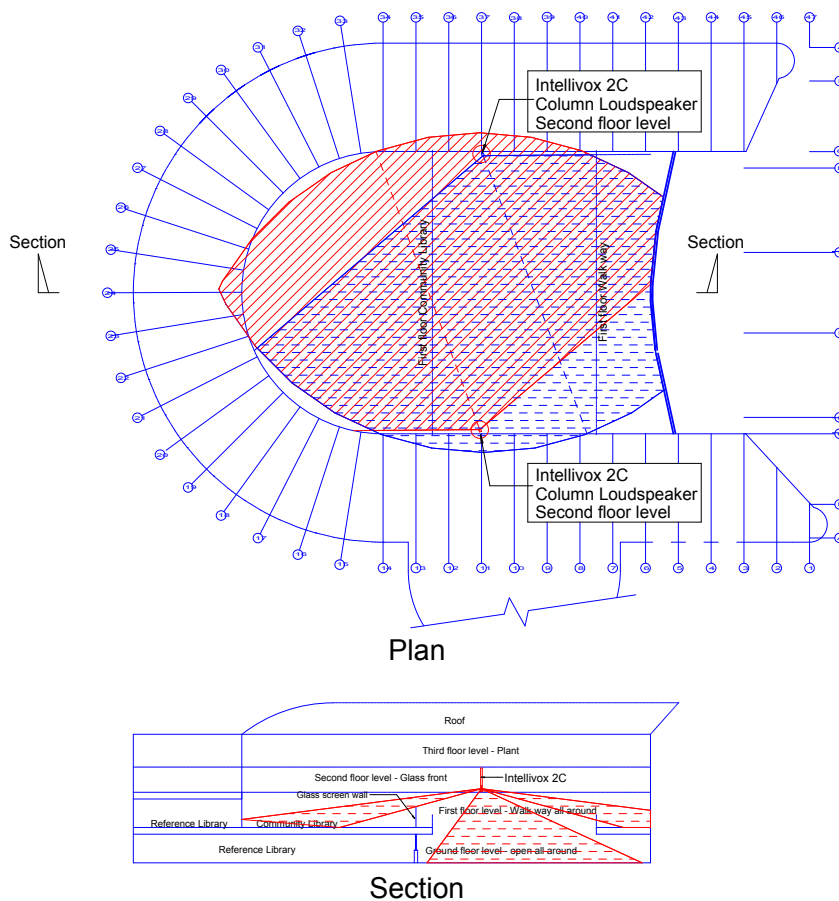
The brief called for a voice alarm system was throughout the building. This was specified by the M&E consultants and most areas were adequately covered by standard single-cone ceiling-mounted loudspeakers set in the ceiling slabs. In the Atrium however, the sub-contractor had proposed a cluster of three small “projector” speakers, similar to those commonly used on underground station platforms, to cover the central area of the Atrium at distances up to 20 m from the speakers. Although described as “sound projectors,” the proposed loudspeakers were simple, non-directional cabinet units with a wide dispersion angle of 160 degrees in both vertical and horizontal directions, which is not helpful in a large reverberant space. They would generate as much acoustic energy upwards as downwards and would this design would have caused high reverberant sound pressure levels in the Forum and Library, greatly reducing intelligibility and nullifying the effect of treating the two areas as separate zones.

We used the CATT model to predict the performance of the system as designed and unsurprisingly found that it failed by a very large margin to meet the minimum requirements for VA systems in terms of both sound level and intelligibility. A number of alternative configurations were proposed by the subcontractor but rejected both on acoustic and visual grounds. We were therefore instructed to develop a design that would work within the constraints of the architectural design. The limited options for the locations of loudspeakers meant that whatever was used would have to “throw” sound over distances of 25-30 m with minimum excitation of the reverberant field.

Our design was based on the use of Duran Audio AXYS Intellivox-2c column loudspeakers, which are unusual in being “steerable” in the vertical plane through internal signal processing. Once installed, the horizontal directivity of each array is fixed within a nominal variation of 120 to 140 degrees. This allows very narrow and accurate beam aiming in the vertical plane without physically tilting the column. In addition the vertical beam can be split to create two separate beams, each adjustable in aim and width, to cover two separate areas. This was necessary as the speakers had to cover both the ground floor and first floor walkways.

The loudspeakers are aligned asymmetrically – one covers the Forum, first-floor bridge and walkway and the area under the bridge (coverage shown in blue on plan). The other covers the Society library, but with considerable additional coverage of the Forum (shown in red on the plan) to provide some redundancy.

The cost of these speakers was initially something of a shock to the client, but were offset against considerable overall savings in components and cabling as these are active loudspeakers with amplifiers, signal processing and equalisation hardware are housed within the column cabinet. In any case they were found to be the only units capable of meeting the requirements, and the quality of the output was found to be not merely adequate to meet all of the requirements for voice alarm but also for good-quality public address in the Forum and first-floor library.



## ***The broadcasting studios***



Since completion of the library a large part of the building has been taken by the BBC for use as their regional television and radio broadcasting facility and we have been appointed for the acoustic design and sound insulation of the studios and technical areas. The acoustic requirements and constraints of this make the rest of the building look easy, but that is perhaps the basis for another article.

*Client* Norfolk and Norwich Millennium Company *Architect* Michael Hopkins and Partners. *Structural Engineers* Whitby Bird. *M&E consultants* Oscar Faber. *Acoustic Design* Adrian James Acoustics (Adrian James, sound insulation and room acoustics; Amber Naqvi, electroacoustics and studio design ; Simon Kahn, VA systems). *Project Value* £63m. *Completion* Library and Forum October 2001; Broadcasting Centre scheduled October 2002. *A Millennium Commission Landmark project*

Adrian James is the principal of Adrian James Acoustics, a consultancy specialising in the acoustic design of performance buildings and studios, and a member company of the Association of Noise Consultants.