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CITY OF MANCHESTER STADIUM: MAXIMISING ACOUSTIC EXCITEMENT FOR PERFORMER AND SPECTATOR

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1 INTRODUCTION

The Commonwealth Games in Manchester this summer was the largest sporting event the UK has ever seen. The hub of the games was the new City of Manchester Stadium, which has been built to the east of Manchester City Centre.

As an integral part of the design team from inception, Arup Acoustics was able to influence the design throughout the project.

The design process started with the team, led by architects Arup Associates, visiting selected large sports stadia. It was generally agreed that the visual impact, intimacy and excitement were intrinsically linked to the stadium acoustics and crowd noise within the stadium. It was also observed, in stadia that were considered exciting, the players or athletes commented more often on how the atmosphere was a driving force in their own performance.

Acoustical excitement and interaction between spectator and performer became a core design goal for the project with the aim of recreating a space where sport was considered 'the ultimate theatre'.

Figure 1 Commonwealth Games Opening Ceremony

2 MODERN STADIUM DESIGN, ARCHITECTURE AND MATERIALS

2.1 Determining the influencing factors

A cross section of old and new stadia were reviewed early in the project to understand their acoustic properties.

Some fundamental issues were noted:

- Inevitably new stadia in urban areas seek to increase spectator capacity.
- Increased capacity needs to be achieved whilst complying with other safety requirements including row-to-row distances, escape requirements, and maximum allowable terrace rake.
- Sightlines need to be optimised to achieve more uniform views of the whole pitch throughout the stadium.

These issues change the relationship of performer to spectator in a number of ways:

In old stadia, the terrace angles tend to be steep and height from the pitch to the roof plane greater than in modern venues. The majority of sound to the pitch is direct sound from the terraces with reflections from the roof having minimal effect.

In new stadia, terraces tend to have a shallower rake and lower overall height to the roof, but extend further away from the pitch. Roof geometry tends to vary more widely with other external issues such as day lighting, rain cover or architectural aesthetics governing the design. New stadia also tend to be built as complete integrated bowl shapes. Older stadia have often evolved over time, with some stands self-contained, often with closed ends, due to the fact they have been built at different times.

It was clear from this analysis, that optimisation of the roof shape, form and angle relative to the terrace rake had a fundamental effect on the acoustic environment.

A number of analysis techniques were used in order to develop the roof geometry of the City of Manchester stadium to maximise the positive influence of the roof on the acoustic response of the space.

One of the key factors considered essential by the design team from the outset was to achieve an ambience within the stadium bowl to enhance, encourage and ‘amplify’ noise from the crowd, as well as providing the players with a sense of crowd excitement.

2.2 The roof, the voice alarm system and acoustics

Understanding that introducing sound absorption would be detrimental to the goal of crowd ambience within the stadium, the use of mineral wool or similar finishes needed to be avoided if possible.

However, a key component in discussions with Manchester City Council was achieving the speech intelligibility targets required of the voice alarm system. A minimum target of 0.45 STI was agreed upon. The design needed to achieve as close to this as possible in the unoccupied condition whilst requiring a target of 0.5 or greater in the occupied condition (in accordance with BS 7827: 1996 *Code of practice for designing, specifying, maintaining and operating emergency sound systems at sports venues*).

An initial architectural goal was also to limit loudspeaker-mounting locations to the front roof edge in a specially designed "kick-up" detail that also housed the floodlights. Preliminary analysis showed that this could cause some undesirable reflections from the roof that could degrade speech intelligibility.

Understanding these complex requirements from the outset, the roof design team worked directly with Arup Acoustics to optimise the roof form whilst balancing the requirements for day lighting and floodlighting. The design process was fully interactive and over the space of several months, as concepts to meet the brief were explored, the acoustical issues were investigated as parallel design activities.

Close collaboration with the architects ensured that CAD models were produced bearing in mind their use by the acoustics team. An additional 'acoustic model' layer was added to the architect's drawings of the stadium bowl. This layer not only simplified some of the more complex geometries, but also constructed the key surfaces using 3-D closed faces rather than the standard unconnected lines, for later import into EASE and CATT acoustic modelling programmes.

The holistic approach to the design of the stadium allowed the early optimisation of:

- roof curvature;
- roof sound absorption;
- roof sound insulation;
- terrace depth.

This was only achieved through the close collaboration of architect, engineers and acoustician.

Figure 2 The Completed Commonwealth Games Stadium

3 THE DESIGN PROCESS

3.1 Stage 1 - 2D Raytracing

Arup Acoustics developed an in-house 2-D raytracing technique for quick assessment of the reflection sequences in spaces. A black and white bitmap outline provides the basic room geometry. The 'Matlab' matrix manipulation programme is used to define a source, with opening angle, and then produces a series of ray trace snapshots at definable time periods. Rays are colour coded to identify direct, 1^{st} order and 2^{nd} order reflections.

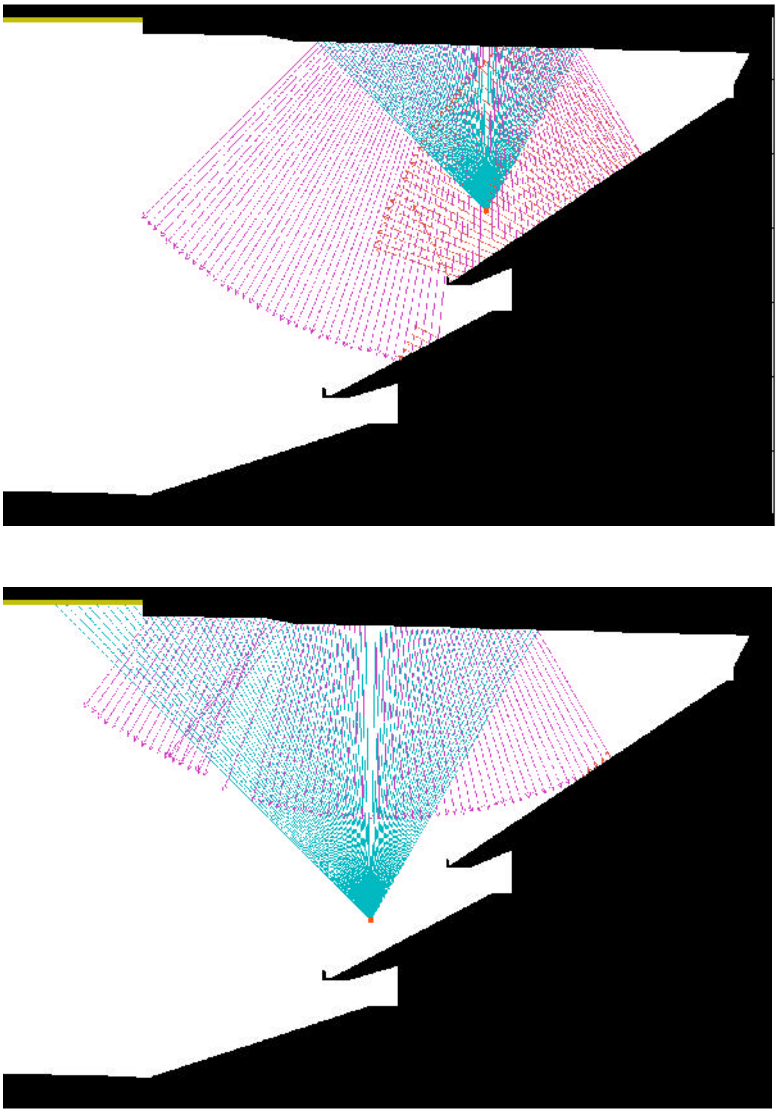


Figure 3 Images of 2D Raytracing Analysis. In the lower image it can be seen that a light green line identifies the surface at the front of the roof soffit as sound absorbing, so there are no 1^{st} order reflections. A black line boundary indicates a sound-reflecting surface.

The roof angle was analysed for source positions on the terraces as well as source locations at the roof front edge to simulate the loudspeakers. The design was optimised using four different representative sections of the terraces.

Although it was desirable to avoid the use of sound absorptive finishes such as mineral wool, the modelling showed that a small, strategically located are of absorption on the underside of the roof soffit would prevent unwanted reflections between the roof and terrace listener locations whilst not jeopardising the atmosphere for spectators or athletes. An area was identified between 10 and 15 m in from the roof edge where sound absorption was likely to be required.

3.2 3-D Raytracing

The acoustic layer was incorporated into the architectural drawings used 3-D closed faces to define surfaces rather than the standard unconnected lines. This meant that the 3-D AutoCAD half model could be imported directly into EASE, Odeon and CATT acoustic modeling packages, allowing rapid iterations of room acoustic analysis, as well as PA system assessment (Figure 4). A rendered 3D model was created in order to further examine the effects of the roof geometry (Figure 5).

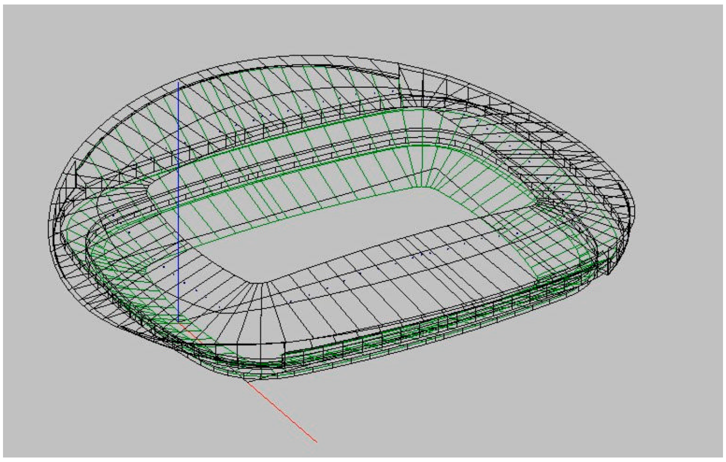


Figure 4 EASE Model created from AutoCAD Model

In the same manner as the 2D model, in house techniques have been developed to create a 3D source (with definable directivity) and create a real time rendering of sound dispersion in the space for a given source location. This was primarily required in order to assess the influence of the curvature of the roof on the reflection of crowd noise (Figures 6 and 7).

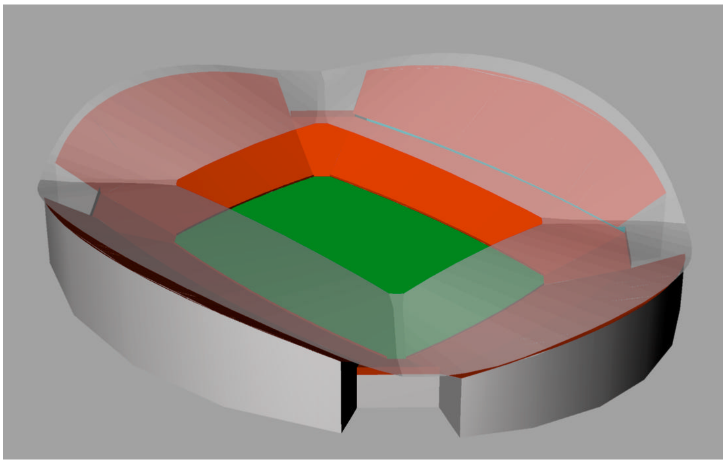
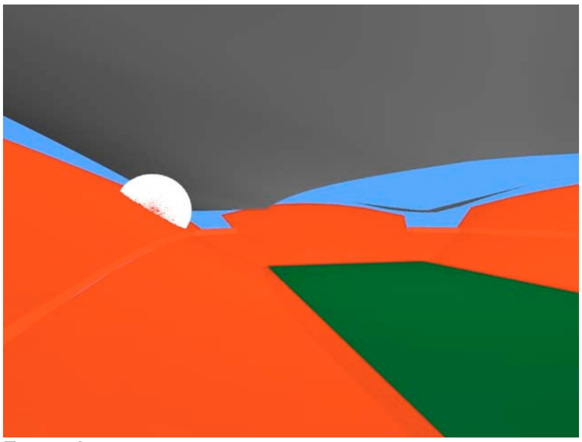


Figure 5 Rendered 3D Model of Stadium



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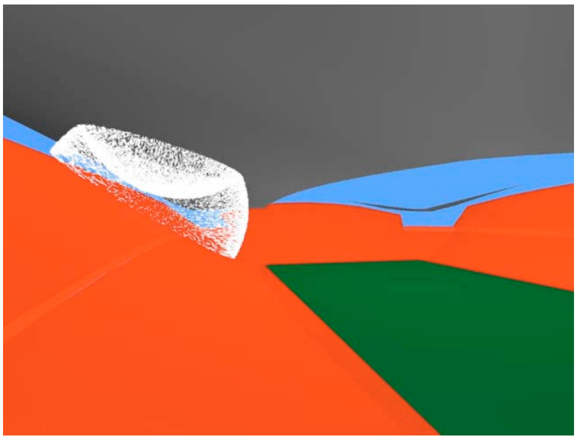

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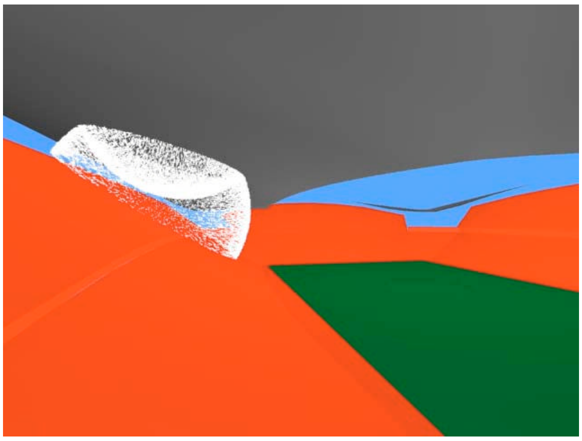

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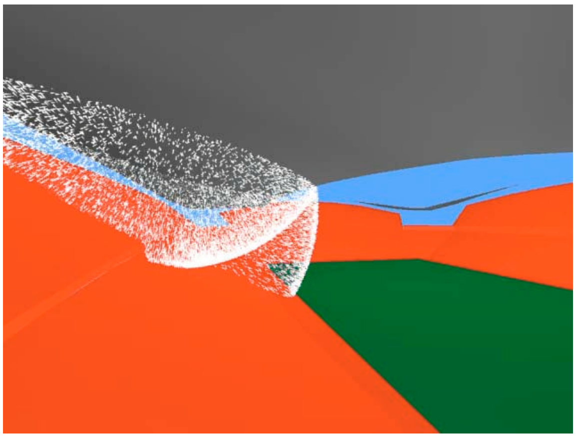

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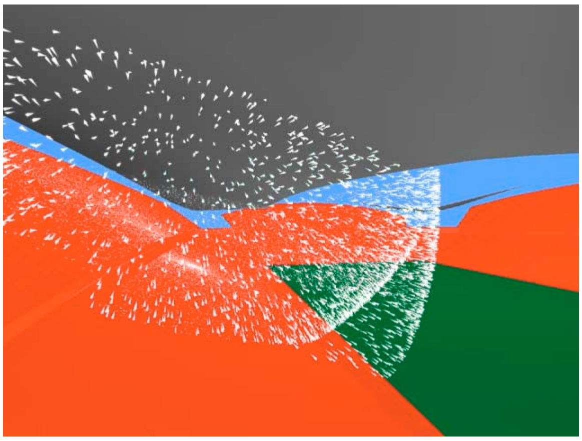

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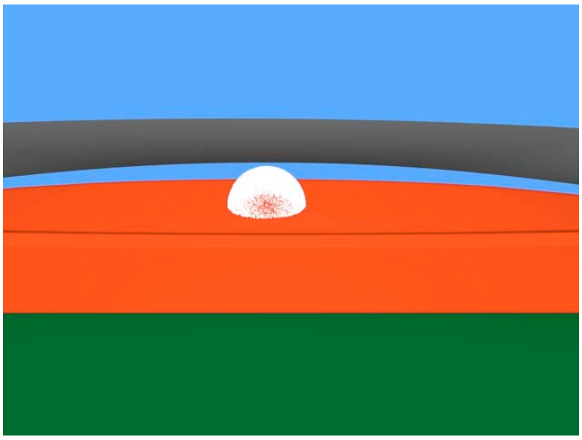
Figure 6 Rendered 3D Model of the Stadium North Stand Showing the Progression of Reflected Sound from the Roof Soffit



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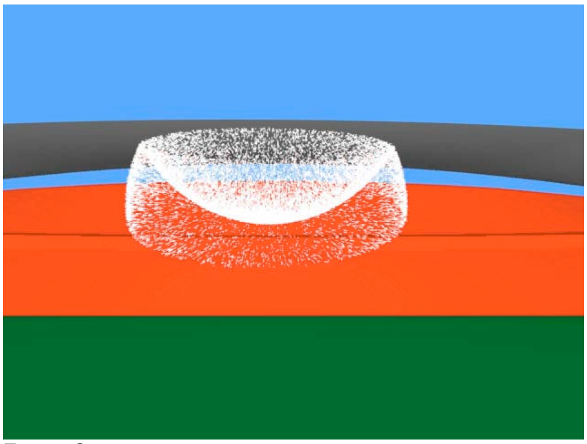

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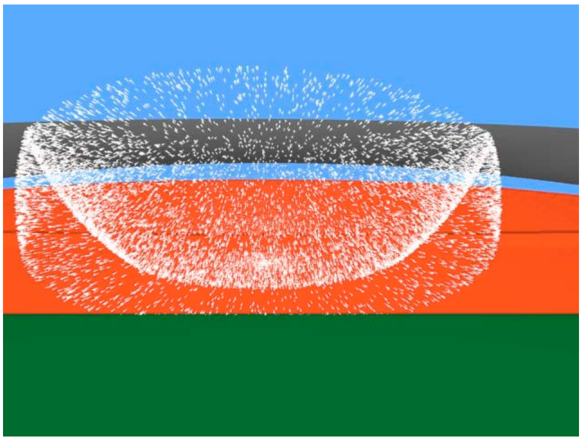

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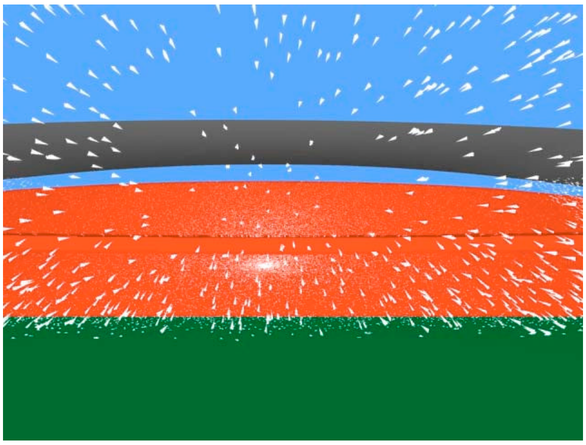

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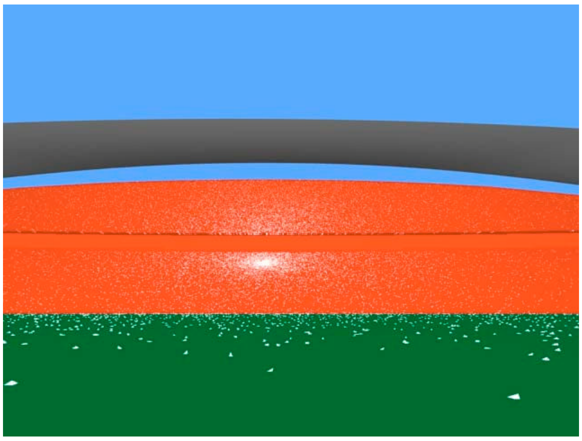

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Figure 7 Rendered 3D Model of Stadium from the Pitch Looking at the North Stand, Showing the Progression of Reflected Sound from the Roof Soffit

4 THE RESULTING DESIGN

The resulting design incorporated four main features optimised through the modelling studies:

- Loudspeakers at the front edge of the roof, arranged in pairs, one covering the lower terrace, one the upper terrace.

- A 6m band of absorption in the roof to reduce destructive reflections from the loudspeakers (optimum location determined using 2D and 3D ray tracing and CATT modelling).

  Speech intelligibility of 0.45 – 0.55 STI was achieved in the unoccupied condition, and 0.65 STI or above was achieved when occupied.

- A roof angle, determined particularly for the rear terraces, that reflects energy from the very rear of the stands down onto the lower stands, as well as down to the pitch. This has the effect of provided reflected sound energy from the rear spectators, to the lower terrace spectators, encouraging them to make more noise.

- A roof curvature to distribute sound energy evenly across the stadium.

5 SUMMARY

Figure 8 Finished Stadium in Football Mode

The major benefit of the 2D and 3D acoustic visualisation tools is that they allow acoustics to be explained very quickly to architects. It establishes major issues requiring attention and focuses the architect to resolve them definitively through design. It also allows the acoustician to use rough forms of analysis to determine an initial starting point before beginning detailed acoustic modelling (using EASE, CATT, Odeon etc.).

Phase 1 of the project opened for the Commonwealth Games in the summer of 2002. Heralded as a success, it was vindicating to hear how many athletes praised the “incredible crowd” and “excitement” that the stadium generated. The design team were certainly of the opinion that the acoustics of the stadium are exceptional.

Phase 2, after the Commonwealth Games, required the track and field to be dismantled. Additional excavations were made and the lower terraces to the football stadium constructed. Manchester City Football Club began their first season in their new home in August 2003. As well as providing a very intimate environment for watching football, the crowd noise generated is exceptional, and has been consistently quoted as such in national and international TV and radio broadcasts.

6 THE FUTURE?

The acoustic design of the City of Manchester Stadium shows what is possible when an architect and engineers unite in a goal to achieve something unique that enhances techniques in acoustic design of stadia. Good collaboration with the architect, using tools that simply demonstrate acoustics in a visual way, rapidly accelerates the mutual understanding of goals early in the design process.

These visualisation tools have also proved useful in subsequent projects to demonstrate noise emission from slots and holes in stadia with fixed or moving roofs, as a first stage to working with architects to tackle environmental noise emission issues.

As venues strive for flexibility, such as moving roofs, these analysis tools, followed by auralisation of the open / closed conditions can quickly establish limiting conditions for internal performance and environmental impact.

As yet, finding usable anechoic crowd noise for auralisation has proved elusive. At present, the modelling packages and hardware do not have the processing power to deal effectively with these situations. However, as they do, it is likely that auralisation will move out of the internal building acoustics field, and into the environmental noise analysis field. Sometime in the future auralisations with calibrated ambient noise conditions, crowd noise and PA announcements are likely to be commonplace.

We continue to develop and use these varied techniques, at differing levels of sophistication dependant on the project.