THE ACOUSTICS OF THE AUDITORIUM OF THE ROYAL ALBERT HALL BEFORE AND AFTER REDEVELOPMENT

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1. INTRODUCTION

When the hall was opened in 1871 by the Prince of Wales (later King Edward VII), the Times reported: *"The address was slowly and distinctly read by his royal Highness, but the reading was somewhat marred by an echo which seemed to be suddenly awoke from the organ or picture gallery, and repeated the words with a mocking emphasis which at another time would have been amusing."*
This is the first comment and even a first analysis of the Hall's acoustics. Many comments would follow, positive and negative. The positive ones usually regarded large musical events, organ play and community singing. The negative ones were usually about echo, large differences in acoustics for different positions in the public area, and about the relative quietness of the hall for unamplified musical events.
Fighting the echo has had major impacts on the Hall's appearance. Shortly after its opening a velarium was hung underneath the than glazed dome, which must also have had an effect to migitate the effects of daylight (figure 1). The effect of this velarium to attenuate the echo must have been very limited.

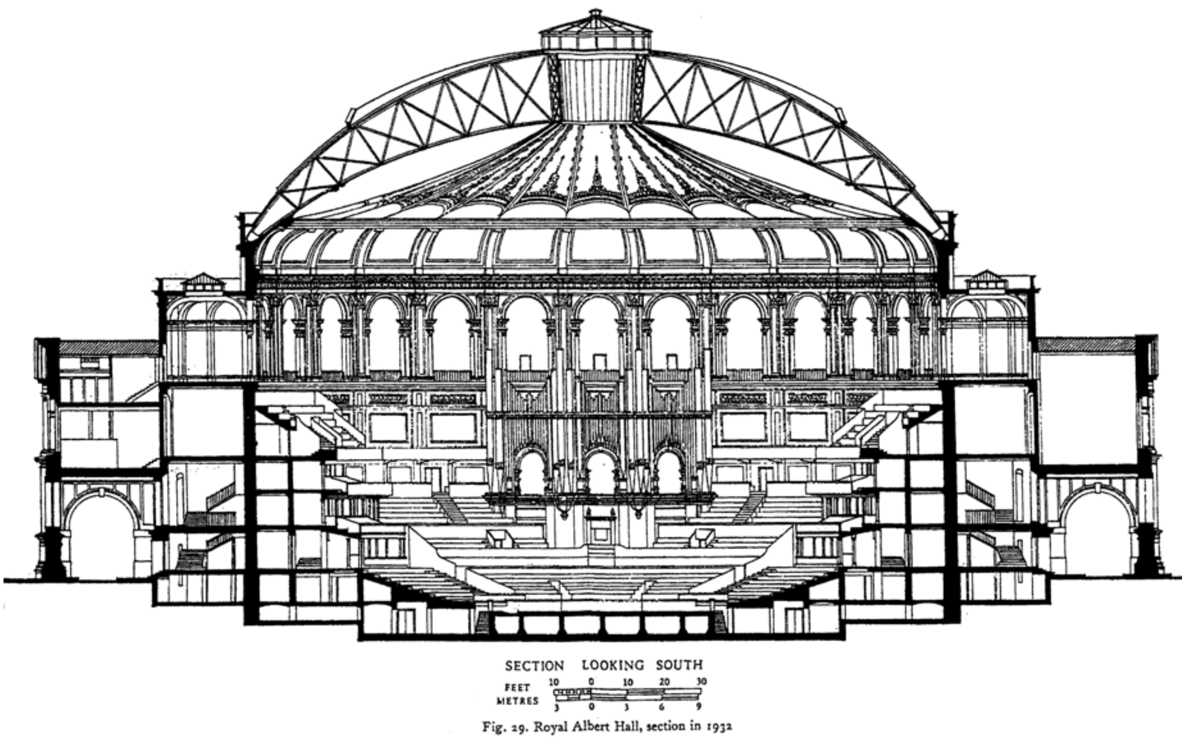

Figure 1, Section of the hall with the original velarium

In the 1890's even wires were stretched across the hall to cure the echo problem, but without success. In the following years experiments were made by changing the height and the sagging of the velarium and by adding banners around its perimeter. Generally these measures had little or none or maybe even negative effects, possibly also because the quite long reverberation time was

not affected. Apart from the echo effects the articulation in the hall (no sophisticated sound systems were available in that time) was not very good anyway for this reason.
Scientists were asked for advice several times, and, although the application of acoustic knowledge in buildings was limited, the analysis that were made, for instance by the National Physical Laboratory in 1928 show good understanding of the acoustic problems. The two-dimensional approach, used in the study, revealed however only a part of the quite complex problem.
When the proms, in 1941, had to move from the bombed Queen's Hall to the Royal Albert Hall, it was the first time that it was adapted specifically for symphonic orchestra. As proposed by the Building Research Station a sound reflector over the stage and a dramatic lowering of the still existing (but far more heavy because of collected dust) velarium improved the acoustics for orchestral music (see figure 2 below from the original paper of BRS).

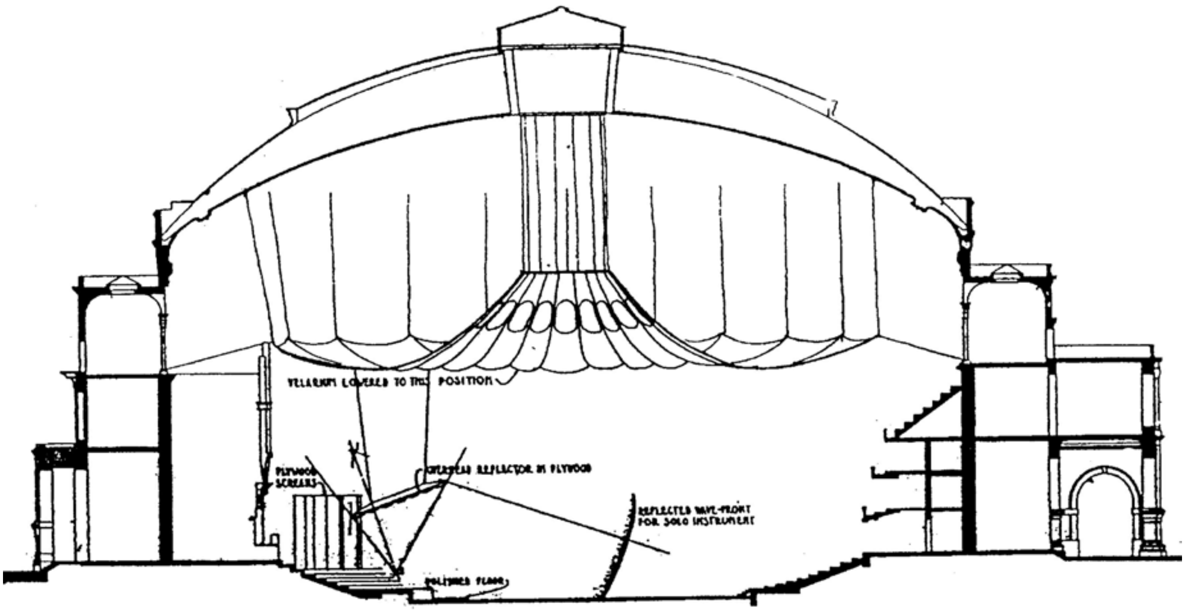

Figure 2, The velarium at the beginning of the proms in the Albert hall in 1941 (original sketch from Hope Bagenal Building research station)

In 1949 the velarium and the glass dome were replaced by the still present perforated fluted aluminium inner dome, that absorbs the sound and attenuates the focusing of sound by the inner dome surface. However, due to reasons we understand better now, this modification must have had a negative effect of the acoustics compared to the situation sketched above. In 1968 the mushrooms as they still exist were put in place, proposed by Ken Shearer of BBC after an intensive study of echo paths (see figure 3), accompanied by acoustic measurements in the hall. The mushroom arrangement gave a strong reduction of the strength of the echo and reduced also the reverberation time from approximately 3.5 seconds to under 3 seconds.

In 1996 a scale model 1 : 12 was built in the acoustic laboratory of Peutz to do studies in order to do proposals for an optimised acoustic after the refurbishment.
Having the model and modern computer based measurement tools it was possible to build the hall in its original (1871) shape and to follow its evolution by measurements and even by listening to it by processing anechoic recorded music with the measured room responses in the model.

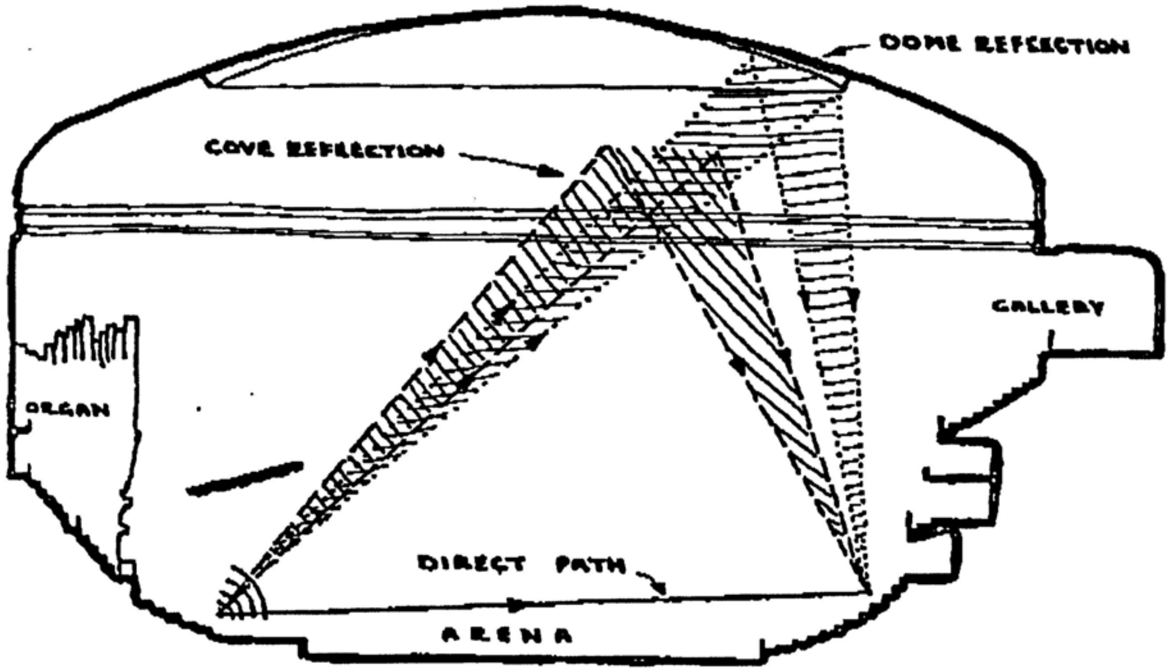

Figure 3, Echo analysis by Ken Shearer of BBC in 1968 (original sketch)

The techniques used for this anralization where presented at the IOA-meeting in Manchester, 1999. So it was possible to reconstruct some of the acoustic effects that must have been heard by the audiences over the last 130 years and, even more important, to understand which elements in the hall were responsible for its acoustic behaviour.
It came out that the gallery never contributed to echo, but that it acts quite effectively as a reverberation chamber coupled to the hall. Adding absorbing materials here and not projecting (amplified) sound into the gallery reduces the general reverberation of the hall significantly.
Although the principal cause of the echo was known for a long time, the model measurements made it possible to distinguish between the effects of the inner dome (originally glass, now sound absorbing) the cove with and without its ornamentation, the plaster area between the inner dome and the cornice and the general ellipse-like plan of the hall with its “walls” of boxes.

One has to realise that any elliptical plan has two focal points, in this case one in the stage area and one in the stalls area opposite the stage. But, and this is the main cause of the echo problem, the hall’s ceiling is close to a (3D) ellipsoid, that focuses almost exactly on floor level to give an extremely strong echo (more than 20 dB stronger than the direct sound) for natural sound sources on stage (e.g. symphony orchestra’s) if the dome is uncovered.

For a loudspeaker cluster, flown 10 of more meters above stage level, the concentration of sound from the ceiling moves away from the audience level, which is the reason that no major echo effect occurs by properly amplified performances.

The model studies also showed the importance of the canopy over the stage; it prevents much of the sound energy from reaching the dome by reflecting the sound directly on the audience. For acoustic reasons a larger and somewhat higher position of the canopy proved beneficial, but the rigging does not allow major changes here.

The findings mentioned here were presented in the paper: The Royal Albert Hall, past, present and future at the IOA-conference in Dublin 1997.

Since then, the velarium option was studied, but rejected due to a number of practical reasons and finally a new, mushroom arrangement was developed in order to give an maximum view of the restored cove and optimized acoustics. In the following chapter the findings of these studies are reported. At the time of this conference the cove ornamentation work as well as the rearrangement of the mushroom will be finished in the Hall. During the preparation of this paper the measurements of the acoustics after refurbishment's are in progress. The results will be presented during the conference.

2. STUDIES OF A VELARIUM DESIGN AND AN OPTIMIZED MUSHROOM ARRANGEMENT

The auditorium acoustics studies in 1997 and 1998 were carried out in the 1 : 12 scale model (see figure 4) to:

a. optimise a velarium design
b. asses the acoustic effects of the cove after restoration
c. optimize the mushroom arrangement.

Figure 4, The scale model with a reflecting and diffusing velarium and added diffusion and absorption in the cove in the cove

The velarium design was studied in the second half of 1997, the optimization of the mushroom arrangement was carried out in the second half of 1998, after the velarium option was rejected.
The studies on the effect of the cove treatment were done for the velarium design and the modified mushroom design. A more or less free view on the (to be restored) cove was used as an architectural starting point. Both options proved to provide improvements over the existing mushroom arrangement, but in different ways.

The velarium and mushrooms options needed to be studied in detail to find the right acoustic treatment to achieve satisfactory results and to optimize the design.

Optimised acoustics for the Royal Albert Hall may include the following items:

- echo suppression;
- sound level increase for unamplified events;

- evenness of responses over the audience.

The canopy over the stage has been a constant factor (the existing one) in almost all experiments. In a few cases changes in reflector area and shape were used to study the cause of echo's.

2.1. Velarium design

The principle of the acoustical reflecting velarium is sketched in figure 5.

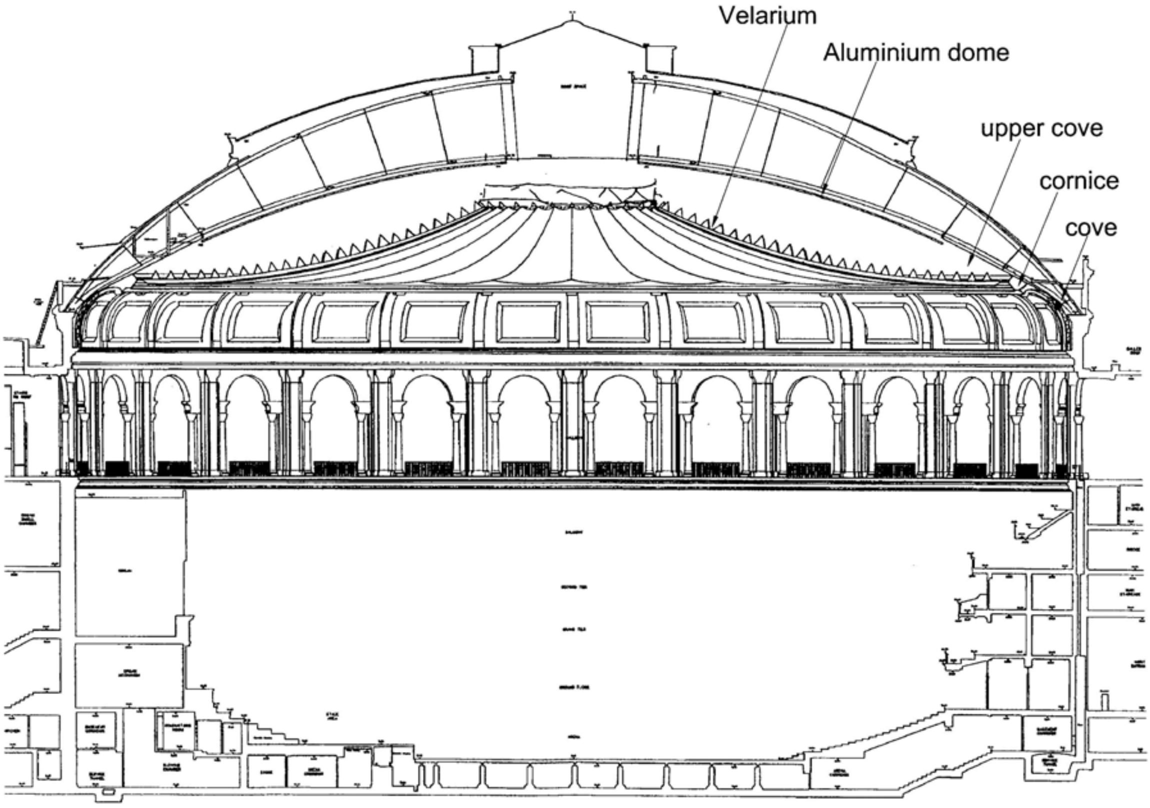

Figure 5, The principle of a acoustically reflecting velarium

Critical for such a velarium are:
- the height at the perimeter (approximately the height of the cornice)
- the treatment of the cove area
- the treatment of the upper cove area (just above the cornice)
- its surface properties (diffusiveness).

The obvious advantages of a velarium are:
- the basically convex surface, which does not concentrate the sound (like a dome) but rather spread it;
- the reduction of the hall's acoustic volume, which will give more strength to the sound if the reverberation time is kept to the existing value. To attain this, since the absorption of the perforated aluminium dome is “lost” , absorption would have to be added, e.g. by heavy curtains in the gallery
- the diffuse reflection of sound by the velarium will spread the reflected sound more even over the audience.

Complications for the use of a velarium turned out to be:
- since it's position is approximately 4 metres higher than the mushrooms, the cove will be revealed to the direct sound field and may cause echo's. The position of the velarium makes it a

"mirror" to make this effect even stronger. Acoustic treatment (absorption and extra diffusion) of higher and lower cove appeared inevitable;

- the higher position than the existing mushrooms delays the ceiling reflection, causing a "gap" in the responses mainly on the side balconies, since no wall reflections are present either. These gap's however don't "look good" in the response, but (from auralization experiments) turned out to be hardly noticeable. However an improved (or electro acoustic) stage reflector would be desirable to compensate for this effect.
- architectural design of the cove modifications in connection to heritage requirements;
- problems for the now extremely flexible and adaptable rigging possibilities;
- cost.

The acoustic problems of the velarium design were solved almost completely (in the scale model), but due to architectural, rigging and cost problems the option was rejected.

2.2. Modified mushrooms arrangement

From earlier studies it proved not well possible to lift the mushrooms to attain an improved view on the cove and cornice, both being restored to their original beauty. Therefore the modification to the arrangement is to move the mushrooms away from the perimeter and to concentrate them more to the centre, keeping them at the existing level in such a way that the critical part of the dome is still and even more effectively screened due to a higher mushroom density. The principle of such a mushroom design is sketched in figure 6, 7 and 8.

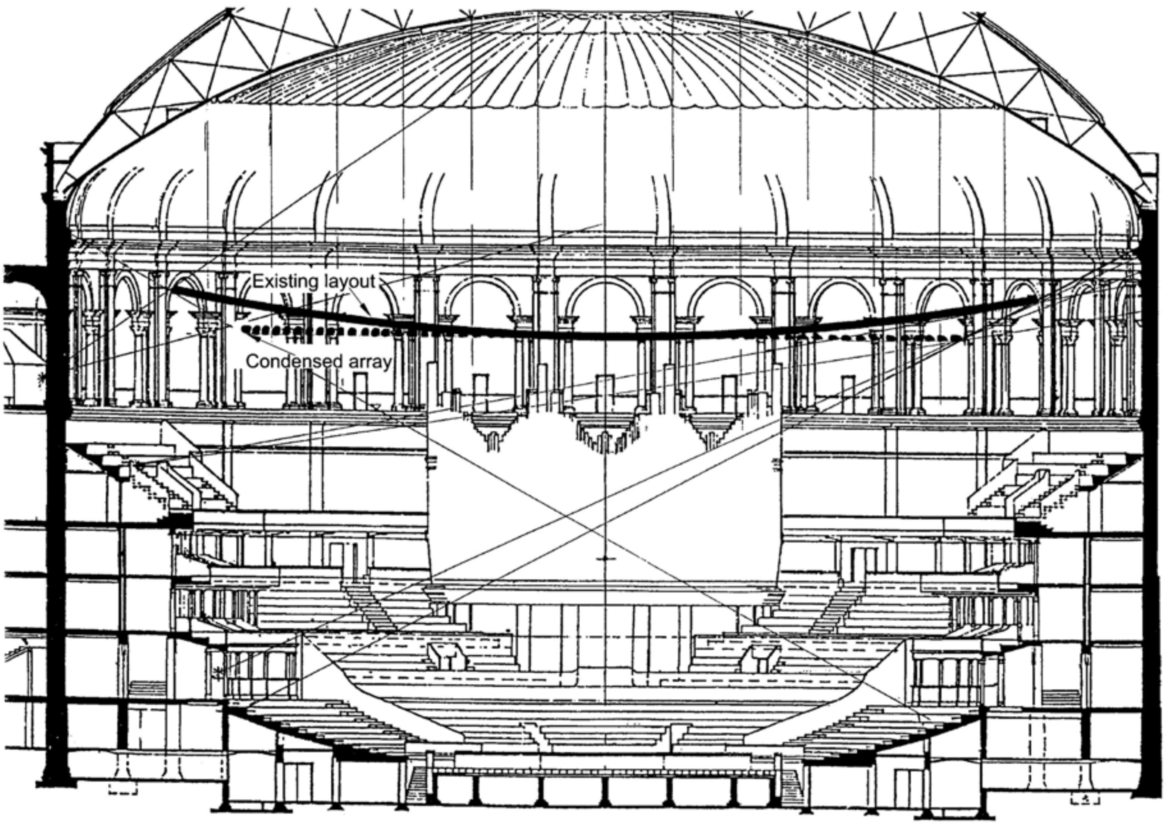

Figure 6, Section of the existing and the new, condensed mushroom array (section)

The strong points of this solution are:

a. improvement of early reflected sound, due to a more closed "ceiling" at relative low level;
b. more effective "screening" of the dome to suppress echo's from this part;
c. more effective screening of the high cove area.

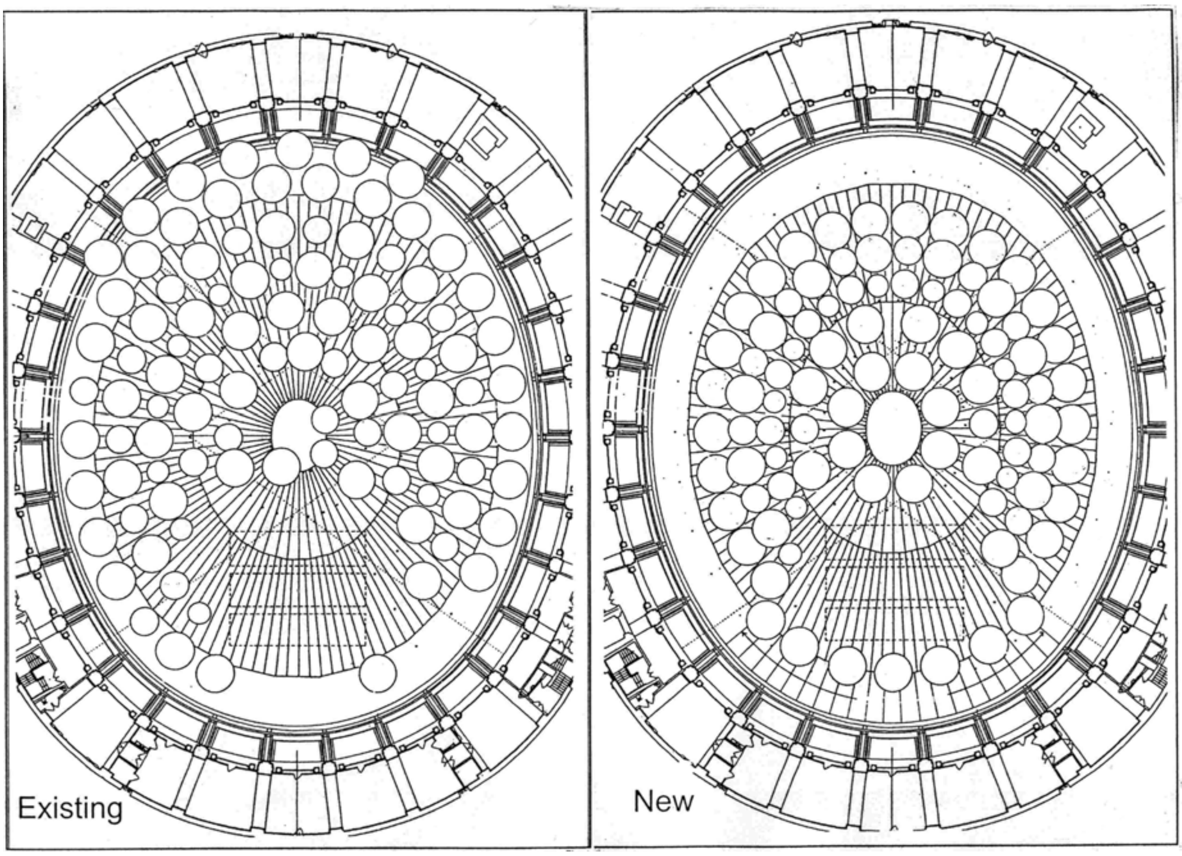

Figure 7, Existing and new mushroom array (plan). The finally chosen configuration is slightly more randomised than drawn here.

The combination of the effects of these modifications gives smoother and more even responses in nearly all measurement positions in the hall.

The “disadvantage” of this approach is that no increase of loudness can be achieved.

Furthermore it proves to be necessary to eliminate the acoustic effect of the higher cove area around the stage area due to the fact that here are no mushrooms present (this was however also the case in the existing arrangement). This is dealt with by 7 extra mushrooms at the rear side.
Extension of the stage reflector to the sides and to the rear would have given the same type of result, even slightly more effective.

It proves not necessary to treat the (refurbished and therefore more diffusive than existing) lower cove acoustically, as long as the mushrooms stay at the existing (approximately gallery ceiling) level. The contribution to echo of the cove is sufficiently suppressed due to the fact that the cove itself is curved with a relatively small radius (which makes it a diffuse element seen from a larger distance) and by the re-introduction of the cornice and the ornamentation in the cove. This means that screening of this part can be omitted without risk. This was proved to be so in the scale model studies as well from echo path analysis with the Odeon (ray based) computer model.

3. REVERBERATION TIME

The refurbishment of the auditorium contained many modifications that have an impact on the reverberation time. After an analysis of the use of the hall it was concluded that, if variable acoustics would not be introduced, maintaining the reverberation time was to be aimed for. This requirement was part of the brief for the project, with an allowed change of 5% in each octave band.
Modifications that could have an effect on general reverberation included:

- new seats at the balcony, the stalls and the choir.
- modification of the stalls floor to introduce quite a large area for air supply at a low velocity of < 0.15 m/s over the perforated vertical area of the steps, total area appr. 120 m^2. The absorption of the floor area increases by the connection of the air supply plenum under the stalls floor by the perforated steps and the perforated steel bars behind that support this floor.
- the number of mushrooms (less than in the old situation) and the number of mushrooms that have absorbing material on top.
- the position of mushrooms. Due to the more condensed arrangement, the acoustic coupling of the spaces under and above the mushroom “barrier” has changed or, in other words, the effective acoustic volume of the hall has changed.
- change of stage lay-out.

The effects of the seating and the floor were measured in a laboratory set-up by BDP acoustics at Salford university. The effects of the changed mushroom and stage lay-out were studied in the 1 : 12 scale model. The results of these were put into the statistical reverberation (Sabine) model and in the Odeon ray tracing model to assess the effects on general reverberation. Conclusively it was decided that the reverberation time would be retained if about half of the mushrooms were filled with mineral wool.

4. REFERENCES

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