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THE ROYAL ALBERT HALL, PAST, PRESENT AND FUTURE

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1. INTRODUCTION

The Royal Albert Hall of Arts and Sciences as it was built, was, as we call it today, multipurpose. The original aspirations were for a large chorus or music Hall, another was for a large conference centre to serve the needs of the learned world. "For the advancement of the art and sciences and works of industry of all nations in fulfilment of the intention of Albert Prince Consort" as the frieze on the outside of the building tells us.

However, under-use and poor attendance gave rise to a widening of the remit towards the end of the century to that which generally now obtains, including sports (boxing, wrestling, marathon running, tennis, badminton), political meetings, dinners, fancy dress balls, evangelical gatherings, trade fairs, demonstrations of clairvoyance, film, circus, bazaars, seasons of folk dancing.

Memorable musical events seem to be mostly associated with singing, either community singing or big choirs, but also great voices, that were able to "fill" the Hall, like Clara Butt singing 'Land of Hope and Glory'. The Hall did not serve as a regular concert venue until after the bombing of Queen's Hall in 1941, the Sir Henry Wood Promenade concerts were held every summer, and their success has been strongly identified with it since then.

Over the last decades rock and pop music concerts are regularly programmed like the Eric Clapton concert series.

The present management is aiming for a revitalisation of the fabric and image of the venue, so it will be an even further improved high-class place of entertainment. A major refurbishment in the period 1997-2004 is foreseen, with a design development programme approved by the National Heritage Memorial Fund and the Arts Council of England Lottery Funds. One of the key projects of the program is to review the acoustics of the Hall and auditorium architecture at high level.

The Hall's problems with its acoustic image began in 1871 when a strong echo became apparent in the opening speech by the Prince of Wales. This echo, the reverberation and - for symphonic music - the weak sound were criticized from the start and have given the Hall's acoustics a bad reputation, although the sound from the big organ, big choirs, its quality for community singing, but also its great dynamic range in the pianissimi were often praised.

However, the acoustics, certainly after the last changes, made in 1969 (after Beraneks 'Music, Acoustics & Architecture' was published), are not as bad as the most reports may suggest. The evidence of regular prom goers, musicians and critics is that received opinion amongst non-attenders is not shared by the committed.

The acoustics for speech and rock music can work remarkably well, but require well designed and properly operated sound systems.

The main statement of the brief on the acoustics was that no aspect of the acoustics after refurbishment should be less good for any type of event than now, and that the appearance of the "dome" would be improved by

the restoration of the ornamentation of the cove and by replacement of the existing mushrooms with other, better looking devices.
Improvement of the acoustics, if feasible, to improve its reputation (a Hall that both looks and sounds better) is of course the preferred option.

2. APPROACH TO THE WORK

From initial study of the Hall a few things became clear with respect to the way the problems would be approached:

- Computer (ray-tracing or the like) models cannot be used for design work, since almost all surfaces of the Hall are either highly diffusing or curved. The strength of echoes (one of the priorities of any acoustic design) cannot be calculated with this type of programme in this environment.

- A physical scale model with relatively precise detail would be necessary. A scale of 1 : 12 was chosen (model size approximately 6 x 5.5 x 4 metres; see photo) to make auralization by convolution of anechoic music with binaural impulse responses from scale dummy heads possible.
  Using auralization was considered necessary to evaluate the audibility of echoes and the evenness of acoustic quality and "character" over the Hall.

- The program of measurements in the model followed the Hall's acoustic history, from the glazed dome (1871) via the absorbing dome (1949) to the mushrooms (1969), to get a full understanding of the Hall's behaviour. Important literature on the acoustics of the Hall [1, 2, 3] gives often contradictory comments and explanations, although some analysis turn out to be very accurate, which is amazing for so little available information from measurements at the time.

- The Hall as it exists now (absorbing centre part of dome, approximately 100 mushrooms, stage reflector) was used as a reference. Both in the model and in the real Hall measurements were made for almost identical source and microphone positions to "calibrate" the model and also to be used as an objective and subjective reference.

A number of consultations with regular users of the Hall took place, which can be summarized as follows:

Symphonic music

a. The sound differs quite a lot from place to place. The balance at the conductors position is sometimes strange. Some conductors have strong reservations about the Hall. Upper balcony gives a nice blend, but is difficult for soloists, definition is sometimes low.
b. The orchestras have problems in ensemble playing and get very little feedback from the Hall. The sound on the stage is quite "dead".
c. The sound in the Hall is quite weak, big orchestras sound much better than small orchestras. Some groups (e.g. strings) sometimes tend to get lost.
d. The sound in the Hall has little intimacy/involvement/immediacy, but is very good for organ and choirs.
e. Dynamics and warmth of the Hall are good.
f. Sometimes echoes are still heard (e.g. percussion concerts).

Apart from the critical remarks, people close to the Hall and regular performers are in general quite positive about the overall acoustics, appreciation seems to grow when people get more used to the Hall. More criticism seems to come from people more "distant" from the Hall. A typical conclusion of this finding is, that the Albert Hall's acoustics are different from anything else, and have specific pros and cons.

Comparison of measured acoustic parameters with those of other "large" concert Hall's (all of them being 3-5 times smaller), or with more or less "standard " values for "good" concert Hall's may lead to wrong conclusions about the quality of the acoustics.

Changes to the acoustics should therefore always be judged with respect to this. Making eventual changes audible (auralization), to asses changes in the acoustic character is therefore necessary.
Acoustic goals were set in such a way, that preferably the following aspects could be improved (but should certainly not become worse than now):

- evenness of acoustics over the different areas;
- echo intensities;
- detachment of early and late sound. Less detachment could allow for stronger reverberation;
- sound level (effective acoustic volume of the Hall);
- ensemble conditions on stage/feedback from Hall.

Acoustics for amplified events (speech, rock music)
Although the reverberance of the Hall does not make it easy to attain clear and intelligible sound, this is not regarded as a major problem, as long as sound systems are properly designed.
Regular users have learned to live with the acoustics and use it rather than try to fight it; touring shows that bring their own sound equipment, have therefore very different results and may blame the acoustics for a bad result.

The Hall's shape, presents difficulties, like:

- echoes in certain places and "whispering gallery" effects both caused by its curved surfaces and size;
- coverage problems, because of the large vertical and horizontal angles over which the sound has to be spread over the audience;
- the maximally attainable directness can be insufficient for very fast speech because of the reverberation.

Consultation with English Heritage made clear that solutions that reduce the acoustic volume substantially, like for instance a closed ceiling at approximately gallery ceiling level would not be acceptable.
Bringing the acoustic elements as high as possible to make the (restored) cove visible would be strongly supported.
A velarium (a similar element to what was in the Hall between 1871 and 1949, made of cloth) could be acceptable. Free elements like the existing mushrooms, but at as high a level as possible, could also be acceptable.
The model studies focused on this.

The most extensively studied areas and elements were (see figure 1):

- the "centre dome"
- the upper cove area
- the lower cove area
- the gallery
- the stage reflector (including a rearrangement of the stage itself)

The other elements, like the seating areas, the boxes and the balcony fronts were regarded as unchangeable within the scheme.

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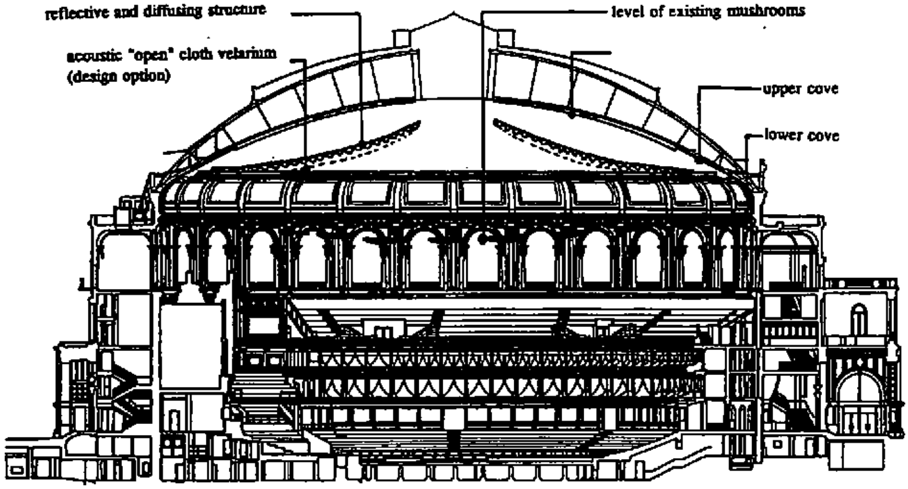

Figure 1: Section

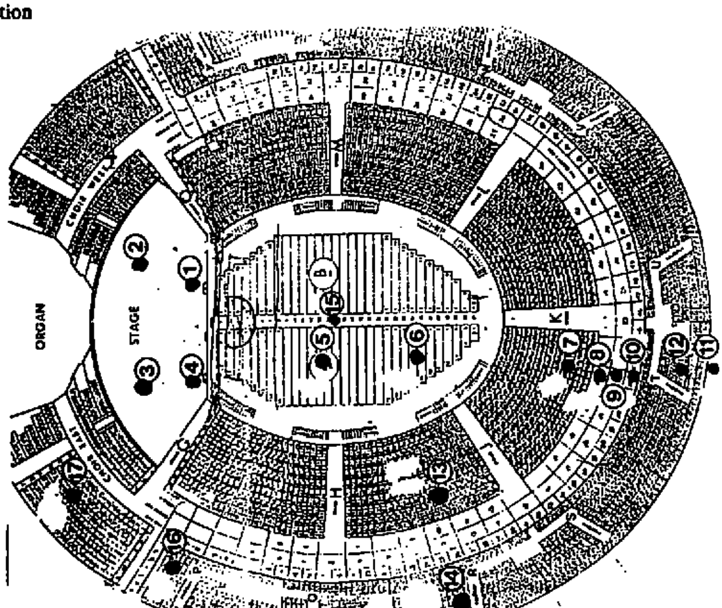

Figure 2: Plan, source and microphone positions

3. MODEL MEASUREMENTS, PAST AND PRESENT SITUATION

Impulse measurements (using MLS, both monaural and binaural) were carried out in the model in the following variants:

- original (1871), reflecting (glass) dome
- situation 1949-1969, absorbing centre dome
- 60% and 100% of mushrooms
- all mushrooms + stage reflector (present situation)

In figure 3 the 1 kHz octave filtered energy time curves are given from the source position 2 and microphone positions 7 (rear stalls) and 14 (side balcony). See for microphone and source positions figure 2.

Striking is the fact that the absorbing dome does not help to suppress echo more than a few dB in the rear stalls (position 7), which is understandable if one considers the whole dome to create echo and that the absorption covers not even 50% of the area.

From these studies it can be concluded that the replacement of the velarium in 1949 by an absorbing centre dome must have had quite a negative effect on the acoustics, although this could not be verified since the acoustic properties of the velarium are unknown, and could not be modelled in a sensible way.
For the higher positions (14) the acoustics, apart from the reverberation time, are not strongly affected by what is done to the dome. The echo in the rear stalls causes strong unevenness of response. The reflected energy to this area is lost for the other areas, which means that effective suppression of the echoes by non-absorptive means should help evenness and strength of sound in other areas.
The responses are also very dependant on the source position, which of course creates balance problems. The source 2 position as presented here is the most critical one for echo. More forward positions prove to give less echo intensity.
The character of the response is also quite different between the higher and lower levels.
Much was said in literature about the strength and the delay times of the echoes. The model reveals that the echo intensity must have been enormous, although comparison of the real Hall with the model with all mushrooms and with stage reflector installed, indicate that the model may exaggerate a little. This can be understood from the fact that the model is slightly less diffusive than the real Hall.
The delay times of the echo are 140-200 ms, which agree with the expectations for dome, cove and side wall reflections.
Longer delay times of echo appear on stage, but only in the variants without mushrooms. As may be expected, the stage reflector obscures echo paths. Stage reflector design is therefore difficult. Optimization for early sound enhancement, if possible at all for all (including balcony) areas, should also be effective for echo suppression.
The mushrooms and enlarged stage reflector developed by Ken Shearer et al. in 1969 prove to be quite effective. His analysis of the height and the density of the mushrooms are fully supported by the model study as far as the echo problem is concerned. The mushroom solution though is not particulary favourable for the strength of the sound; a substantial part of the energy gets lost in the volume of the dome.
Measurements of IACC as they were taken from the dummy heads led to the conclusion that only in the "echo-zone" strong dissimilarity and very low IACC-values appear, because all the echo energy comes from the sides. LEF though cannot be high because this lateral reflected energy is too late for this measure.
In the side balcony only late, reverberant lateral energy is present, almost completely independant of the arrangements in the dome or the stage reflector.
Measurements with a source at a higher level e.g. the normal loudspeakers cluster position circa 10 m above stage front, show that hardly any echoes occur, which explains the good acoustic results that are achieved with well designed clusters and the positive effects of stage reflectors.

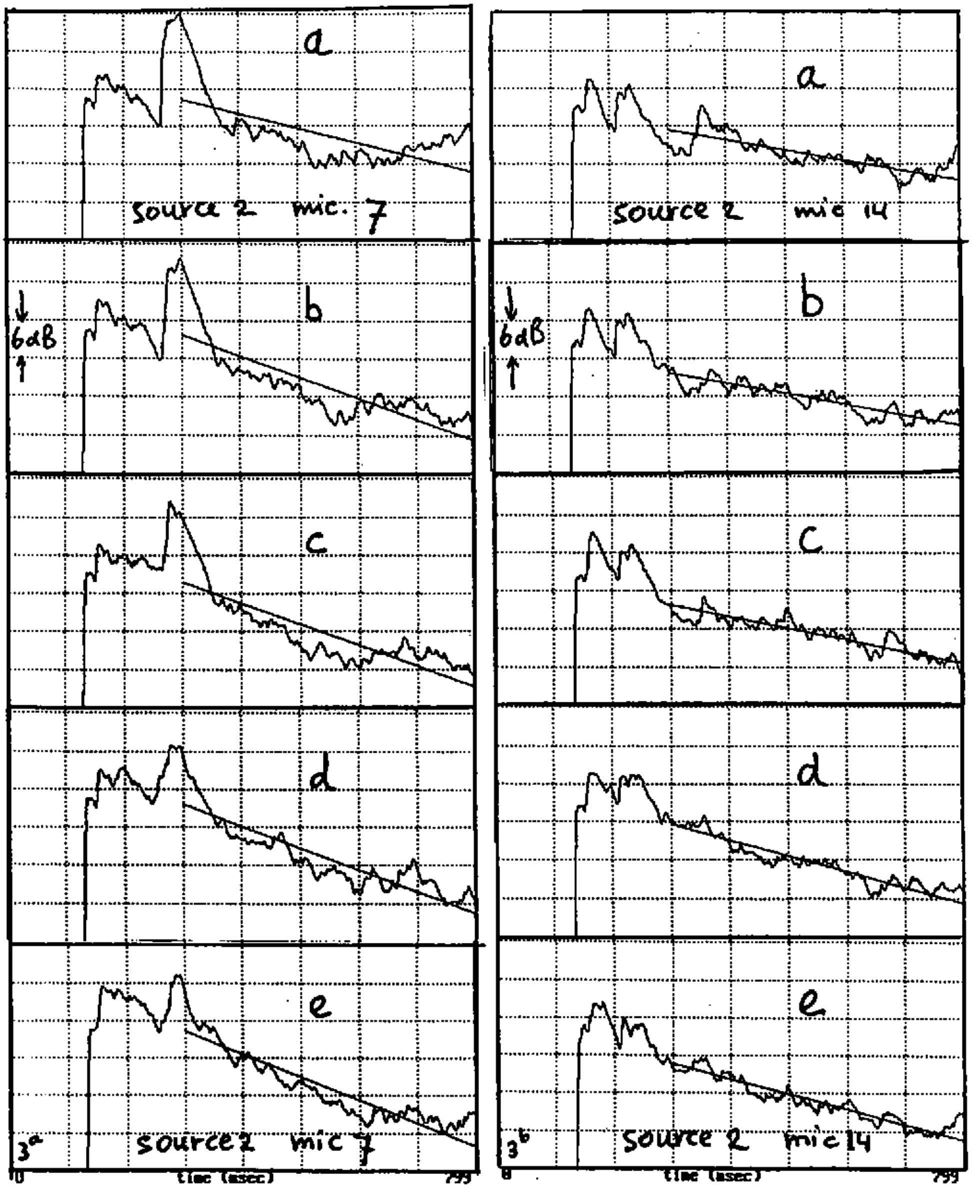

Figure 3: ETC's (smoothed τ = 20 ms); a. reflecting dome (1871); b. absorbing centre dome (1949); c. 60% mushrooms; d. 100% mushrooms; e = d + stage reflector.

4. POSSIBLE FUTURE DEVELOPMENTS

That Ken Shearer was right in the position of the mushrooms became evident when we raised them in the model to a circa 6 meter higher position (level of the cornice) while keeping the mushroom density constant. In the rear stalls the echo reappeared strongly (figure 4), definitely caused by the upper and lower cove parts.

To find out if there was any contribution from the gallery, the gallery was closed off with absorbing material. Figure 4 shows that the gallery has nothing to do with the echo built-up, but that it (more than one would expect from Sabines formula) affects the reverberation time considerably. The gallery seems to work more or less as a coupled "reverberation chamber" for late sound.
These experiments made clear that the cove is a determining factor for echo and that the height of any type of ceiling elements is critical.

A velarium was tested as shown in figure 1 which was sound reflecting and highly diffusing. Such a velarium is meant to make the Hall a bit louder because the absorption in the dome is "hidden" and the extra reverberation could be compensated for by some absorption in the gallery.

The evenness of sound level and responses improves, but the echo (from the upper and lower cove area) needs treatment.
In figure 4 the effects of respectively an absorptive treatment to the higher cove and diffusion of the lower areas are shown for the rear stalls position.
This proves to "cure" the echo problem.
The IACC, although the highly diffusing velarium should give some extra lateral sound in the side areas, tended not to change significantly whatever arrangement was tested.
The total effect of this design option gives some improvement over the present situation, a small raise in sound level, improved evenness and echo-suppression. However, although no real echo is present any more, the response still bears the following character: a "plateau" up to approximately 200 ms, then a sudden drop to the statistical reverberation. This pattern is what remains from the basic oval shape and is a summation of nearly all first reflection paths from diffusing surfaces.
Further studies were made to the type of diffusion/absorption of the outer ring of the velarium, which proves to be very critical for echoes, because it more or less acts as a "mirror" to double the echo from the lower cove area.
The architectural proposal for a velarium like this includes an acoustic "open" fabric to give the reflection/diffusion elements a smooth shape and surface (see figure 1).
The velarium design will have to be compatible with rigging and lighting.

The stage reflector design includes an even larger reflector than the present one, optimized to give (again) more evenness of its reflected energy over the audience; relatively more to the higher and balcony areas and less to the arena and stalls areas. The present reflector directs mainly to arena and stalls.
The optimized design also screens as much as possible the cove area from the stage and is positioned 2 to 3 metres higher than the present reflector.
The optimized velarium design is still under consideration because of its high cost and high load to the roof structure and other problems of a smaller order.

An interesting option - and if one looks to the type of acoustic problems of the Hall a quite obvious one - is to install an electroacoustic reflector and an electroacoustic enhancement system combined with natural acoustics that are as "dead" as possible.

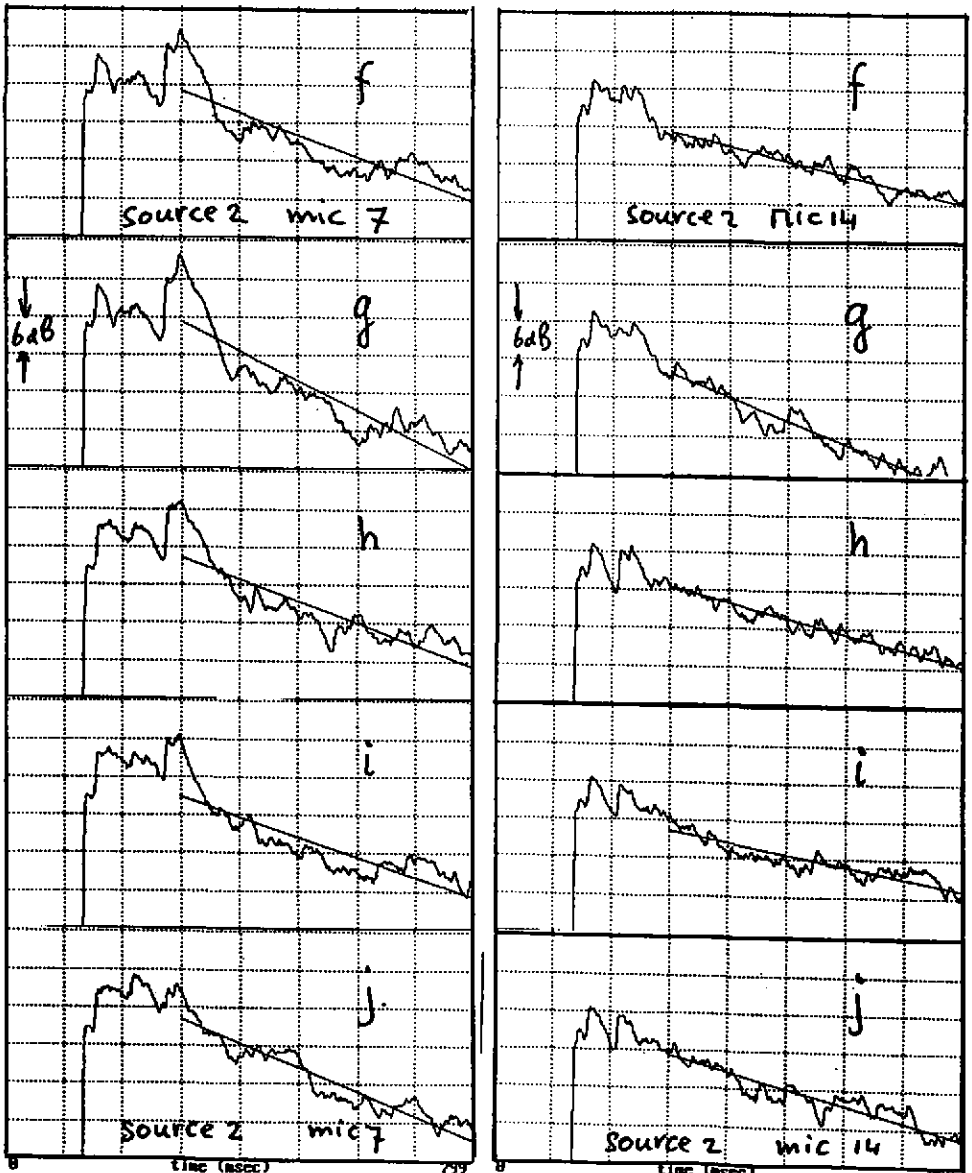

Figure 4: ETC's (smoothed τ = 20 ms); f. mushrooms 6 m higher; g = f, gallery front absorptive; h. velarium; i = h, absorption on upper cove; j = i, diffusion on lower cove.

This may have the following general advantages:
- the view of the organ would be restored (apart from light- and sound trusses and other show equipment that will always remain);
- more flexible rigging;
- less weight.

For acoustics the system could mean the following:
- the desired increase in strength of the sound for symphonic music can be created;
- clarity and evenness can be relatively easily optimized for the whole audience area;
- "gaps" in the responses due to the higher level of the reflecting ceiling surfaces can be "filled";
- variable reverberation times, adapted to the type of event, are possible;
- the natural reverberation time of the Hall can be shortened to suit amplified events better and to improve echo suppression by bringing the absorbing materials in critical areas like the cove and the outside velarium area, which otherwise have to be reflective to maintain the strength of the sound.

The principle of the electroacoustic reflector would be the following:
A number of microphones over the stage (height approximately 8-10 metres) pick up the sound and this is sent, after being processed, to a number of loudspeakers at the position of a normal reflector to create early reflected sound as a normal reflector would do, but in a more controlled way in terms of reflected sound level and direction. Processed signals can also be sent to loudspeakers in the velarium to create reflections or increased reverberation in the higher volume, where these were also created if the materials of the velarium were sound reflecting.

Critical points in the system design are :
- the normal stage reflector is important for echo suppression. An increased use of sound absorbing materials in critical places should (and can) compensate for this. This complies with the shortening of the natural reverberation time. Since in the model studies many variants were measured without stage reflector and also with a source in the reflector position all necessary acoustic information is available to adapt the acoustic design.
- stability (no ringing allowed under any circumstance). The system has to control this by itself permanently.
- maintainability and handability. The loudspeaker and microphone racks over he stage have to be taken out and reinstalled without damage or other problems.
- the system should provide microphone positions for very large performances like choruses where the Upper Choirs are in use and community singing when everyone is singing. Further complications arise for "in the round" events.
- cost (of both velarium and electroacoustic systems) and cost in use. Especially cost of maintenance and reconfiguration to suit different events. This could require specialist skills, unsocial hours and may introduce delay in sound checking etc.

5. CONCLUDING REMARKS

The model studies in many variants (over 50) gave a lot of understanding of the Hall's acoustics. The proposed designs, as they were tested in the model, promise to give the Hall a better architectural appearance while at least retaining, but most probably improving, the acoustics.
The electroacoustic option, if designed in optimal form, seems promising to give the Hall a variable acoustics to serve its multipurpose use. Its feasibility and acceptance is under study now.

6. REFERENCES

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3. H.Y.D. SCOTT, C.B. & C., 'On the construction of the Albert Hall', Professional Papers of the Royal Engineers, Volume N XX1, 1873.
4. L.L. BERANEK, 'Music, Acoustics & Architecture'.
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Photo 1: Patrick Deuchar (chief executive of the Hall) and the author in the 1 : 12 scale model.

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