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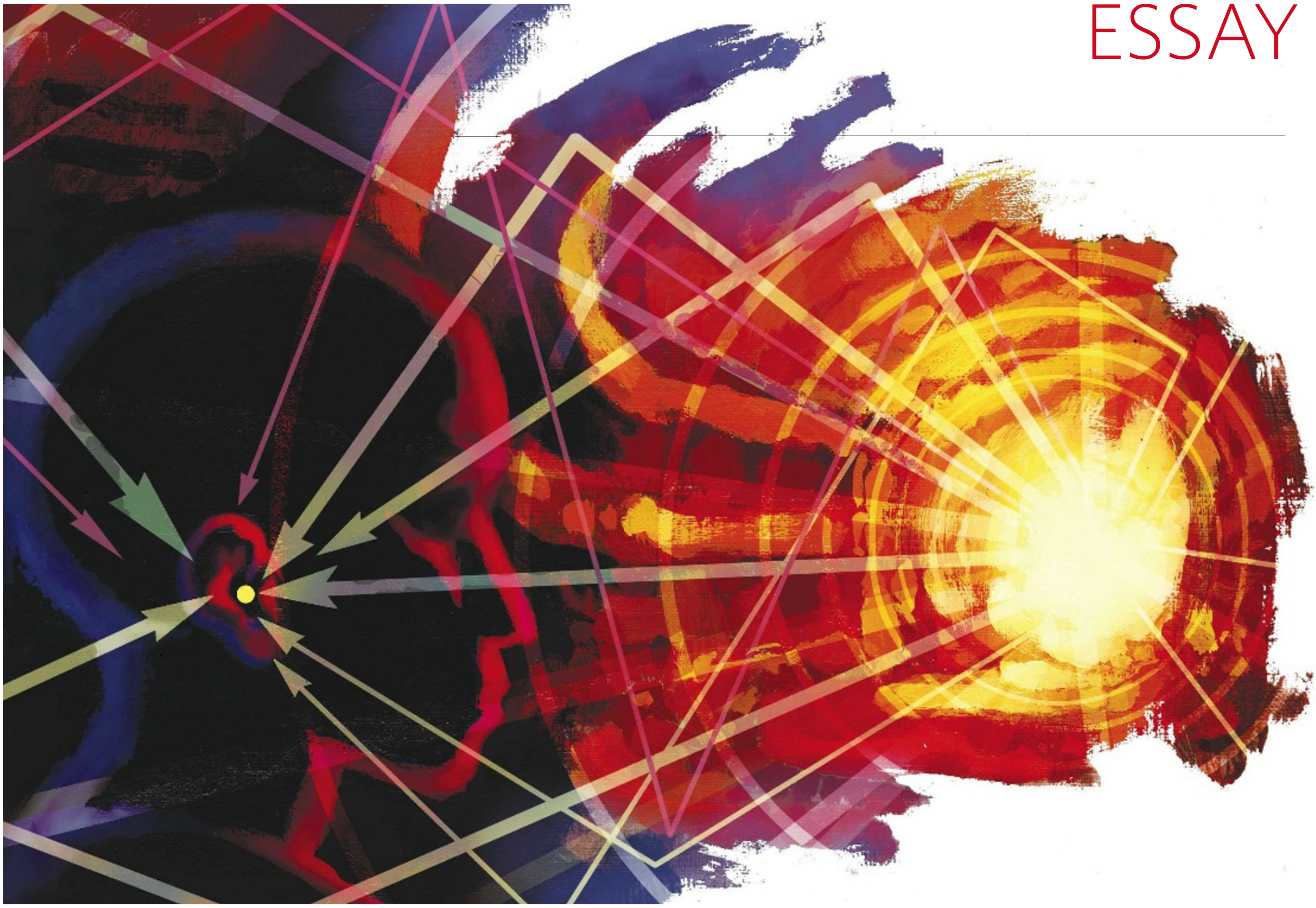

D. PARKINS

Raising the roof

Michael Barron explores how physics, psychology and fashion have influenced concert hall acoustics.

A concert hall is a hall of mirrors — acoustic mirrors. When sound hits a hard surface, it is reflected just as light is. Masonry, plaster, timber and glass all reflect sound with very little energy loss. Sound in rooms is predominantly a question of thousands of reflections. In a typical concert hall, only the audience and the seating absorb sound as a black surface absorbs light.

The science of concert hall acoustics is founded on our understanding of the physical behaviour of sound and how our ears interpret it. But concert halls are, of course, more than just scientifically designed spaces. The raised status of acousticians within design teams since the mid-1980s has resulted in less risk-taking and more conservative designs.

Much remains to be discovered about how our ears and brains process sound reflections. Understanding this has been complicated, for instance, by our remarkable ability to work out where a sound is coming from. This ability, called localization, works even when the sound arriving directly from the source represents only a small proportion of the total sound we receive, perhaps only 5% at the back of a concert hall. Usually we are listening to speech or music, which have short elements such as syllables or notes that vary with time. Our brains use this time-varying information to extract where the initial sound comes from. Continuous sound from a fan, for instance, is much more difficult to localize.

The downside of this localization is that, in effect, our hearing suppresses awareness of sound reflections. We notice early sound reflections but are often not conscious of their effects — such as making sound seem clearer than it would be otherwise. In a cathedral-type space, sound persists for several seconds, reflecting back and forth between walls, pillars and ceiling. We can hear this process in a large space because it happens slowly. The sound we hear is known as reverberation, which occurs in virtually all rooms. In smaller spaces, our brains cannot unscramble it because it happens too quickly.

Between 1850 and 1900, concert halls and theatres were built following earlier precedents, with acoustics handled on a trial-and-error basis. Large theatres that provide intelligible speech are a testament to designers from this period, but sadly they left no written record. The importance of reverberation for musical performances was probably appreciated by some, who realized that concert halls need high ceilings; again we have only the buildings as evidence.

The science of room acoustics began around 1900. As in architecture, radical new approaches followed periods of consolidation.

Taming reverberation

In 1895, physicist Wallace Clement Sabine of Harvard University, Massachusetts, was asked to investigate the disastrous acoustics of a new lecture theatre in the Fogg Art Museum at the university. Sabine must have suspected that reverberation was the key. Rather than just solve the problem of one room, he chose to make a fundamental study. He discovered that the duration of sound persistence, or reverberation time, is proportional to the volume of the space divided by the amount of sound-absorbing material. This relationship, published in 1900 and now known as the Sabine equation, is still the basis of room acoustic design. The

NATURE|Vol 453|12 June 2008

lecture theatre itself was eventually demolished, although the museum still stands.

For speech to be intelligible, a short reverberation time is needed, typically between 0.8 and 1.0 seconds. For a symphony concert hall, a long reverberation time of 2 seconds is the optimum. Musical clarity is equivalent to speech intelligibility, but for music we prefer to hear more reverberation from the room, which adds a bloom to the experience. Sabine's equation leads to the first rule of concert hall design: a large room volume is needed, with ceilings that are higher than would be selected on purely visual grounds.

Sabine was acoustic consultant for the Boston Symphony Hall, Massachusetts, which opened in 1900 and is world-renowned for its good acoustics. That the reverberation time in Boston is shorter than predicted suggests an equation is not the whole answer. The sound absorption by objects and building materials also had to be determined, and assessing the absorption by seating and audiences was (and still is) particularly difficult.

During the first half of the twentieth century, seat area gradually increased for reasons of comfort, but it took some time for acousticians to realize that the absorption of each person also increased with seat area. This affected many auditoria of the time, such as the 1940 Kleinhans Music Hall in Buffalo, New York, and London's Royal Festival Hall, completed in 1951, which has a reverberation time shorter than the preferred value because audience absorption was underestimated. A solution would be to raise the roof, but during the hall's refurbishment, completed last year, this was deemed too expensive and damaging to architectural heritage. Some sound-absorbing material was removed and small increases in volume were made, both of which increased the reverberation time. But the change remains too small. Experienced listeners comment that the sound is still 'drier' than in the best halls.

Sound psychology

By the 1950s, it was apparent that there was more to concert hall acoustics than just reverberation time. Research moved into the realm of experimental psychology and away from the area of physics, where acoustics had traditionally been studied. Scientists explored the subjective significance of early sound reflections. They simulated concert hall conditions in anechoic chambers (where the walls, floor and ceiling are covered with sound-absorbing material) to ensure that the listener received only sound direct from individual loudspeakers. For reflections, modified tape-recorders produced the delay, and the direction of simulated reflections from loudspeakers could also be varied.

This research revealed that musical clarity is related to the ratio of sounds that arrive early to those that arrive late, and that listeners prefer to receive a significant proportion of sound from the side. Key studies at the universities of Göttingen and Berlin in Germany during the 1970s used a 'dummy head', a solid artificial head bearing anatomically accurate ear lobes with microphones mounted in each ear canal. A recording made with a dummy head allows for accurate reproduction of sound as heard at each location. By listening to recordings of music made at different seats in actual concert halls, the acoustics could then be rated.

The current consensus is that there are five subjective dimensions for concert hall listening. These are clarity, or ability to hear musical detail; reverberance, or being able to hear reverberations; acoustic intimacy, which describes how involved we seem to be in the performance; envelopment, the extent to which we feel surrounded by sound, and loudness. A range of measures has been developed that allows concert hall designs to be tested before building starts, using computer programs or acoustic scale models. As a result, acoustic disasters are now much less likely.

"Acoustic disasters are now much less likely."

Music box

That's the science, what of the reality? Concert halls represent a civic statement by the client, and are designed by architects advised by acoustic consultants. Many pragmatic aspects come into play, not least architectural fashions. One of the most famous buildings in the world, the Sydney Opera House, was designed back-to-front with the concert hall and opera theatre having to fit within those famous shells.

Sabine's formula says nothing about the appropriate shape for a concert hall. Between 1960 and 1990 there was virtually a free-for-all in auditoria shapes. One success from this period is the striking design of the 1972 Christchurch Town Hall auditorium in New Zealand. Its acoustician, Harold Marshall, used his theory about the importance of sound reflections from the side to develop its acoustic design. It has an oval plan with large tilted reflectors above and behind gallery seating.

In the mid-1980s, clients realized that a hall with poor acoustics was likely to have financial problems and to reflect badly on the city or local area. Once a concert hall is built, acoustic faults are often difficult to rectify, as in London's Royal Festival Hall. This realization shifted the balance within design teams away from the architect and towards the acoustician. It also introduced a period of conservatism, with just two forms predominating for symphony concert spaces: the rectangular shoe-box hall and the terraced hall. Two important parallel-sided auditoria from this period are the 1989 Eugene McDermott Concert Hall in Dallas, Texas, and the 1991 Birmingham Symphony Hall in the United Kingdom. The rectangular form was resurrected from more than 100 years ago. Three such halls from the nineteenth century are regularly mentioned as having the best acoustics in the world: the Vienna Musikvereinssaal, Amsterdam's Concertgebouw and Sabine's own Boston Symphony Hall.

The terraced hall subdivides the audience into different seating levels with useful sound-reflecting surfaces in between. These are often referred to as vineyard terraces, as on a hillside. The first example of this form, the Berlin Philharmonie of 1963, remains the most impressive. Two more recent examples are the 1982 St David's Hall in Cardiff, Wales, and the 2003 Walt Disney Concert Hall in Los Angeles.

This then is the current state of the art and practice of concert hall design. The era of intense research is probably over, although optimizing acoustic conditions for orchestral players remains to be resolved. The period of ultra-conservatism in design is also waning and tentative steps are being made towards new forms. The new Philharmonie concert hall for Paris, due for completion in 2012, promises to be an exciting development. The aim in Paris, as in Christchurch, is to provide musical clarity with a rich sense of reverberation by suspending seating areas in a larger surrounding volume.

Some acoustic designers have offered variable acoustics in their halls, which has met with mixed enthusiasm. Tools include variable volume, variable additional absorption and electronic enhancement. These need to be used in the correct way and should be obvious to the ear. Perhaps such features will allow acoustics to be tailored to the music of different eras. The technology is there, less so the acceptance by musicians and hall managers.

Most large cities in the developed world now have concert halls, and they are unlikely to be demolished because of disappointing acoustics. Maybe we will have to look to other countries such as India and China to find the wild boy or girl of acoustic design for the next generation of concert halls. ■

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