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ARCHITECT AND ACOUSTICIAN: AN HISTORICAL OVERVIEW

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Unlike the more apocryphal moments of revelation which punctuate the history of science, the occasion is documented when, one autumn evening in 1898, the young assistant Harvard professor Wallace Clement Sabine suddenly shouted from his study, "Mother it's a hyperbola", on realizing that the sound absorption of a room multiplied by the reverberation time is a constant number. After devising the simple reverberation time equation, together with further experiments to give common building materials a coefficient of absorption, Sabine was able to accept the invitation of Henry L. Higginson, chairman of the building committee to be acoustic consultant for the proposed Boston Symphony Hall.

Until the time of Sabine, architects had but little available acoustical guidance. Even in 1912 the eminent Viennese architect Adolf Loos, who had been asked for his opinion on the Bösendorfer Hall in Vienna, as a result wrote a quaint essay titled "Das Mysterium der Akustik" so that the secrets of the subject did not go with him to the grave. He concluded that concert halls become acoustically excellent when fine music played in them is gradually absorbed by the walls. In the mortar, he said, live the sounds of the great composers. The music of our symphony orchestras and the voices of singers impregnate the building materials, causing mysterious changes in the molecular structure, as in the wood of old violins. But brass instruments, he warned, have a bad effect, and military music, played in a fine hall could ruin its acoustics within a week. For the same reason, opera houses have poor acoustics on the side where the brass players sit.

Others claimed no such insight, and perhaps the most famous admission of acoustical ignorance was Charles Garnier's statement in his book, *L'Opéra* (Paris, 1880) regarding the Paris Opera House: "I gave myself pains to master this bizarre science of acoustics but ... nowhere did I find a positive rule to guide me; on the contrary, nothing but contradictory statements ... I must explain that I have adopted no principle, that my plan is based on no theory, and that I leave success or failure to chance alone ... like an acrobat who closes his eyes and clings to the ropes of an ascending balloon".

Despite Sabine's pioneering role as acoustician to the new symphony hall for Boston, the basic design had in fact already been carried out by the architect Charles Follen McKim of the renowned firm of McKim, Meade and White, and had been presented to the building committee as far back as July 1893, along with two alternative designs, a semicircular amphitheatre and an elliptical hall. Sabine's involvement was one of adjustment rather than of fundamental design. In the absence of acoustical knowledge, architects had developed a tradition of auditorium design whereby the requirements of the building are interpreted into built form simply through the use of intuition. At the same time the architect would draw on precedent as a guide to the suitability of room shape, dimensions and building materials for any given situation.

A group of architectural sketches by Leonardo da Vinci illustrate a highly original - and entirely intuitive - projection into three dimensions of the two basic auditorium types, auditoria for music performance and those for speech. The first sketch is labelled "Theatres for hearing mass". It depicts a building with a centralized plan, and consists of three amphitheatrical banks of seating, with the curved forms being expressed on the outside of the building. The seating areas are set back from the central platform and enclose it on three sides. The next sketch is labelled a "Place for Preaching". This on the other hand is a building designed to bring all the listeners as close as possible to the speaker, who stands on the top of a raised column-like pulpit, reached by a spiral stair. Surrounding the speaker are six tiers of galleries, equidistant from the speaker, giving the auditorium a spherical shape. If we assume the accompanying sketch to be a floor plan, the building in fact is not spherical, but a segment of a sphere, presumably taking account of the directionality of the human voice. Access for the audience is via staircases up the conical exterior, so that the outside of the building presents the appearance, as it were, of an "inside out" classical Roman amphitheatre. The building is apparently open-air, without a roof, and we have to assume a crowded auditorium, perhaps built of wood with an open balustrade for maximum sound absorption by the audience. The design is remarkable for the sense of involvement it provides the audience with, with excellent sightlines and a direct sound path to each listener. Taken together, the sketches illustrate how an idea or functional requirement can be projected into three dimensional spatial form. As the parameters are changed, so too the optimal form is also changed.

As concert halls and theatres evolved during the succeeding centuries architects drew extensively on precedent, even though little might be known of the actual reasons for a hall's success. For the most part, the architect was able only to use established methods and forms, and trust his good luck. Even in our own day with the Royal Festival Hall, London - that "complete statement of present acoustic theory" as the *Architectural Review* put it - the rectangular plan was adopted in the absence of theoretical knowledge on the subject, simply because the so-called Leipzig model seemed to work best.

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Writers on acoustics in the eighteenth century often recommended the opposite of what we know as good practice. Concave surfaces were regarded as best acoustically because it was thought that sound could be usefully amplified by focusing it like light. Convex surfaces that scatter sound were thought to be least desirable. The ellipse was said to be the optimal plan form for auditoria because the shape has not one but two foci. This was especially so for opera houses, because the directionality of the voice was considered to cause ellipsoidal sound waves, so that the elliptical galleries would represent, as it were, contours of equal loudness. The 500-seat St. Cecilia's Hall in the Niddry Wynd, Edinburgh, by Sir Robert Mylne, which was opened in 1762, was based on the ellipse and was judged by contemporaries to be highly successful. The amphitheatrical seating layout was said to be based on Aleotti's Teatro Farnese at Parma, of 1617-1628, and the arrangement where listeners faced each other, as in the boxes of an opera house, emphasised the social nature of concert going, and was similar to the parliamentary seating adopted at the Altes Gewandhaus, Leipzig, of 1780-1781.

Invariably, too, fallacious explanations were given for room shapes and building materials that had proved by trial and error to be successful. The hallmark of the Galli-Bibiena family, who worked as theatre architects at every princely court in Europe, was the flaring reverse-fan shape plan. Though there is no surviving statement by the Galli-Bibiena on the acoustic design of their bell-shape opera houses, contemporary writers suggested that a singer could excite the wall surfaces into vibration by standing in the equivalent position to the clapper of the bell.

Opera houses were usually lined with thin wood panelling, and contemporary writers on acoustics emphasized the importance of wood, though, again, for the wrong reason - that it acts as a resonator analogous to a musical instrument, rather than as an absorber of the bass frequencies which would have helped reveal musical detail and increase speech intelligibility. They stressed in particular the function of the ceiling as a sound reflector, and specified that the walls of theatres should be masonry for fire reasons but finished with thin wood panelling on battens, with an air space behind.

Even the reports of early experiments in acoustics that form the foundations of acoustical theory today were combined with pseudo-scientific speculation, myth and magic. The Franciscan friar Mersenne, friend of Galileo and the so-called father of acoustics, is best known for his formulation of the physical laws that govern the frequency of a stretched string. He also carried out accurate work on the speed of sound propogation. He found with a pendulum that you could pronounce seven syllables in one second, and by determining that the seven syllables could be returned as an echo within one second when standing 519 feet away from a rock face, he deduced that sound travels at 1,038 feet per second. He also discredited various claims made at that time about echoes - in particular that a voice in French could be made to echo off a wall in Spanish. However, in determining the velocity of sound during his echo experiments he then somewhat spoilt his scientifically accurate results by further deducing that a sound wave would take 21 hours and 5 2/3 minutes to go round the world, and therefore the trumpet on the last day of judgement will be heard within about 10 hours from the point at which it sounds.

Other scientists were glaringly incompetent. Athanasius Kircher tried to repeat Mersenne's classic experiments. Alas, this was not to be, for he concluded that sound has many speeds, faster when loud and at midnight, slowest in the early morning.

Speaking trumpets were a subject of fascination for early acousticians. Sir Samuel Morland in 1672 published a brochure describing a horn he had made, 21 feet long, with a 2 foot mouth, which he called the tuba stentoro-phonica; he claimed it could make the voice audible up to a mile. The horn is twisted like a rifled gun barrel as it was thought that this helped the sound to project. Athanasius Kircher describes a similar idea in his *Phonurgia Nova*, published in 1673. He constructed a tapering horn connecting his workroom with an outside wall, by means of which he could talk to his gatekeeper without leaving his desk and eavesdrop on conversations in the courtyard in the manner of Dyonisis, much to the amazement of his friends. He also suggested connecting such a horn to the mouth of a "speaking statue" and broadcasting music from an inside room to dancers in a courtyard outside, or alternatively piping it into the landscape beyond.

Thomas Mace, a lay clerk at Trinity College, Cambridge applied the idea to auditoria. In his book, *Musick's Monument* of 1676 he presents a design for an ideal concert hall. He suggests a square room with galleries on all sides, so that the musicians are surrounded by the audience to give all seats equal audibility. The galleries separate the musicians from the audience. He then suggests piping the sound from the musicians to the rear seats through tubes - perhaps in anticipation of acoustical difficulties.

Such curious acoustical devices were commonly built into both new and existing opera houses. Alterations were carried out at the Teatro Argentina, Rome whereby a brick enclosure was built under the parterre from the stage to the back of the theatre. This was filled with water to form a canal on the basis that water is an efficient sound reflector: the music would be chanelled to the rear seats, emerging through grills in the floor. At the Teatro Nuovo in Parma the entire parterre was built over a great semielliptical masonry saucer connected with passages from the orchestra pit. Such installations were claimed at the time to be highly successful, though their effect in reality must have been slight.

The principle reason for the success of most early auditoria was, of course, their intimacy. George Saunders, an English architect and author of *A Treatise on Theatres* in 1790, stresses repeatedly the importance of minimal overall dimensions. The extended forestage used in eighteenth century theatres also gave extremely close contact between actor and audience, and influenced profoundly the style of playwriting and acting. When the so-called picture frame stage developed after the invention of gas-lighting, the actor retreated beyond the proscenium arch and actors developed a booming, rhetorical style of delivery, as practised by Victorians such as the celebrated Charles Keane.

Concert halls, too, were small. The Altes Gewandhaus, Leipzig, contained just 400 seats, though up to 1000 listeners were accommodated at times. It was only in the nineteenth century that halls became problematic as orchestras and audiences grew in size, and dimensions became excessive. Few of the more outlandish projects, however, were realised, such as Viollet-le-Duc's design from his *Entrétiens* of 1868-1872. During the present century, the original design for the Royal Festival Hall, London was for a saucer-shaped auditorium for 6,000 people - which was said at the time to be "the minimum for a city of the size of London". In his *Evenings with the Orchestra* Hector Berlioz fantasises about an auditorium "built to provide superior acoustical conditions" that holds 20,000 listeners and 10,000 performers. Worse still, London's Royal Albert Hall of Arts and Sciences was originally intended to hold 30,000 people. (The architect, Captain Francis Fowkes, officer in the Royal Engineers, had never in fact designed a concert hall before; he had, however, designed a barracks, a portable rubber bath for officers - and an umbrella that could turn into a walking stick).

By the early 20th century acoustical science had advanced to the point that the architect and acoustician could collaborate and predict the acoustics of an auditorium. The work of Rayleigh was especially significant. Born in 1842, the Third Baron Lord Rayleigh, a dairy farmer with a 7,000 acre estate, is chiefly known for his discovery of the gas Argon, for which he received the Nobel prize. Yet he was also author of the important treatise *The Theory of Sound*, which collated the available knowledge on acoustics to date. He also carried out original work on the perception of direction and binaural hearing.

In the twentieth century, the principle difficulty with acoustic prediction has been that the scientific viewpoint of acousticians has not always coincided with the instinctive taste of the musician. The design method of translating an acoustical concept into three dimensional form, through the use of analogy or a conceptual model of sound behaviour, must of course rely not only on the accuracy with which the designer effects the translation, but also on the soundness of the initial theory. For example, the pre-war American acoustician F. R. Watson advocated the analogy of the outdoor music pavilion - the sound-reflecting stage enclosure combined with a sound-absorptive auditorium so that the reflected sound is reduced for greatest clarity - a viewpoint that few would agree with today.

Maximum sound clarity was for many years an overriding goal, and the moulding of the hall around the graphic ray diagram was the favoured method for achieving this. The most complete expression of the design method was the Salle Pleyel, Paris, opened in 1927, designed in consultation with the French piano manufacturer and amateur acoustician, Gustave Lyon, who had carried out a series of bizarre experiments on speech intelligibility in a non-reflective environment whereby speakers were suspended from hot-air balloons on the end of ropes. At the Salle Pleyel sound is chanelled from the stage to the rear by the smooth flaring walls and ceiling, so that music played in the hall has remarkable clarity and loudness, highly directional, though curiously "monophonic" - like listening to music played through a single loudspeaker turned to high volume. For what it set out to achieve, this hall (at least after various renovations that have taken place), together with the other "directed sound" halls which followed, were successful, though to the severe detriment of tonal fullness. The model had proved over-simplistic in addressing only one aspect of the acoustical problem.

The main difficulty of auditorium design remains today that the design criteria themselves are mostly contradictory and often incompatible. For instance, economic demands may require a large hall while acoustical preference is for a small hall. The criterion of visual intimacy generates a short, wide auditorium, yet acoustical intimacy dictates the need for sound reflective side walls and implies that the hall should be long and narrow. Socially, the theatre-in-the-round plan might be best, but for musical balance is worst. For sightlines the raked fan shape with splayed walls is ideal, while a reverse fan-shape plan converging toward the rear is desirable for the lateralization of reflected sound. Upholstered seating is necessary for comfort, while hard seating is preferred acoustically. When a hall is used for chamber music the room is more reverberant with fewer performers on stage than with a large symphony orchestra, yet the reverse is desirable. Similarly for opera, open air scenes on stage are often more reverberant than indoor scenes that have enclosing stage sets, while in real life the opposite is the case. The architect and structural engineer may wish to express the ceiling beams in the auditorium, while the acoustician may wish to conceal them in case of "sound shadows" from uneven ceiling reflection. Perhaps the major conflict in music auditoria in the era of the compact disc is the difficulty of combining front row clarity with tonal fullness - the quality, as it were, of sitting close to the performer and far away at the same time.

The success of an auditorium relies to a large extent on the relationship between the architect and the acoustician in the context of the design team structure. Yet the teams that have successfully established a happy collaboration, often extending over several projects, are unfortunately balanced by other relationships of lost opportunities. Sometimes an architect is over-willing to accept the consultant's instructions without developing the design. Sometimes the acoustician may push his particular point of view, to the detriment of other, non-acoustical aspects of the building. The result can be an architecturally unrefined "built acoustical sketch".

The reverse problem occurs where the acoustical consultant is engaged after the initial design studies have hardened to the point where the architect has begun to derive the overall building form from an initial schematic concept for the interior, expressing his pre-determined form on the exterior shell. This was the failure of Functional Expressionism as a stylistic device, as at the Sydney Opera House, where the exterior form lost its original "meaning", and the audience chambers had to be shoe-horned into a pre-determined shell. The same occurs when the requirements of the brief change, especially in the case of long-term projects, when personnel or interest groups change and the clarity of the link between intention and built form is lost. The concert hall of the Barbican Arts Centre, London was originally conceived as a 1000-1300 seat symphony hall with a platform which could convert to a forestage for Elizabethan drama, or theatre in the round. The auditorium finally opened as a 2000 seat single use concert hall, having to fit itself within the constraints of the building boundary, as construction on the project progressed.

With the latest generation of auditoria, inspired by the admired halls of the past, which will be discussed over the next two days, intuition and precedent have for the architect and acoustician once again become essential ingredients in seeking the integrated design solution. Most important, the technology of the subject is not an end in itself, and the designer must never lose sight of the qualitative end product. Like a musician's technique, the science of room acoustics is a means to an end, not an end in itself.