Is There an Acoustical Tradition in Western Architecture?

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Abstract: - This paper will attempt to show that after the Roman Empire yet before the acoustical experiments of the eighteenth century (which are considered by too many acousticians as the true beginning of their science), there was a profusion of acoustical ideas, practices, and accomplishments in architecture.

Key-Words: - architecture – history – acoustical phenomena – echo

Introduction

Throughout the history of architecture, buildings incorporated particular acoustical phenomena, which were noticeable, are often surprising, and sometimes even spectacular. If from the group of these buildings are eliminated those having musical drama or speech (theatres, concert halls, or odéons) as their principal use, there remains nonetheless an important series of structures distributed over the centuries. Here the first question can be asked: are these structures in which acoustical phenomena can be found isolated cases, works resulting from a local and transitory interest in certain auditory concerns, or are they points on a continuum, permitting us to retrace an ongoing concern extending across a vast period of time? Put in another way: aside from theatres, odeons and concert halls, were the builders and the architects of the past preoccupied with acoustics; were they part of an acoustical tradition in Western architecture? This is a difficult question to answer.

Certain acoustical ideas and practices extended through time and space, getting lost sometimes, then reappearing in a more advanced stage than before. An early example is the use of resonators, employed by the Greeks and Romans in their theatres, and also found all over Europe, from Scandinavia to Yugoslavia and from Brittany to Moscow, in Romanesque churches. Certain phenomena are inherent to the construction and geometric form of the building which contains them; whispering galleries, according to acoustician Leo Beranek, were conceived without any particular acoustical design. Another instance, apparently resulting from structure alone, is the propagation of waves beneath an elliptical vault, permitting someone placed near a focal point to converse over long distances and secretly, whispering to another person placed near the opposite focal point. One encounters as well certain buildings containing multiple echo effects, and a large number of other structures generating substantial reverberation.

Let us examine these different acoustical characteristics case by case

As concerns the first case, it is indisputable that the small vase inserted in the masonry represents a conscious attempt that could give a specific acoustical caracter to a space. Here a new question can be asked: how old is the practice of using acoustic vases? Vitruvius, in his Ten Books on Architecture (1), teaches us that they come from the Greeks, and describes how to choose their sizes and where to place them. Apparently their use was limited to theatres, yet not all theatres: only those constructed of stone or marble were chosen, those that according to Vitruvius "don't produce any resonance."

They reappeared in the Middle Ages, in churches this time, but again in a curious manner. They are found both in basilicas and in chapels, and although distributed throughout Europe, are not systematically employed. For example, in Paris, acoustic vases can be found in the chapel of the Conservatoire des Arts et Métiers (today the library) but not in the large churches: neither at St. Sulpice nor at Notre-Dame or St. Eustache. On the other hand, in the north of Paris, they can be found in the basilica of St. Denis, in the cathedrals of St. Pierre de Beauvais, Notre-

Dame de Senlis, and Notre-Dame d'Amiens; in the south, they are found in St. Etienne de Sens and Notre-Dame de Chartres. In Brussels, an inventory has not been taken, but there are vases quite close nonetheless, at St. Rombeau de Malines. In Bologna, the cathedral of St. Petronio
contains more than four hundred, and, a few hundred meters away, in St. Ietro, only twenty-five can be found, which are of varying diameters (although a single sounding can show which holes do contain vases and thus through which can be passed cables from the vault extrados).

To this day, some two-hundred churches in Europe containing acoustic vases have been counted, half of which are in France (2). The numerous examples found are of such different types that it is difficult to draw a general conclusion regarding this medieval practice because of the diversity of the forms used (from the straight-necked [amphore] to the [jarre pensue]) and the diversity of placement (sometimes in the choir, sometimes in the lateral walls or in the vaults), especially since certain vases were chosen and placed by people who {may not have been} certain how they functioned, a secret jealously guarded by medieval guilds. To all this must be added an enigma: why are vases encountered only in churches, and not in palaces or castles? Nevertheless, the following constants can be determined:

(1) the vases are located in the interior of closed spaces,
(2) there are generally of small dimensions,
(3) they are situated far from the auditor's ear, and
(4) they are almost always surrounded with masonry, and not, as Vitruvius describes, placed on three corners to facilitate free vibration.

It is remarkable that these four points are exactly contrary to the Greek and Roman tradition.

Here it is useful to point out an historic curiosity: almost everything is known about the resonators of the Roman era thanks to the text of Vitruvius, although not a single vase has been found; on the other hand, we possess many examples of medieval acoustic pottery, yet no text on their function has ever been discovered. René Floriot, who for almost twenty years has studied these vases, has shown that they are above all correctors of acoustics (3). They affect the standing waves of resonant frequencies (and their harmonics) of the room: the overlapping of incident and reflected waves by the walls and vaults creates in some places maximum pressure points and in others minimum points. In addition, they partially absorb frequencies in the region of two hundred Hertz, and smooth out the peaks seen in a reverberation time analysis. The copper vases discussed by Vitruvius, which render an actor's voice "stronger and more clear because of the resonance it would have with one of these vases" (4), and which are true resonators, are the contrary of the medieval acoustic vases, which have an ability to absorb and to regulate in low tessituras, those registers which are known to be the most awkward and difficult to eliminate (5).

It is remarkable that, although we know today what the acoustics of old churches resembled by the simple fact that they have almost all come to us in perfect condition, the customs of those people that frequented them are not well understood. Did they place straw on the floors? Was fresh grass placed on the ground as was the habit in most of the buildings of the time? How were these spaces lighted in the evening? Were draperies or tapestries hung from the galleries? Many questions remain unanswered, about things that would by their nature change the reverberation time. Was singing a more important part of the mass in medieval times? Is it necessary to investigate the place in which music was practiced in a particular church, to discover whether resonators exist?

The second case mentioned in the introduction, whispering galleries, has an associated question: are these galleries accidental or created purposefully? The answer is simpler in the sense that there are fewer examples, whose acoustical function, if it existed, is not well understood. The propagation of waves perpendicular to a curved wall can only take place in a building having a smooth circular surface: the drum at the base of a dome, for example. This is precisely what one finds beneath the domes of the cathedrals of St. Peter in Rome and St. Paul in London, where two people, with ears placed against the concave wall, are able to converse in a low voice across a distance of thirty-five meters. Sound propagates amazingly well along the length of these walls, and people who have had this experience are consistently surprised to hear their interlocutor, located on the opposite side, so clearly, especially since the dispersion of sound waves renders inaudible their attempts to speak directly across the dome. Jearl Walker, in a text about echoing vaults, writes:

"when the sound produced by a small source propagates in a plane without encountering obstacles, its intensity diminishes as the inverse square of the distance which separates it from the source. On the other hand, in the multiple-reflection model (against the wall) of the Cathedral of St. Paul, the intensity decreases only as the inverse of the distance. This shows that the sound which travels the length of the gallery wall remains stronger than that which is transmitted directly across the dome."(6). Yet if this acoustical phenomenon encountered in these well-known monuments was not intended, it can be asked why, at the base of the dome in the Cathedral of St. Paul in London, the stones are particularly well arranged, covered with oil and polished, at forty meters above the ground, in a place rarely frequented by the congregation.

The same phenomenon occurs outdoors as well, along the length of circular walls of certain gardens (Kingston, for example) or in fortifications (the enclosing wall of the village of Urbino, below the ducal palace), and also in certain ancient theatres, where two people placed at the opposite ends of the same step are able to communicate, with heads facing the angle formed by the run and rise of the stair. In the Roman theatre of Orange for example, it is possible to whisper across a distance of more than eighty meters.

Although the effect is striking in each case, it is a truly geometrical and not acoustical choice that predominated in the elaboration of the plans of the aforementioned buildings. For spaces in which the crossing of two barrel vaults forms an elliptical surface in the diagonals, sounds emitted near a focal point concentrate themselves in the opposite focal point, without human intervention, since this is a result of the structure: the acoustical phenomenon is inherent to the geometry of the space itself and to the convex angle formed by the two planes.

As in the preceding case, the example of the transmission of a low intensity sound (a whisper) across a distance which would be otherwise impossible without the help of the building form presents itself. It is for this reason that places where these phenomena are found are well enough known to have become tourist attractions. An example: the effect that one hears, in the "echo hall" of the Conservatoire des Arts et Métiers, is listed in the Michelin Guide.

The oldest examples, like the "salla de los secretos" ("hall of secrets") in the Alhambra of Grenada, apparently do not stem from an acoustical preoccupation on the part of the builders so much as from an active and living acoustical custom, perhaps applied to the architecture after the fact, since it was probably quickly noticed that, if placed in a good spot, two people could communicate in whispers without being heard by someone situated between them. To eventually build certain spaces intentionally with this particular geometric ceiling form would seem logical. The majority of examples that I have been able to examine: the Loggia dei Mercanti in Milan, the Passagio lei Enzo in Bologna, and the Salla dei Giganti of the pallazo del Té in Mantua, are located in Italy and were constructed in the Renaissance. As is well known, this period was replete with conspiration, intrigues, and even a uncommun practice of espionage. In France, the hall of the Caryatides of the Louvre is similar to the Italian examples. On the other hand the acoustical purpose of the hexagonal room in the Paris Observatory is not obvious.

Extraordinary uses of this possibility are encountered: in a church in Lyon where this phenomenon was witnessed, lepers were given confession from a good distance away, in secret. In certain prisons, the detainees communicated amongst themselves or with the outside in this manner. What remains intriguing is how in Rome, in the basilica of St. John-Lateran, only one out of twelve of the inner side-aisle buys, wich are all similarely vaulted, exhibited this acoustical characteristic . These many examples could not come from a simple coincidence. In reality, this acoustical phenomenon had been "demonstrated" and explained for many centuries; the German scholar Athanasius Kircher described it in his Musurgia Universalis, published in 1650 (7). It is interesting to note that a little bit later, Antoine Ferretiere, in his Dicitonnaire Universel, published in Rotterdam in 1690, defined the term echo thus:

ECHO: "in Architectural terms, said of certain vault forms which form elliptical surfaces, or parabolas, which redouble sounds and create artificial echoes."

He defines the word [Echométrie] thus:

[ECHOMETRIE]: "Science, or Art of creating echoes; to build structures whose disposition, especially of the vaults, forms echoes" (8). In the end, it becomes evident that this phenomenon, clearly linked to architecture, is not as accidental as is too often thought.

One thinks initially that echoes are inherent to the geometry of a building (for example, the Villa Simonetta in Milan, or the basement of the Panthéon

in Paris). But when the building is examined more closely, one cannot help but think that the proportions of spaces and their particular dimensions are not simply the result of a single visual motivation, but instead that an attention to and preoccupation with acoustics guided the builders. In the Villa Simonetta in Milan, the proportion of the rear court is seventeen meters by thirty-four meters, and it is known that in order to produce a clear echo, seventeen meters or a multiple thereof between the point of emission and the reflecting wall is necessary. This villa had long been visited for its acoustical properties; unfortunately the bombardment at the end of World War II damaged it extensively. The echo occurs only once along the axis of the widest side. And yet "from a window in the upper floor, in the left wing of the palace, and overlooking the court, a pistol shot repeats forty to fifty times, [and] the sound of the voice is reproduced from twenty-four to thirty times. Monge and Addison verified this fact, Bernouilli has affirmed that he counted up to sixty repetitions" (6).

If one considers that sacred architecture must contain some divine manifestation, certain representative rules of divine law, as well as the cosmology of the era, it is understandable that our predecessors wished to reproduce particular echo effects in the interior or exterior of sacred edifices. And it is perhaps no accident that in the Baroque era, two Jesuits gave the different echo phenomena a significant place in their books describing the many aspects of the world and the laws of the universe. Josephus Blancanus dedicated thirty pages of his "Book of the Globe" to the term "[Echométrie]", including a large number of additional theorems and clauses (10), and Athanasius Kircher, in his Musurgia Universalis, devoted seventy-one pages to the chapter "Magia Phonocamptica" (11).

Yet, closer to home, echo phenomena present themselves more often than one thinks: in the past each city of some importance was encircled with ramparts, and a person placed at an appropriate distance and facing the walls heard his voice reflected; the same thing happened under certain bridges, or between the well-enough spaced piles of a bridge, or against the banks of certain rivers, and it is said even that the sails of ancient ships created echoes. It is interesting to note that the people of the past paid attention to the quality of echoes, to their different returns, resulting from the architectural form of the space, or from the air and the nature of the building material of the reflecting walls: such echoes would return only certain special notes, while others would seem to sometimes approach and sometimes recede.

To return to architectural expressions, wished or not, the curious echo that can be observed in the basement of the Panthéon adds a singular impression to the halls accessing the tombs of these great men: striking a coat or other item of clothing with a dry blow produces a sound analogous to that of an explosion, and when a coin is dropped on the floor, the resulting noise is strongly amplified and accompanied by multiple echoes. The sound of footsteps is equally amplified and is accompanied by other footfall-noises seeming to come from different directions.

The Haas effect, which is encountered primarily in nature, has been recognized for many centuries. A.C. Raes has shown that Christ used this effect when he addressed crowds and in particular when he gave his sermon at Lake Nazareth (12). His listeners placed themselves on the sloping edge of the lake, and he stood in a boat at some distance. The direct sound plus that which was reflected on the surface of the calm water added together. There was thus the effect of amplification. This effect was maximized in ancient Greek theatres, as François Canac has demonstrated, and is in fact the basis for the success of these structures (13). The actors played before a reflective wall on a long and narrow stage. The judicious use of this procedure can be found twenty centuries later, when the installation of "thrones of truth" in churches is viewed generally. These pulpits are surmounted by sound reflectors which make use of the Haas effect. The direct voice of the preacher is amplified by the sound reflected by this small ceiling.

As examples of the focus of sound either inside or outside certain edifices, two well known cases must be cited, one of which was voluntarily conceived. In one of the palaces of Philip II, the royal chamber, hidden from the public, received sounds emitted in its direction due to the reflection of sound waves on a concave surface (14). The other is in the Bomarzo park of the villa Orsini in Viterbo, where there is a large opening, like an immense mask, which one can walk through and then be seated around a table inside. When one speaks, everything said can be heard in a particular part of the park, a good distance away. In a similar way, the hemispherical form and the [cul-de-four] in the apse of early Christian churches, which functioned as acoustic reflectors, permitted the priest, who faced the apse with his back to the congregation, to be suitably heard by all.

A relatively long reverberation time is found in all "larger stone" churches, and in certain cases it is remarkably prolonged, as, for example, in the Baptistry of Pisa, where a twelve second decay is not out of the ordinary! When several notes are sung staccato, they are next perceived reunited in one chord lasting several seconds. Cistercian churches, which do not have many large openings, which have floors unencumbered by chairs, and which are relatively bare, are particularly reverberant, so much so that in the Abbey of Thoronet, for example, anything spoken in the nave is rendered incomprehensible. It was intended thus that the principal space be dedicated to chant and that a smaller room, the capitulary hall, just next door, be used for sermons. What remains extraordinary in this abbey is the complete "response" of the nave which resonates at the slightest sound, even a whisper. When one sings in the lower frequency ranges and the chest begins to resound, the church acts as a resonating chamber for the same frequencies. There is at this moment an unusual unity of body and space; song is carried and sustained by the acoustics due to the generous reverberation which gives an harmonic aura to monody by transforming melodic intervals into harmonic intervals.

Inevitably, the essential reverberation of medieval churches suited the musicians of the era. Even if polyphonic music and the first written perfect harmonies didn't appear until the fourteenth century, the music that was played in these voluminous spaces with reverberation times of several seconds was automatically given an effect like that of polyphony. The special acoustics of these churches became an advantage and not an inconvenience, brought a certain richness, and engendered denser and more complete musical effects. The sonic image inherent to these religious edifices magnified and accentuated their difference from profane spaces (even of large dimension such as barns, for example).

There exist yet more acoustical peculiarities linked to architecture which cannot be placed into the various categories described above. For example, in the villa Parizi in Frascati, one listens, by facing a basin, to all that is said on the floor below. (Incidentally, this is used in one of the scenes of the film "La dolce vita" by Fellini.) The acoustical intention of such an arrangement, which cannot be accidental or resulting from the geometry of the building, cannot be doubted.

To give another example: as early as the quatrocento, two of the three principal architectural theorists spoke of acoustical conduits. Francesco di Giorgio Martini, in his treatise on architecture published in 1490, explains their purpose as well as their construction:

"It is possible to make an instrument with which the lord may easily hear all that is said in the house, 'in his absence', let us say, and in this way: a concavity is formed which is like a window carved in the wall (a niche), and which is hollowed out into a little tube; in the upper part a nook is formed which opens onto a place in which the lord, by applying his ear to the tube, hears all despite efforts to speak quietly. This is because the remainders of sound and of the voice in this angular room fortify themselves; in a certain way the dispersed fragments unite and become stronger as experience has shown" (15).

Leon Battista Alberti speaks of them as well in his treatise De Re Aedificatori, published in 1485: "It is convenient to recall how usefull to tyrans are acoustical tubes hidden in the walls , by which is perceived the discussions of both guests and people familiar to the house" (16). And in 1650, Athanasius Kircher explains the technique and placement of these conduits in his Musurgia Universalis (17). This system is in fact the predecessor of speaking tubes, pipes permitting the transmission of speech to the interior of large homes and certain hotels of the last century (18).

Finally, another example that we have seen earlier is that of the throne room in the ducal palace at Urbino. In the ceiling are arranged several small openings, at the center of ceiling-roses and bosses. When one visits the attic above the ceiling, it is possible to hear (and spy on) all that is said in the hall, even if of low frequency, simply by listening through these openings.

Conclusion

It would be tempting to reply affirmatively to the original question, "is there an acoustical tradition in Western architecture?", although a definitive answer cannot be given here. It is certain that the acoustical phenomena in a large number of the buildings cited are not accidental. Yet, due to the efforts of certain builders of the past who wished to create impressive spaces from a sonic viewpoint, or containing certain interesting effects, it is necessary to superimpose a frame of reference of living acoustical practices which encompasses a field tangled with different

motivations, obscure practices, legends, false rumors and coincidences. Nonetheless a retrospective investigation of an important series of historic buildings is necessary and will bring many surprises.

To conclude, it is necessary to remember that in the vast period extending from the end of the Roman empire to the beginning of the nineteenth century, acoustics are present: if not in the form of a science, at least in the form of successful and living expressions. It is this period, forgotten by acousticians, that I have attempted to describe.

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(4) VITRUVIUS , op cit. pp. 160-161.

(5) René FLORIOT (frère) *Les vases acoustiques du Moyen-Age*, in: bulletins du GAM, n° 98, Paris, juin 1978, p. 8.

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(9) R. RADAU, *L'acoustique ou les phénomènes du son*, Librairie Hachette et Cie, 1ère Edition, 1867, pp. 121-122.

(10) Josephus BLANCANUS *Sphaera Mundi, seu Cosmographia Demonstrativa, ac facili Methodo tradita in qua todius mundi fabrica, una cum novis,Tychonis, Kepleri, Galilaei, aliorumq, astronomorum adinventis continetur accessere*
I. Brevis introductio ad Geographiam
II. Apparatus ad Mathematicarum studium
III. Echometria, id. est Geometrica traditio de Echo"
Boroniae, typis Sebastiani Bonomii Sumptibus Hieronymi
Tamburini, 1620.

(11) *Magia fine Ars Phonocamptica eft recondition fonorum fcientia, qua reflexal & multiplicatae vocis virtute, prodifiofos & canfarum ignaris miraculofos effectus* p & Stames: pp. 250-320.

(12)Auguste RAES, *Isolation sonore et acoustique architecturale*, Ed. Chiron, Paris, 1965, pp. 325-326.

(13) François CANAC, *L'acoustique des théâtres antiques - ses enseignements*, C.N.R.S., Paris, 1967.

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(15)F. di GIORGIO MARTINI, *Trattati di Architettura Ingegneria e arte militare*, secondo trattato, et figures f. 24 TAV. 207 et f. 24 v TAV. 208., Edizione il Polifilo, Milano, 1966, pp. 352-353(trad. J.Baldasso).

(14) L. Battista ALBERTI, *De Re Aedificatoria*, (l'architettura), libro quinto, capitolo III, Edizione il Polifilo, Milano, 1966, p. 346, (trad. J. Baldasso).

(17) Athanasius KIRSCHER, Op. Cit. II, f. 303.

(18) E. BARBEROT *Traité de construction civile*, Librairie Polytechnique Ch. Béranger, Paris et Liège, 1920, pp. 831-832. This work gives a good deal of technical information about the function, construction and use.

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