

From Methodology to Archeoacoustics in the Time of Scripture: Complex Dialogue Between Archaeological Evidence, Texts from Scholars and Written Mentions

Jean-Christophe Valiere¹; Estèle Dupuy²; Bénédicte Bertholon³

¹ CNRS – PPRIME, UPR 3346, Université de Poitiers, ENSMA, France

² FORELLIS EA 3816 - Université de Poitiers, France

³ CESCO - CNRS - Université de Poitiers, France

ABSTRACT

Nearly 15 years of research on the acoustics of pots from 11th to 18th centuries have led us to crossing data from various disciplines and developing a specific methodology. The presentation analyzes the pitfalls of interpreting this technique through the eyes of the scholars that have addressed the issue since antiquity and of written mentions rather than using the archeoacoustical data found in France and Europe. An archeoacoustic research will only be meaningful if it can prove a deliberate intention to produce an object with an acoustic function. However, such a proof necessitates observing regularities, by studying several buildings or objects that attest that an effective choice has been made. A common error is to restrict the hypotheses to those which are scientifically admissible today. The case of pots acoustics is particularly edifying in this respect. Nevertheless, precise analysis of historical texts makes it possible to widen the field of hypotheses. Semantic study of the evolution of the meaning of key words and their associated concepts makes it possible to study the evolution of the acoustical techniques and to observe their progress through the centuries.

Keywords: Archaeoacoustics, History of Sciences, History of Techniques,

1. INTRODUCTION

Archeoacoustics is a growing science in the acoustics community as well as archaeologists and musicologists. But behind the word *archaeoacoustics* lie many practices that differ considerably not only in their objectives but also in their methods and approaches. They include, for instance, the reconstruction of ancient instruments from iconography, measures to better understand how speakers were positioned during prehistory, digital simulation of theatres of the 18th century, or the question of acoustic pots. None of these examples are similar, although we can admit that all of them are archeoacoustics.

Our purpose is not to develop a general method that define virtuous scientific approaches, but to point out the difficulties of certain practices of archeoacoustics when, in addition to material evidences, texts exist written by scholars, scientists, or men of practice. However, these texts are not recipe books, which precisely describe techniques related to acoustics. They are either texts of scholars (Aristotle, Saint Thomas Aquinas, Mersenne) who describe physical phenomena or devices, texts of architects (Vitruvius, Alberti, Philibert de l'Orme), texts of abbey chroniclers, or finally texts of practitioners (mason, potters) who report their daily practice (1, 2, 3). They are therefore different in their level of knowledge, especially since acoustic was far from being a stabilized science at their times. We have to "put ourselves in the place" of the authors to understand their point of view and understand with which authority they are speaking (specialists, observers, builders, payers ...).

Beyond the contents, the very understanding of the texts is in question. Studies on the Latin vocabulary used in Vitruvius and its translations into Old French are interesting from this point of view (4). In particular, the gradual shift of meaning of the word *resonance* between Vitruvius's and the present epoch is a source of ambiguities, both for historian who use it in a common sense but also for

¹ jean.christophe.valiere@univ-poitiers.fr

² estele.dupuy@univ-poitiers.fr

³ b.palazzo@yahoo.com

acousticians who use it with the restricted sense of today's science. The position of the observer must also be analyzed with care in the study of literature and historiography. Researchers from the humanities often have an incomplete view of acoustic effects and minimize their complexity. By symmetry, researchers from the physical sciences often overlook the analysis of texts and the context of their production. They often use an advantageous quote that reinforces a theory previously defined by them. Developing these reflections is the topic of Section II of the paper, entitled "Avoiding anachronism".

Our experience has shown us that we have to start from low-level, uncompromising hypotheses, that are commonly accepted by the community. We must avoid wanting to prove a theory from the beginning with few data. We must diversify the origins of the hypotheses, for instance from outside the scientific fields, such as explanations of religious or symbolic nature. Above all, it is important to collect a large amount of data of all kinds and to observe the techniques on large scales. The conclusion of these observations must then be confronted with specific buildings. It is developed in Section III entitled "Starting from Low Level Assumptions".

Finally and before the conclusion, we apply this methodology to the question of acoustic pots (Section IV), bringing unexpected observations for acousticians since pots are as much related to acoustics as to musicology or symbolic representations.

2. AVOIDING ANACHRONISM

2.1 Learning the history of acoustics science and technology

The first thing to consider is the general framework of admitted knowledge at the considered times. The science of sound, *acoustics*, does not take autonomy until the 17th century; the word "acoustique" (acoustic) was first invented by Sauveur in 1700. Does it mean that the problems are absent from the texts of scholars? of course not. Until the 17th century, the "scientific" culture includes four disciplines: arithmetic, music, geometry, and astronomy, called the "Quadrivium". The study of sounds was therefore a part of music, which was the science of proportions; it was rational calculation according to Pythagoras. Geometry had also to do with sound since the interpretations of sound propagation were of geometrical nature in the straight line of the Aristotelian interpretation. However, already at the end of the Middle-Ages and at the Renaissance, the link between music and acoustic science no longer seems so obvious. For example, the architect Alberti (5) does not hesitate to write, "he [the architect] did not need to be a musician, just because the vases are arranged in the theatres".

As far as we know, concerning acoustic correction for example, the effect of the resonance of pots was known at that time in terms of amplification. The geometry of the pot was said to have an influence on its resonance (6). The effects of absorbing vaults were known (5). On the other hand, we have no mention of the effect of absorption by pots, but we have some for curtains (7).

2.2 Prioritizing written sources

One of the problems with the use of sources is who is writing and from which point of view. Indeed, history in general, and the history of science in particular, are characterized by the analysis of almost exclusively written sources. We consider four sources of texts: texts from scholars, abbey chronicles, texts from architects, and texts from artisans.

In filiation with Antiquity, scholars from the Middle Ages to Renaissance are the first source of texts because they had an homogeneous culture based on the readings of ancient texts (8). Then come the abbey chronicles, such as daily registers, which can be factual and describe building works in a church, for example. They are often associated with moral remarks or supposed intentions on the potential success (or not) of the architectural modifications. However, sources are diversifying at the Humanist Period with in particular books of architects and some literate artisans.

Striking is the difference between the words of architects, Alberti or Philibert de l'Orme, and those of scholars. Architects make comments that do not only refer to ancient sources, which they do not seem to ignore, but also to a certain practice that has to be the practice of their time. Without straining lines, one can say that their remarks probably hoard the knowledge of the times in which they lived. When Alberti writes that the voice of the preacher is better understood under a wooden ceiling than under a stone vault (5), he describes a perceived reality that today is fully accepted and explained: reverberation times are lower under a wooden vault due to low frequency absorption. This is ignored in the "theoretical" treatises, as far as we are aware of it.

The chronicle texts are short mentions, most of the time related to buiding work orders. They are

not intended to describe phenomena nor to reflect physical reality but just to record factual information. On the other hand, they give indirect testimony of the context in which the work was carried out, particularly by the vocabulary they use. The latter often retransmits the nature of the exchange between the authorizing officer of the order and the executor.

For scholars and architects, biographies can give contextual elements; for the often anonymous others, only socio-professional or regional context can provide information.

2.3 Acertaining the meaning of words – avoiding historical misinterpretations

One of the difficulties we have had to face is the question of understanding the texts. In fact, many misinterpretations appear in the translations from Latin to modern French (or modern Italian, or modern English) concerning the vocabulary of sound because of misunderstandings of technical vocabulary. The most obvious case is the Latin word "Circumsonantes", which Vitruvius clearly describes as reverberation, but which is almost never understood in this way by translators. Vitruvius writes that "the circumsonant [place] are those where the voice, wandering round, is at last retained in the centre, where it is dissipated, and, the final syllables being lost, the meaning of words is not distinguished" (8). It perfectly describes the effect of reverberation.

At the Renaissance time, this problem was critical too. The most singular case is the term *resonance*, which we have studied (9). In Latin, it clearly is a simple reflection, and is synonymous with echo. But gradually, it takes the sense of amplification of sound (without necessarily involving reflection), and only late in the 20th century its current physical meaning. The problem is that all these meanings of the word *resonance* are still preserved in French and most European languages. For example, Sabine remarks that « *The word resonance has been used loosely as synonymous with reverberation, and even echo, and is so given in some of the more voluminous but less exact popular dictionaries* » (10).

There is still much to be done on analysis of the texts of scholars. For example, a recent study analyzes the translation of the text of Vitruvius by Jean Martin, at the Renaissance time. It helps to better understand his translation strategy: Martin, as often in the Humanist Period, makes an effort to include in the text of Vitruvius the language of the masons. Like an anthropologist, he thus collects information on the language of craftsmen (4).

3. DEPARTING FROM LOW-LEVEL HYPOTHESES

3.1 Avoiding to demonstrate a "theory"

To start from low-level hypotheses means that we must liberate ourselves intellectually from current scientific results and start from hypotheses admitted as well by acousticians as archaeologists and historians. It is possible, for example, to start from the principle of an acoustic rather than a thermal intention, in conformity with the texts. At this stage and without data, we do not have to specify the nature of the acoustic intention.

In a second stage, this intention can be declined in several fields that are then explored one by one. It may seem tedious, but it is the only way to avoid overlooking a possible explanation and to guarantee good overall consistency.

3.2 Diversifying the sources of hypotheses

If an intention to act in one direction is really identified, it is then necessary to check whether its implementation is credible with regard to the knowledge and the experimental capacities of the considered periods. For acoustics, this point is often evaded. Acoustics, as we have seen, was not defined as a specialty in itself. Interpretations have to be compatible with knowledge in geometry and music. Furthermore, experiments have to be compatible with auditory capabilities because it was the only way to test.

Further, it is also necessary to extend the range of hypotheses to disciplines outside the acoustic field. Explanations of the world were multi-factorial at that time, because a link between music and the organization of the cosmic world was taken for granted.

3.3 Collecting data vs. writing monographs

Archeology of buildings often involves studies of specific buildings in the form of multidisciplinary monographs. It is obviously very effective when one wants to understand all the aspects of a particular space; but the few rare, typically acoustic elements found are not really studied

and appear at most as peculiarities. Many buildings have been analyzed in the past without mentioning, or just at the turn of a sentence, the presence of acoustic pots, or of a whispering room, without further analysis.

We must therefore find ways to carry out large studies, at the scale of a region or a country, to see if we can identify characteristic features of a technical culture, of a regular practice that give matter to interpretation. We must identify particularly well-chosen buildings about which there are texts, in-depth studies, or known historical developments (foundation, works ...).

3.4 Accepting unexpected results

We have to accept that an explanation compatible with today's knowledge can be coexistent with an associated religious (or symbolic) interpretation without having the impression that it disqualifies the interpretation. Until the Renaissance, even technical objects could have symbolic interpretation. This does not disqualify the utilitarian use of technical objects.

4. ACOUSTIC POTS: A CASE STUDY

4.1 Assumptions and hypotheses vs. texts

4.1.1 Acoustic effects

Today, 20th century physical science has established that a series of wall-mounted pots has four cumulative effects around their resonant frequencies when they are far from the sound sources: amplification and reverberation near the pots, associated with diffusion and absorption elsewhere, in accordance with the principle of energy conservation. To those effects is added a coupling effect that brings a very strong reinforcement of the voice around the resonance frequency of the pot, when the pot is close to the mouth of a speaker.

There are therefore five possible identifiable effects. Depending on the volume of the space, the position of the pots in relation to the sound sources or in relation to the listeners, the perceptive effects are exerted differently. It is particularly clear for acoustician experts that a few dozen pots have no measurable effects in a church of even average size: it would need hundreds of them at least.

4.1.2 The words and expressions used

To describe the effect of pots, we find the following expressions: "echo", "It will be easier to sing [...] and it will resonate louder", "so that the voice of God is more easily heard", "apt to make the voice resonate", "the sound ... becomes softer when we sing and play". We identify two semantic fields, one related to physics in which the main notion is amplification, the other to perception with the notion of "facilitation of singing" or the use of the word "soft" (1-4).

4.1.3 Assumptions by non-acousticians

Non-acousticians, be they 19th century's scholars or 20th century's archaeologists, have accepted the hypothesis of amplification. Historiographically, it is most logical. However, among scholars of the times, voices rose to say that it is not so simple, which has led to some skepticism on the issue. For example, Alberti writes that it is not easy to put acoustic vases in theatres as Vitruvius recommends. It is not simply a comment over the Roman architect, but the taking into account of a reality he seems to know well. Mersenne also criticizes Vitruvius's echea, which he thinks could not resonate under the sole effect of the voice; but contradictorily, he declares in the following that earthen pots can resonate with the voice.

An additional point in favour of an intention to amplify the voice is that it is credible with regard to the experimental means of the epochs concerned. Indeed, determining by ear the resonant frequency is very easy by tapping on the neck or singing near the pot as Leonardo writes in one of his notes (6).

The hypotheses of historians do not stop there. Indeed, the pots are organized in space or inserted into painted decorations. Thus the hypothesis that they form symbolic representations in relation to religious or symbolic objectives is now admitted (3).

4.1.4 Assumptions by acousticians

20th century's acousticians reject the hypothesis of amplification because it is incompatible with the arrangement of the pots and not in accordance with today's knowledge. Their main hypothesis, and the most logical in terms of current knowledge, is a remote effect of sound absorption in the likely goal of reducing reverberation. The factual reason is that pots are generally far from the sound sources,

except in very rare cases, and that only absorption effect is then possible.

This very restrictive assumption is not based on any text. Dedicated measurements gave very little result (11,12,13) which led to a lot of frustration and some experts to look for new, even more improbable and less documented, physical hypotheses (thermal regulation, moisture absorber ...).

Even in the absence of text, methodological difficulties remain concerning the absorption hypothesis in order to decrease reverberation. As said previously, we find mentions of problems of perception of sound related to church reverberation in Alberti (5) and in a more recent text from the daily register of the Abbey of Montivilliers (7). Assuming the reality of this hypothesis, it would still be necessary to prove by archaeological texts or data that the pots were chosen in relation of acoustic characteristics perceived in the buildings. In other words, it seems difficult to adjust the resonant frequency of the pots to the sound of the building.

This hypothesis is slightly more conceivable in the case of pots inserted after the building of the church; however, in the case of pots inserted from the beginning of the building, it assumes an anticipation that is less admissible. Although centuries of construction and of accumulation of empirical knowledge may have led to empirical considerations, no text corroborates this practice.

Therefore, the absorption hypothesis poses methodological problems of historical type in the sense that it is essentially derived from extrapolation of current knowledge.

4.2 Our method: do not have assumptions - accept all hypotheses and work on the intention and choice of pots

4.2.1 The question of intention: "Vox - Locus - Transitus"

When one cross-analyses the texts, the buildings and the archaeological observations, one obtains a large number of hypotheses, all of which with some connection to the voice. From our point of view, separating singing and its symbolic strength from the other modes of vocal production is not relevant for the times concerned.

Experience has led us to classify our field hypotheses into three areas that we have called "Vox", "Locus" and "Transitus":

- "Vox" gathers all the written and archaeological evidences related to the voice about a building.
- "Locus" gathers all the written and archaeological evidences compatible with the idea of acting on the acoustics of the building
- "Transitus" gathers all the written and archeological evidences for an action aiming to elaborate a symbolic link between human singing and divine singing.

Note that these three interpretative areas are not incompatible. One can for example find pots with frequencies tuned to a fourth and positioned in triangles or crosses, which amounts to saying that intention to act on the voice ("Vox") is as probable as intention to act on the symbolic plane ("Transitus"), without really being able to distinguish the two intentions.

4.2.2 Elaboration of a corpus and choice of specific buildings

Our research covers a corpus of more than 50 buildings in which we have systematically collected the positions of the pots, measurements of their resonance frequencies, archaeological data, and textual data if necessary (1,2).

Then we selected three particular buildings, the crypt of the cathedral of Noyon, the "Abbaye des Anges" in Brittany, and the Abbey of Montivilliers in Normandy, which is presented later on.

4.2.3 The question of choice

One of the first results of this methodology is clearly, and contrary to the doubts expressed by some authors in the wake of their disappointing observations, that the insertion of pots does correspond to an acoustic intention in the broad sense.

Once this intention is proven, the second question concerns the choices: as said above, choosing pots to act on a building is a bold assumption. However, statistical analysis of the corpus and the analysis of particular buildings give a framework which we explain in reference (7), the essential characteristics of which are:

- A frequency range of pots between 100Hz and 400 Hz, which confirms previous European studies (11,12,13).
- Identification of groups of pots tuned to frequencies either a fourth or a fifth apart; or distributed over a fifth or an octave, continuously or discontinuously
- Pot groups have a low frequency dispersion of about 5% relative to manual production

- They are most often located high above the floor
- They are more numerous when the churches are large
- In monastic churches, they are more often in the choir, unlike in parish churches, or they are distributed throughout the space.

4.3 Interpretation and surprising results

4.3.1 Overall interpretation

All these results lead to two complementary interpretations that depend on each other.

The first interpretation is that the difficulties linked with the perception of sound in large spaces ("Locus" hypothesis) lead to use the pots in terms of amplifier ("Vox") to fight against reverberation. If this explanation is surprising from a physical point of view, it should be noted that in small spaces, like the crypt of Noyon, this effect has been proved, even if it does not work quite as imagined by the ancients in their writings. Extrapolation to larger buildings, though not convincing in terms of results, is probably due to traditional extrapolation of what is noticed on small buildings.

The second interpretation is that local amplification of the voice through pots ("Vox") represents a mediation between the word and the songs of officiants and monks or nuns, and the divine word ("Transitus"). The power of this belief has probably allowed pots to remain a technique used over a long period of time despite its lack of efficiency in large buildings.

4.3.2 Open questions

While these interpretations are suitable for all buildings, even special cases, there remain outstanding acoustic and archaeological questions.

One of the questions is that, when groups of pots are tuned, they are often tuned at the fourth. This may seem surprising. From the point of view of musical theory since Pythagoras, the fourth is consonant just as the fifth and the octave. But musicologists know that the fourth was progressively abandoned because of its observed inharmonicity. This point should therefore be considered from a musicological point of view.

Another difficulty is the orientation of the pot distribution as a function of frequency. In the majority of buildings, the low frequency pots are mostly located on the left looking at the choir (North side) and high frequency pots mostly on the right (South side). This makes think of an organization of the different voices of the singers around the lectern. This point, like others, is under study.

5. CONCLUSIONS

Archaeoacoustic issues in periods where coexist texts and archaeological evidences pose particular difficulties. A purely experimental approach to the objects or devices of acoustic nature is often in contradiction with texts. But these texts are no recipe books, and rather describe reality from the point of view of their authors.

Caution is therefore advisable. One must be open to all possible explanations even when they shock current scientific conceptions. Interesting is then to see emerge a whole science of acoustic techniques in construction with its beliefs, its failures and its successes

ACKNOWLEDGEMENTS

The authors warmly acknowledge the contribution of Jean-Dominique Polack, David Fiala and Vasco Zara through fruitful scientific exchanges.

REFERENCES

1. Valière, J.-C., Palazzo-Bertholon, B., Polack, J.-D. and Carvalho, P. , "Acoustic Pots in Ancient and Medieval buildings: Literary analysis of ancient texts and comparison with recent observations in French churches", *Acta Acustica united with Acustica* 99 (1), 2013, pp.70-81.
2. Valière, J.-C., Palazzo-Bertholon, B. "Towards a history of architectural acoustics using archaeological evidence: Recent research contributions to understanding the use of acoustic pots in the quest for sound quality in 11th—17th-century churches in France", in "Worship Place" Lavandier C. and Guillebaud C. (Ed.), Routledge, London, 2019.

3. B. Palazzo-Bertholon and J.-C. Valière (Dir.), « Archéologie du Son : les dispositifs de pots acoustiques dans les édifices anciens », Suppl. to Bulletin Monumental 5, SFA, 2012, Paris, (<http://archeoacoustique.labo.univ-poitiers.fr/>)
4. Dupuy E., and Féron C., « Contribution à l'étude diachronique du vocabulaire relatif au son : remarques sur la traduction du livre V du De architectura de Vitruve par Jean Martin (1547) », Romanica Wratislaviensia, (53), Wroclaw University, 2016, pp. 21-40
5. Alberti, L. B. (1485). De re aedificatoria (trans: Rykwert, J., Leach, N. & Tavernor, R). Boston: MIT 1991
6. Leonardo da Vinci. (1515). Manoscritti di Francia, Manoscritto L, folio 0063r. <http://www.leonardodigitale.com>. Accessed 6 june 2019.
7. Polack, J.-D., Valiere J.C., Bertholon B., Carvalho P., " A case of archaeological evidence in favour of acoustical intentions linked with pots in church vaults: Montivilliers Abbey ", 23rd International Congress on Acoustics, 9-13 September 2019 in Aachen, Germany
8. Vitruvius Pollio, Marcus, "De Architectura", Livre V, translated in french and commented by Catherine Saliou, Paris, Les Belles Lettres, 2009.
9. Valiere J.-C., Dupuy E. & C. Féron, « Evolution du mot résonance et des mots de même base à partir du XVe siècle (textes techniques, traduction de Vitruve par Jean Martin) », 13e Congrès Français d'Acoustique joint avec le colloque Vibrations, SHocks and NOise, Le Mans, (France), 2016, pp. 2115-2119. ISBN: 978-3-200-03433-4, <http://www.conforg.fr/cfa2016/cdrom/data/articles/000412.pdf>
10. W. C. Sabine, Collected Papers on Acoustics (New York: Dover Publications, 1964) [first published by Harvard University Press, 1922], 1922.
11. Mijic, M. & Sumarac-Pavlovic, D. "Analysis of contribution of acoustic resonators found in Serbian Orthodox churches". Building Acoustics, 11(3), 2004, 197-212
12. Zakinthinos, T. & Skarlatos, D., "The effect of ceramic vases on the acoustics of old Greek orthodox churches". Applied Acoustics, 68(11-12), 2007, 1307–1322.
13. Desarnaulds, V., Loerincik, Y., & Carvalho A., "Efficiency of 13th century acoustic ceramic pots in two churches". Noise-Con. Portland (USA), 2001, 29-31.