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CONTRIBUTION OF THE KNOWLEDGE OF THE ACOUSTIC POTTERIES IN MEDIEVAL AND MODERN CHURCHES STATISTICAL STUDIES OF ABOUT TWENTY FIVE FRENCH EDIFICES

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Abstract

In the present paper, a statistical study of about twenty five French edifices is presented, in order to answer the question of the acoustical intention of the builders. More than fifty churches have been visited and measured: data were collected as geometrical dimensions of the church, date of foundation, number and localisation of the potteries, resonance frequency of each pottery.

Only half of the buildings were studied because of the lack of data on several of them: for example, potteries were out of reach, broken, or simply disappeared because of a recent restoration. Study shows that the potteries seem to have been chosen in relation with the human voice but also, which is more surprising, with characteristics of the church. Indeed, dependence is observed between the mean resonance frequency of the potteries and the size of the church.

Keywords

Acoustic potteries, architectural acoustics, Helmholtz resonator, resonance frequency

1. Introduction

Within more than one and half century (1830-1990) the problem of acoustic potteries has been mainly addressed by archaeologists. As our knowledge, only R. Floriot [1], in France, achieved an acoustical study, followed by J.-M. Fontaine [2], fifteen years later. These two last decades, the subject knew a renewal of interest especially in Europe [3-7] even through a multidisciplinary approach [8,9]. A large part of these recent studies will be edited very soon (in French), in the special issue of the "*Bulletin Monumental*" next February [10]. Nevertheless all these works, the "mystery" of the acoustic potteries raises numerous problems.

There is no more doubt on the intention of church builders, thanks to the recent discovery of several old texts. This proves that the way to improve acoustics remains obscure, even though some experiments have been conducted *in situ,* giving different results. In the first case, a noticeable amplification occurs [2] and in the second, nothing clearly appears [2,4]. In the third case, an attenuation of the reverberation seems however perceptible [4-5] on reconstitution in a large room or in a church (with many potteries).

Regarding the preceding studies, it seemed not useful to assume a possible acoustic effect (amplification, absorption …), very difficult to prove, but to collect by a simple experimental method, all the data on the potteries and the environment likely to influence acoustics. Thus about fifty of French churches buildings with potteries have been visited. Geometrical measurements of the church were carried out, observations on the nature of walls were achieved and the potteries were studied in order to measure their resonance frequency and to collect their related data (position, size of the neck, visualization with a webcam of the internal volume …). The objective is to statistically analyze the data related to potteries in order to compare with church geometry (volume, height), its history, its localisation, its use (monastic, parish). The results are then compared with present understanding of room acoustics, in order to determine if empirical knowledge could have been the basis of the choice of the potteries.

Section 2 presents the corpus of selected churches as well as the methodology of acoustic measurements. Section 3, the collected data on potteries is compared with church characteristics (volume of the church, height, use of the church, position in the church…). Section 4, resonance frequencies of 197 potteries measured in eleven selected churches have been also analyzed according to the volume of the churches.

2. Corpus and methodology

2.1 Corpus

The corpus is based on census carried out by various French and foreigners authors. Consequently, more than 320 churches were listed in Europe and in the Middle East, from which approximately 200 in France but this list increases every days.

On about fifty buildings visited in France (Poitou-Charentes, Brittany, Loire Country, Aquitaine and Auvergne) only the pots of 25 churches could be measured. Quickly the first missions revealed deficiencies of the archaeological and historical information on the churches. Indeed, if certain churches have been studied others, more modest, were not the subject of architectural studies. The knowledge of the history of the building and its architecture, in relation with the date of insertion of the pots is thus very variable from one case to another. In addition, the objective of these first meas-

urements was to make a survey, among some churches, in order to evaluate the potential and the feasibility of such a research.

The churches visited in the south, the middle and south-west of France date rather from the period lain between XIth and XIIIth century while those of Brittany, which are generally well preserved, belong rather to XVIth century. However, in some of the churches of XIIth, it appears that the potteries were inserted into XIVth or XVth century during restorations. Thus we probably have an over-representation of late churches, in particular owing to the fact that our study includes most of Breton churches.

For certain statistics, we add to the corpus French churches where the potteries were only counted impossible to measure because their height and some churches studied by foreign colleagues [4,8].

2.2 *Methodology*

For each church, we try to obtain:

- The number of visible pots *in situ*,
- The full number of estimated pots
- Their localization in space (the nave, chorus, the transept, in several places).
- Their distribution in space (horizontal line, square, triangle, around bays or according to atypical diagrams).
- The height to which they are positioned
- The heights of the church (walls, vaults…), its surface
- The volume of the church is estimated their previous measurements. The maximum error of our calculation is estimated at approximately 8%, which remains acceptable.
- The type of wood roofs (panelled frame, with boxes) or the type of vaults (stone or wood, in cradle, semicircular arch or broken)
- Type of walls (coated or stone)

When we had access to the neck of the potteries or when some of them had been extracted from masonry, the length and the surface of the collar are measured and the volume estimated.

For each pot, one or more recordings were carried out using a device made up of a carbon fibre pole 10 m height provided with a microphone and a webcam remotely controlled. Thus, it is possible for only one person being held on a bench or small scales to reach a pottery located at almost 12 meters. The microphone is connected to a laptop which has a real-time analyzer, and a spectral analysis makes it possible to validate the good quality of measurements.

Two excitations are used: a repeated slapping (by the hands) and a broad band noise allowing testing the whole range of frequencies. The frequency responses to the acoustic excitations are collected.

2.3 Analyzes results and protocol of selection of the data

In situ, the resonance frequency is estimated in real-time on the frequency response and compared with the frequency calculated from the geometrical data collected on the pots when those were accessible. Visualizations with the webcam make it sometimes possible to observe the state of the highest potteries in order to confirm measurements in particular when they are broken inside.

In laboratory, the data are analyzed more precisely. Often some potteries do not function as Helmholtz resonators because they are cracked or they are filled of refuse.

The surface state of the potteries is difficult to observe with the webcam as well the damping to the resonance. Thus, only the resonance frequency is collected and sometimes the first partial ones.

A preliminary experiment has been carried out to evaluate the uncertainties of a measurement *in situ*. A microphone was positioned inside the pottery, then in the neck, at exit of the neck and finally to 10 cm outside the opening. The experiment shows that by using a ¼ of inch microphone, the measurement error on the frequency estimation does not exceed 3% according to the position of the microphone.

In practice, if the neck is often accessible on the other hand, the volume is difficult to determine. Moreover, for the potteries which appear identical, the thickness of the coating can lengthen the neck and thus modify the frequency of resonance. By making a theoretical calculation on geometrical data and by imagining all the possible sources of errors, the uncertainty of an in situ pottery measurement cannot exceed 10%.

Table 1 – Selected churches with potteries in good working order. F is the mean frequency for each church and F1 and F2 is the mean frequencies if the churches have two types of potteries. The χ^2 test checks the validity of the sample in case of a church with only one type of pottery.

Church	Volume (m3)	Number	F (Hz) (std %)	χ^2	F1 (Hz)	F2 (Hz)	F2/F1	Type
Quinçay	953	8	398 (5%)	0,73				One
Le Trévoux	1172	10	169 (6%)	0,85				One
Trégourez	1439	12	372 (10%)	0,97				One
Ergué Armel	2050	17	437 (10%)	0,87				One
St Blaise (Arles)	2486	15	272 (22%)		220	331	1,50	Two
Quemeneven (Kergoat)	2736	22	135 (26%)		106	171	1,62	Two
Pommiers	3200	16	210 (14%)		196	246	1,26	Two
Le Juch	3419	37	126 (11%)	0,48	122	149	1,23	Unclear
Moisdon la rivière	3699	9	251 (18%)		212	283	1,34	Two
Ploaré	4739	45	171 (14%)		141	184	1,30	Two
Chemillé	5615	6	124 (6%)	0,82				One
Total		**197**	**242**		**166**	**227**	**1,37**	

If the pottery is cracked or if it contains invisible elements inside (nest, straw, mortar, etc) generally the error is quite higher than 10%. Thereafter, this value of 10% will be used either to distinguish 2 groups of potteries or to draw aside potteries probably damaged.

On the 25 churches whose potteries were measured, eleven have a sufficient number of non broken potteries and were selected. In table 1 are catalogued the volume estimated for each church, the number of potteries in good conditions and the average of their resonance frequency. The churches whose dispersion exceeds 10% were initially isolated. Five churches seems to have one type of pottery, this was checked by a test of the χ^2 which is rather high (orange churches on table 1). The other churches have two types of potteries which have a dispersion of less than 10% (not tabulated in table 1). A church remains undetermined (Le Juch), the dispersion is weak but the χ^2 is too small. It seems that there are two types of potteries but rather close in frequency.

3. Summary of previous results

The full analysis of the geometrical data is carried out in the work which will be published soon (in French) [10]. The principal results are listed below.

No dependence was noticed according to the nature of the church or of the monastic or parish use.

The mean number of potteries (broken or not) by church (648 potteries) is about 25 which is exactly the number find out by Floriot in 1964. On the other hand, the number of potteries (N) increases according to volume (V) like $N = \alpha V^{0.6}$ with a R^2 (coefficient of determination) equal to $R^2 \approx 0.5$. This result testifies to the perception of the builders that the effects were cumulative and shows a certain empirical knowledge of acoustic rules.

The height to which the potteries are established is directly proportional to the height of the building. This result removes the assumption of an amplification effect which is very localised. On the other hand, it reinforces the symbolic assumption mentioned in certain texts and also the assumptions according to which the only possible effects are the absorption and the reduction in the reverberation time.

4. Statistical study of the resonance frequency

4.1 Resonance frequency and potteries choice

We focus now on the churches selected in table 1. The majority of the found potteries have a resonance frequency ranging between 100 Hz and 300 Hz, which corresponds to the waveband in which the human voice is strongest. However, the dispersion is very large as shown table 1. A more advanced analysis shows than the mean frequency of the potteries of a church decrease when volume increases with a good statistical correlation (Fig. 1).

The curve is compared with the Schröder frequency estimated starting from two independent studies whose results are comparable [11,12]. It is surprising to observe that the potteries frequency follows the frequency of Schröder in a proportionality of approximately 3. Thus, the potteries seem to have been selected in the frequency range of the diffuse field, where the reverberation is generally strongest.

The results are consistent with the observations by certain authors who reproduced the system of the potteries to large scales [1,4,5]. The potteries would thus be included intentionally to decrease the time of reverberation in low frequency.

The sound source which is mainly the voice in medieval time does not seem to be the only parameter with the choice of the pots. The characteristics of the church and "its sonority" seem also taken into account. This observation shows that the control of the sound in low frequency seems present in the intention of the builders and was probably understood by empirical methods. This device complements usefully what furniture carries out in high frequency, which is better known.

This double constraint (voice and the "sonority" of the church) seems to be confirmed by the presence of two or several types of potteries in numerous churches.

Those they are often tuned like a fourth or a fifth as shown table 1. Both (or several) potteries made it possible to extend the useful frequency band, each pot acting only on a weak range. Moreover, this ratio akin to the recommendations of Vitruvius concerning the *echea*.

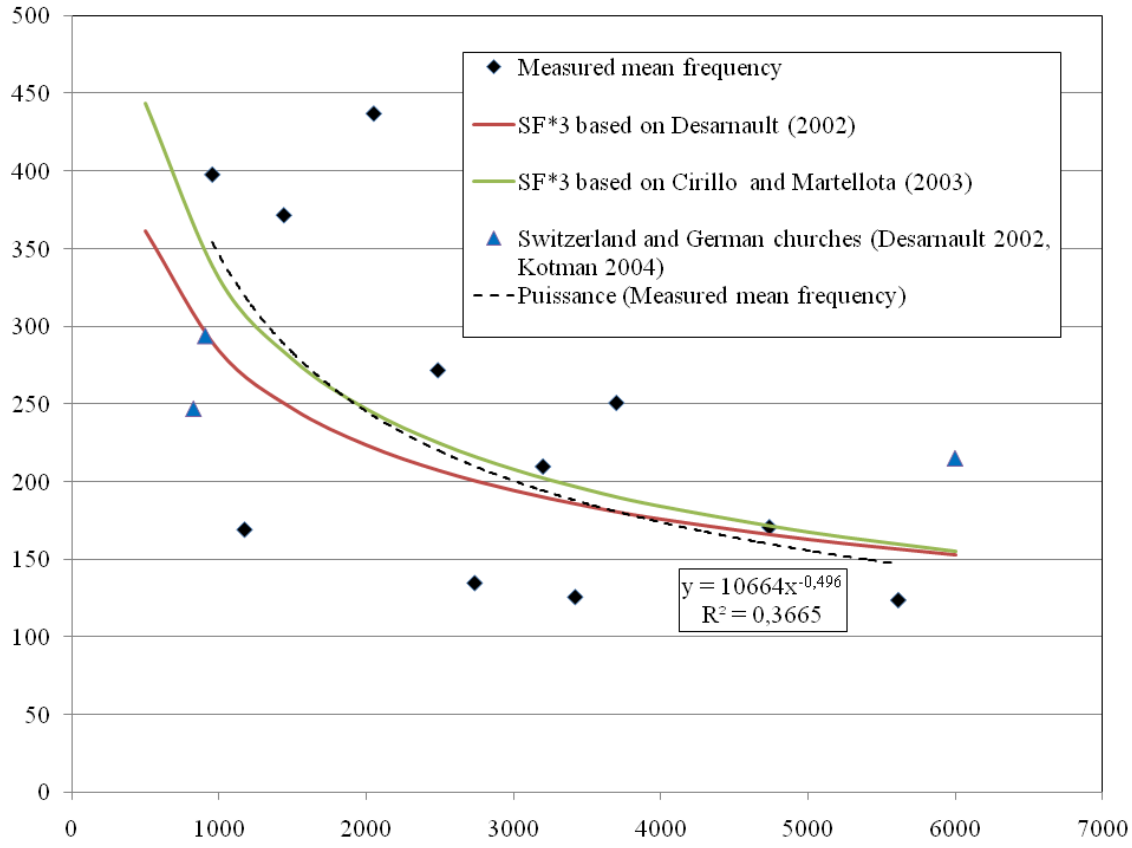

Figure 1 – Mean frequency versus the volume of the church. The dashed line models a law in power. The lines in full feature represent the estimate of 3 times the Schröder frequency calculated as from time of reverberation deduced from previous studies [11,12]

This double consideration, equally in terms of "room acoustics" and voice reinforcement, also appears explicitly in the texts.

5. Conclusion

The results of this study show, following many example of the building archaeology, that the acoustic potteries were inserted according to rules relative to consequent empirical knowledge, at medieval and modern times. Although the effects are often difficult to perceive like often in modern buildings, the tendencies quoted in this contribution cannot come by chance and are often relevant taking into consideration current knowledge.

Thus, the buildings which are preserved until today seem to result from an empirical compromise aiming at the same time, to improve sonority of the church in low frequency and to better perceive the voice.

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