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A case of archaeological evidence in favour of acoustical intentions linked with pots in church vaults: Montivilliers Abbey

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ABSTRACT

Montivilliers Abbey near Le Havre in France presents a case where pots in the vault were obviously employed to act on the acoustics. The archives of the abbey contain a written mention that links pots with acoustics. Originally built in the 13th century, the Romanesque vaulting of the transept crossing was later modified at an unknown date by the addition of pots. In 1648 the vaulting was lowered down, hiding the original pots. A dozen of new pots were inserted in the new vault. The presentation focuses on the acoustics of the abbey and documents the organization of the pots by the builders in the 1st and the 2nd vaults. Room-acoustical measurements of the church were also carried out in order to evaluate its acoustical quality. A major conclusion is that lowering the vault has singled out the church choir where the nuns chanted and which is characterized by reverberation times lower than in the nave. Intermediate reverberation times were measured in the crossing. Reverberation times in octave 125Hz, which includes the resonance frequencies of the pots, are marginally lower in the choir and the transept for source in the nave, which could indicate an effect of the pots.

Keywords:

1. INTRODUCTION

Singing and speaking are fundamental practices in the religious sphere. The texts of the Church fathers and their commentators are explicit about it. The evolution of singing from monophony to polyphony is also well-documented (1). What is less known are the methods and techniques used by builders for modifying spaces to better serve songs and words. Many assumptions exist, but theoretical texts from Antiquity (Aristotle, Vitruvius), to the Modern Era (Mersenne, Kircher), even those of architect (Alberti, Ph. De l'Orme), are discrete on these practices (2).

Acoustic pots, spread throughout Europe from Antiquity to the 18th century, are one of the few identified evidence of efforts to modify sound spaces (2). Rediscovered by scholars in the 19th century but badly understood due to deficient acoustics knowledge by archaeologists, it was revived in recent (3, 4).

From some 50 churches throughout France and Europe, rules for pot implantation and selection according to resonance frequencies have been determined by acoustic measurements. More than 1000 pots have been analyzed, and lead to the determination of trends in space according to resonance frequencies and liturgical uses (5). More recently, effort has focused on particularly significant buildings such as the Abbey Church of Montivilliers.

2. HISTORICAL ASPECTS

Montivilliers has several unique features. The project aims at better understanding the historical sequencing of the building modifications and their reasons.

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2.1 Historical sequence

The plan of the Church of Montvilliers (Figure 1) shows the separation between the monastic Church of Notre-Dame and the parish church of Saint-Sauveur. According to the sources, (3) the nuns were mainly located in the transept crossing, the very place where modifications related to the acoustics were carried out. Figure 2 sums up the available information.

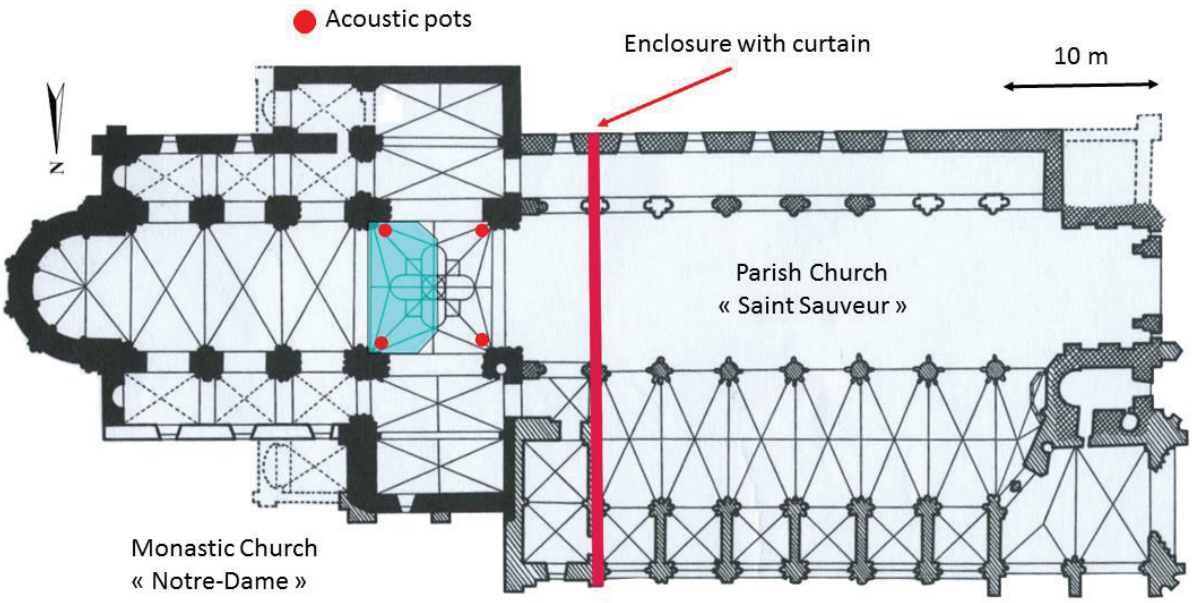


Figure 1: plan of the Church of Montivilliers with the Abbey part (Notre-Dame) and the parish part (Saint-Sauveur), probably separated by a gate.

The Abbey was consecrated in 1141 and the Romanesque vaulting was realized in 1251, probably without pots. Between this date and 1648, pots were added to the vaulting as shown in Figure 3, at an unknown date. This was probably at the time of the apogee of the Abbey as a result of awareness of discomfort due to reverberation. The ceremonial of 1626 is quite explicit, as shown in Figure 4. It recommends that the nuns leave "some small space (...) at the end of the verse before starting the other." Likewise in the responses from one choir to another, "one must not take over immediately: but wait for them to be finished, & the other choir will take over with what it must say..." The nuns were separated into two choirs, with the indication that "all the above inclinations must rotate from choir to choir".

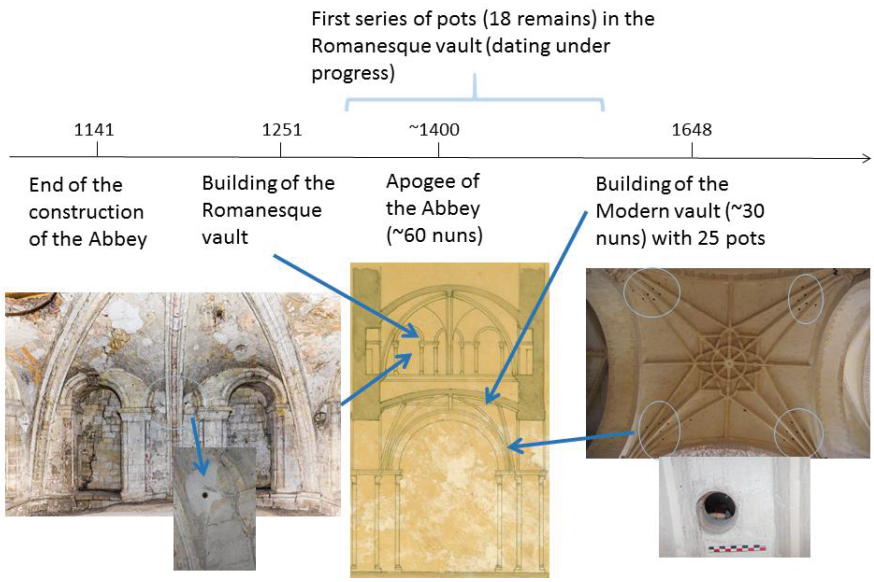


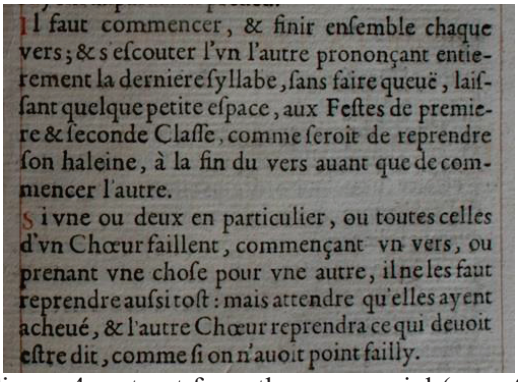
Figure 2: historical sequence of acoustics-related interventions.

2.2 Text mentions in “ceremonials” and “daily registers”

The 1626 ceremonial traces the experience and practice of the years or even centuries before. Polyphony further complicates the perception of voices and of overall harmony, but we do not known if it was in use at Montivilliers. In any case, this type of mention is not common in ceremonials. But it can be set in relation with the description of very reverberant places ("circumsonens") by the Roman architect Vitruvius, described as

> "those where, by the fact that [the voice] spins around, only producing reduced effects and making the words ring without their end terminations, it dies out leaving their meaning uncertain"

Figure 3: pot number 14 in Romanesque vaulting.



Il faut commencer, & finir enſemble chaque vers; & s'eſcouter l'vn l'autre prononçant entierement la derniere ſyllabe, ſans faire queuë, laiſſant quelque petite eſpace, aux Feſtes de premiere & ſeconde Claſſe, comme ſeroit de reprendre ſon haleine, à la fin du vers auant que de commencer l'autre.

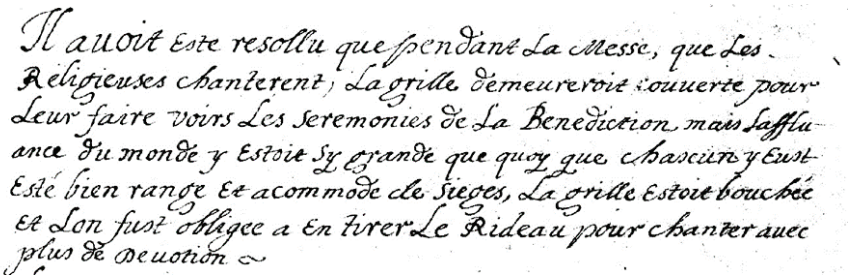
Si vne ou deux en particulier, ou toutes celles d'vn Chœur faillent, commençant vn vers, ou prenant vne choſe pour vne autre, il ne les faut reprendre auſsi toſt: mais attendre qu'elles ayent acheué, & l'autre Chœur reprendra ce qui deuoit eſtre dit, comme ſi on n'auoit point failly.

Figure 4: extract from the ceremonial (page 9)

In his 1787 "dictionary of music", Meude-Monas recommends to the chapel masters to play only slow music in large spaces:

> "Chapel masters [...] do not pay enough attention to the space the sound has to cross, and consequently to the size of the space. They should know that lively pieces executed in a vast and sonorous place, produce only confusing noise, not a clear and detailed execution. It is therefore necessary, in a large space, to only sing pieces of an easy, noble and posing character.”

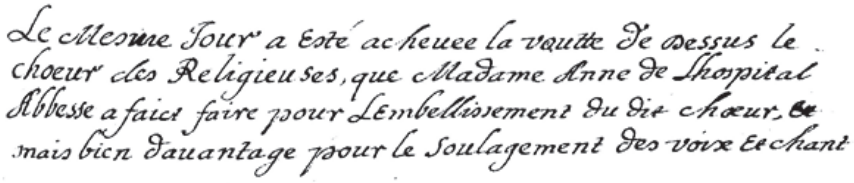
The sound question is also present at ceremonies hosting large audiences. According to the daily register, on 30 November 1643, the nuns were visibly embarrassed by the hubbub and "one was obliged to draw the curtain to sing with more devotion" (Figure 5).



Il auoit este resollu que pendant la Messe, que les Religieuses chanterent, la grille demeureroit couuerte pour leur faire voirs les seremonies de la Benediction mais laffluance du monde y estoit sy grande que quoy que chancun y eust esté bien range et acommode de sieges, la grille estoit bouchée et lon fust obligee a en tirer le Rideau pour chanter auec plus de deuotion.

Figure 5: extract from the daily register for 30 November 1643

The curtain seems to satisfy two functions: refocusing the nuns on their prayers by limiting the space (visual aspect); damping space a little (auditory aspect). This interpretation could seem arbitrary if it did not appear 5 years earlier in the daily register on the day where the vaulting was delivered (29 November 1648, Figure 6), where it is written that the embellishment of the choir is above all made "for the relief of voices and singing"



Le Mesme Jour a esté acheuee la voutte de dessus le choeur des Religieuses, que Madame Anne de Lhopital Abbesse a faict faire pour lembellissement du dit chœur, et mais bien dauantage pour le soulagement des voix et chant

Figure 6: extract from the daily register for 29 November 1648 (file 349)

In the 5 years between these two notes, there is no mention of building works in the choir itself,

only in the refectory and the dormitory in 1647: they are adjacent to the south transept. The register very rarely mentions building decisions nor the discomfort they cause, but only their reception. On delivery, the nuns seemed reassured because the Abbess had them sing the Te-Deum in the presence of the workers "to have preserved them during this very risky work", a sign that it did not take place without disturbance for the community.

Though difficult to prove an intention to act on the acoustics when the pots were inserted in the Romanesque vaulting, it seems that lowering the vaulting in 1648 was undertaken to act on the sonority of the space, the space was not very comfortable acoustically for the choir of the nuns.

3. ANALYSES OF THE POT SYSTEMS

What distinguishes Montivilliers is not several distinct series of acoustic pots nor the addition of pottery on pre-existing vaulting, but that these successive devices concerned the same part of the Church: the crossing of the transept, traditionally reserved for singing. However, in spite of the texts evoking the acoustics difficulties encountered and the associated site works, no mention of pots has been found until now in the texts of Montivilliers.

A comprehensive international study of acoustic pots has led to four characteristics (5):

Point1. Pots are chosen in relation to their resonance frequency, mostly in the range of the singing or spoken voice.

Point 2. This choice is organized:

- the set of pots is homogeneous in frequency (unimodal type)
- two groups of pots are chosen and tuned to the fourth or the fifth (bimodal type)
- continuity of frequencies over an octave approx. (continuously distributed type)
- discrete distribution most often over an octave (discontinuously distributed type)

Point 3. Pots are organized in space according to:

- a high/low principle
- a north/south principle
- both sometimes

Point 4. Pots are positioned:

- above the monks/nuns or in the liturgical choir
- in the entire space

Characteristic 4 (point 4) is evident in Montivilliers, as in many monastic buildings. But in Montivilliers with its two liturgical spaces, only the monastic space is concerned. The other three characteristics differ for the Romanesque and the modern vaulting. The points 1, 2 and 3 is analyzed in the following.

3.1 Romanesque vaulting

There are originally 18 acoustic potteries. 16 were installed at the corners and 2 on the piers supporting the arches. Niches were practiced in the masonry for inserting the pots (figure 3). They were sealed with mortar shaped in form of reflector around the opening of the pots. Today, 17 pots are in place, and one is kept in a Museum in Rouen. We have carried out acoustic measurements of the pots as well as non-invasive acoustic and archaeological observations. Some pots are cracked and several types of pots have been used: globular belly, conical belly, round belly pot without collar.

The analysis of the measurements follows the preceding classification.

3.1.1 Choice of pots (Point 1)

The number 18 is not a surprise, but symmetrical distribution would lead to 24. There is no trace on the walls that there have been so many. Only 10 pots give reliable frequency measurements, and 17 reliable geometric measurements.

Figure 7-a and 7-b respectively present the frequency distribution of the 10 non-broken pots and the depth distribution of 17 geometrically measurable pots. Pots are numbered clockwise from 1 to 18 starting from the northwest pillar. The frequencies are rather evenly distributed from 130Hz to 252Hz or approximately from C2 (130 Hz) to C3 (260 Hz), i.e. one octave. These frequencies are quite characteristic of what is observed in France, with an average at Montivilliers of 177 Hz and a dispersion of 23%. For a monastery of nuns, the frequencies correspond to the range of female spoken voices, but not to singing voices: it is globally too low, corresponding to the lower range of current Alto voices.

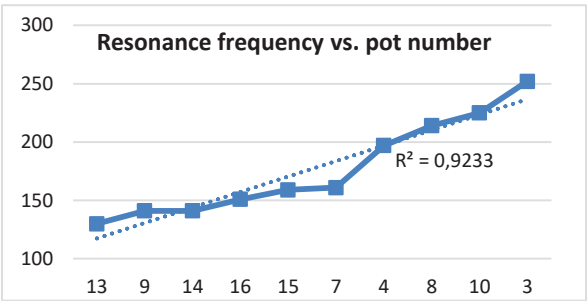


Figure 7-a : frequency distribution of non-broken pots

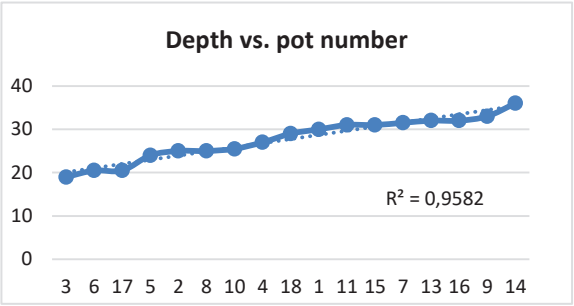


Figure 7-b: depth distribution of 17 pots

3.1.2 Frequency organization (point 2)

Grouping does not resist analysis. In the classification, it corresponds to an extended frequency distribution. As shown in Figure 7-a, linear regression gives a very high correlation coefficient. The distribution of the lengths of the pots is even more linear and cannot be due to chance.

Correlation between frequency and length for the 10 measurable pots is -0.95, which is statistically significant. We expect a minus sign as frequency is inversely proportional to the square root of the volume, which increases with length. Correlations between resonance frequency and neck length, resp. neck diameter, are as low as -0.2 and 0.25. This indicates that choice is made on the volume, and that the shape of the pots must be relatively homogeneous, conical or oblong, as observed by the ceramologist. Indeed, if parts of the pots were globular, the correlation with the length would not be as strong.

Pots were thus chosen in quasi-linear fashion covering an octave, a "continuous distribution" in our terminology. But this choice is difficult to explain, as it does not correspond to the range of the singing voice.

3.1.3 Spatial organization (point 3)

Frequencies are on average higher on the north wall and lower on the south wall, inversely to the general trend.

3.2 Modern vaulting

Acoustic measurements were carried out with a nacelle. There are 25 pots, 6 on each pillar at the bottom of the vaulting, except the North-West one with 7. The rule of 6-grouping is almost respected. Cochet (9) mentions that a pot was taken down in his time, but direct observation does not confirm it. Unlike the pots of the Romanesque vaulting, all pots were installed during the construction of the new vaulting, which is confirmed by the fact that some pots are partially masked by the ribs.

After cleaning all pots but one that was not accessible, resonance frequencies and geometrical data were systematically collected. What strikes is the great homogeneity of pot shapes: long and straight necks, sometimes flared, sometimes with a flat bottom. It could be a model of pot for culinary use (carafe). The mean resonance frequency is 117 Hz with 7.5% dispersion, and the mean height of the pots 33 cm with 6.8% dispersion (Figure 8). Necks vary most with average external diameter 79.4mm (7.7% dispersion), length 143mm (nearly 13% dispersion) and average narrowing 62.5mm (12%dispersion).

3.2.1 Choice of pots (point 1)

The configuration differs from the Romanesque Vaulting. The two difference are: a lower mean frequency of 117 Hz, corresponding to the spoken male voice, certainly not to a female voice; a narrow range of frequencies (104 – 136 Hz, about G#1-C#2), that is, 7.5% variation, just slightly larger than manufacturing randomness for pots which is in the order of 5%.

3.2.2 Frequency organization (point 2)

The 3 pots standing out of the main group have an average frequency of 133.7Hz (2.63% dispersion) and the main group 114.4 Hz (5.45% variation) and 133, 67Hz (2.63%), slightly more than one tone, which is hardly interpretable in terms of musical theory and relevance.

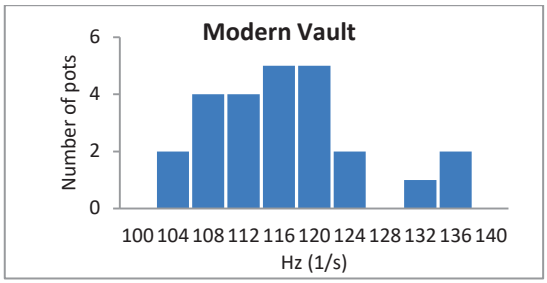


Figure 8: histogram of pots per resonance frequency

3.1.3 Spatial organization (point 3)

No clear trend could be singled out.

4. ACOUSTIC MEASUREMENTS

4.1 Hypotheses to check

The texts mentioned that the acoustics of the Church could be cumbersome for the voices, and corrective actions were clearly undertaken throughout the centuries. Acoustic measurements were planned to verify whether the pots have an effect in the 125Hz octave band, as the 17th century pots resonate in this band.

4.2 Measurement method

The acoustic measurements were carried out by the LAM team of the Institut D'Alembert at Sorbonne University, using an omnidirectional source "outline GSR", a "Tannoy VS10" subwoofer , and an "Ambisonics® SoundField ST250" microphone. The measurement software is the "Aurora" plug-in (6-8) installed on "Adobe Audition", which drives a "motu traveller" sound card. The protocol consists in transmitting in the church a sine-sweep of 20 to 20kHz and 10s duration, and to record the microphone signals simultaneously on the computer.

There were 3 source positions and the 10 microphone positions. The source positions are imposed by the configuration of the Church, with its well-delimited choir and nave volumes, and the transition through the transept crossing. The same applies to microphone positions, which are distributed in each volume.

4.3 Results

Only the omnidirectional responses (output W of the Ambisonics ST250 microphone) and the lateral responses (output Y, figure-of-8 response) were analysed.

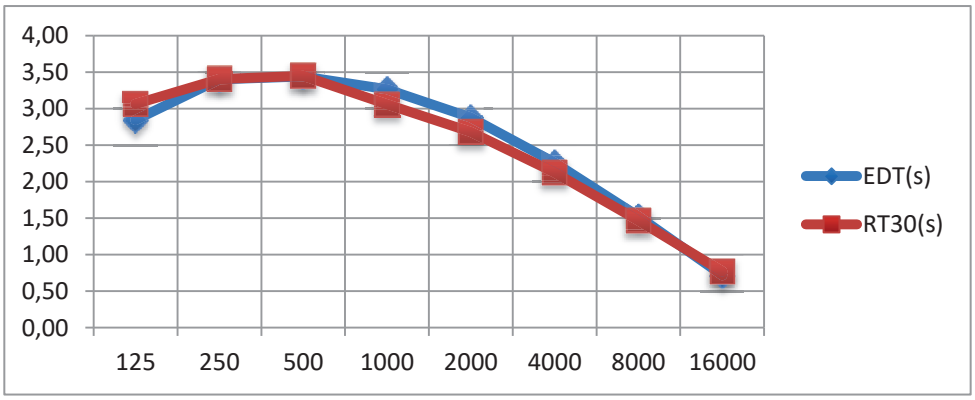


Figure 9: Mean reverberation times (RT) and EDT in Montivilliers.

Figure 9 shows the mean reverberation times (RT) in Montivilliers. In fact, they vary slightly depending on the source position

RTs at Montivilliers are surprisingly short for a 14000m^3 church: around 3 seconds at mean frequency, which is rather good for intelligibility. But the critical distance is only 20 m, and speech will not be really intelligible beyond that distance. Sounds emitted in the choir will hardly reach the

nave, justifying the installation of the choir of the nuns at the transept crossing.

Detailed analysis of the RT reveals 3 coupled volumes: the choir, the transept with its crossing, and the nave and its aisle. Indeed, RTs are the same throughout the church for the source in the nave But RTs increase for the source in the choir when the receiver moves from the choir to the transept and to the nave. Lowering the vaulting of the transept crossing certainly improved the acoustics, but only that of the choir by reducing and confining its volume. For the other parts of the church, it has probably not changed much.

The average levels in the nave are significantly higher for a source placed in the transept crossing than in the choir, and the inverse for the average level in the choir. This corroborates independent coupled volumes, and the assumption that lowering the vaulting of the crossing has improved the acoustics of the choir, but only in the choir.

As for an effect of acoustic pots on reverberation, it is not visible since there are virtually no RT differences between the transept crossing and transept, the and that RTs are significantly lower in the choir.

5. SYNTHESIS OF RESULTS AND PERSPECTIVES

The Abbey of Montivilliers is a very special case where during 4 centuries it is possible to identify building works related to acoustical purposes.

Local texts from the 17th century are particularly explicit regarding both the discomfort felt by the nuns when praying and the building works undertaken to relieve their voices. The building sequence long, with a first lowering of the vaulting at the crossing, the insertion of pots in the Romanesque vaulting, the use of a curtain to separate the parish part of the church form the monastic part, and a further lowering of the vaulting with new insertion of pots.

In this paper, we have presented two superposed systems of post. In the first system, the pot resonance frequencies are regularly spread in frequency on an octave in the range of a female spoken voice, but also in the very energetic 250Hz band. The second system of pot is much more homogeneous with respect to sizes and frequencies, all of them in the 125 Hz octave band which is difficult to relate to the voice. The question therefore arises whether in the 17th century knowledge concerning pot selection had been lost or whether this frequency range was a deliberate choice whereas pots are tuned on voices in the majority of buildings in France. From a point of view of Architectural Acoustics, current knowledge justifies this choice; but there is no evidence that the builders of that time have had this knowledge and practice.

Measurements were carried out to find out whether the current church has particularly difficult acoustics. However, the pots of the 17th century vaulting were not cleaned prior to the measurements, and the curtain does not hang any longer. Measurements reveal a rather low TR (2 to 3 sec.) for a church of this size. The wooden vaulting of the nave certainly plays an important role in absorption, but no evidence supports it. Secondly, TRs vary significantly with source and receiver positions, indicating that the church consists of a series of coupled volumes (nave, choir, transept). Most significantly, the transept crossing with its lowered vaulting due to the 17th century's modification by the nuns presents a lower TR. But no definite effect of the pots was observed in the 125Hz band.

ACKNOWLEDGEMENTS

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