Towards a history of architectural acoustics using archaeological evidences

how recent works on acoustic pot implementations enlighten the quest of sound quality in churches from 11th to the 17th century.

J.-Ch. Valière

Synthesis developed from the results of the archaeo-acoustic team co-directed with B. Bertholon-Palazzo
Summary

• State of the art
• Current interpretations and discrepancy with historical texts
• Analysis of the collection of multidisciplinary data on a large scale
• Summary of evidences as a conclusion


Acoustic Pots and Symbolism

Cross arrangement (frequently)
Triangle arrangement (Holy trinity) (very frequently)
here some more complex arrangements

Church of Obenwinterthur (Suisse)

Pots at the angels trumpet horn
Symbolism of the voice of the angels with regards to the choir

Saint-Séverin of Köln

Insertion of pots in pictures (stars)
Relationship between music and cosmology

Saint-Jean-Baptiste of Baindt (Germany)

Published by Vachez en 1840, Cochet (1862 et 1864) and Floriot in 1964.

- Pots of domestic use
- From the region of the church
- Sometimes, when the frequency is not satisfactory another hole has been perforated.


Pots extracted from the vault of the Tourtoirac chapel (Dordogne) – Cl. A. Bertholon

Pots from St-Martin d'Angers (Maine-et-Loire) Cl. D. Prigent

Pot extracted from the vault of the church of Pommiers-en-Forez (42), cl. J.-C. Valière
• Technic over a large part of Europa and near-east
• France: about 200
• Europa + near-east: about 350
• But new records often occur

XX\textsuperscript{th} century interpretations

• Researchers try to find absorption effects
  – The effect is difficult to prove, it needs much more pots
• Relationship with voice and singing
• Could have some relationship with the problem of vaults and/or “reverberation” of church

Contradiction with texts of scholars and builders

• The concept of \textbf{absorption isn't known} (as far as we know)
  – Notion of “\textbf{energy conservation}” also not known
• On the other hand the notion of \textbf{amplification of pots is known} from the antiquity (Aristotle) and it is commented in medieval times by Saint Thomas d’Aquinas

« bodies which are hollow owing to reflection repeat the original impact over and over again, the body originally set in movement being unable to escape from the concavity. », Aristotle, \textit{On the soul}, trans. J.A Smith, Online Library, MIT.

Baskévitch, 2008.
qu’il y fesoit **mille chanter** et que il y **resonneroit** plus fort

Temple protestant de Lutry (Lac Léman-Suisse), mention datée de 1587, où l’on monta des ponts, afin que le maçon Jacques Bodmer puisse «fayre des pertuis ès vottes du templ, afin que la parolle de Dieu qui y est annoncée soit tant plus **facilement entendue** ».

(from Desarnaulds 2002)

Extrait des comptes du chapitre de Saint-Denis-de-Vergy en Côte d’Or, datés de 1616. «Payé 24 sols au tupinier de Belon pour trois douzaines de petits pots pour mettre dans la muraille du chœur; propres à faire **raisonner** la voix.»

Texte de 1666, émanant des comptes de fabrique de l’église Saint-Idunet de Trégourez dans le Finistère. La fabrique commande à Hervé Lecan, d’Ergué «dix pots à mettre dans les murs de l’église pour **faire écho** » et elle paye la somme de dix livres pour ce travail.

«Add to this, that the Voice of the Pontiff, when he preached, might be more distinctly heard in a Basilique ceiled with a **Timber [wood]**, than in a Temple with **vaulted Roof** » (Alberti, **1435**, first english translation 1755 de James Leoni from the Italian Translation of Cosimo Bartoli 1505, )

**Abbey chronicle**

Chronicle of the «Célestins de Metz» (**1432**)

(Metz, Bibl. mun., ms. 833, fol. 133 et 134)

**Texts from masons or potters**

**Texts from scholars**

E. Dupuy, C. Féron, Le vocabulaire relatif au son dans les traductions françaises, Romanica Wratislaviensia,E., to be published

**Resonate, to sing better, better heard, doing echo, problem with vaults**
Then, it appears that amplification (in a large sense) of the voice seems to be a target for builders.

The questions are:
- What they would like to do exactly
- How they wanted to achieve this system
- What were their assumptions and their empirical knowledge

- Measurements and data:
  - Resonance of all the pots in the church.
  - Position of the pots
  - Churches sizes (volume, high ...)
- Archaeological information
  - Dating of churches, renovation, pots ...
  - Church destination (parish, monastery, order ...)
- Writings
  - Chronicle, account, liturgical books
  - Studies of the buildings

- 40 visited churches
- 850 measured pots
- 450 validated measures (pots accessible and not broken ...)

The direction of research
Adaptation to the voice

The mean pots frequency by church is low [100 Hz – 500 Hz]
- Where the energy of speech is highest
- Frequencies close of the voice pitch [100 - 200]
- In 15th, 16th polyphonic music (correspond to Bass-Baritone)
- Tendency reinforce for monasteries (more regular)

Frequency area involved by the pot’s frequencies

Average spectrum of the speaking voice

Mean frequency by churches

Parish churches

Monasteries
### Adaptation to the voice

<table>
<thead>
<tr>
<th>Churches</th>
<th>F1 (Hz)</th>
<th>F2 (Hz)</th>
<th>Ratio (F1/F2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ploaré (Britany)</td>
<td>141</td>
<td>184</td>
<td>1.3 (Fourth-)</td>
</tr>
<tr>
<td>Chemillé (Loire region)</td>
<td>96</td>
<td>116</td>
<td>1.2</td>
</tr>
<tr>
<td>Moisdon (Loire region)</td>
<td>212</td>
<td>283</td>
<td>1.33 (Fourth)</td>
</tr>
<tr>
<td>Saint-Blaise (Provence)</td>
<td>220</td>
<td>331</td>
<td>1.5 (Fifth)</td>
</tr>
<tr>
<td>Montivilliers (Normandy)</td>
<td>143</td>
<td>199</td>
<td>1.39 (Fourth+)</td>
</tr>
<tr>
<td>Montivilliers (vault XIIe)</td>
<td>143</td>
<td>199</td>
<td>1.39 (Fourth+)</td>
</tr>
<tr>
<td>Noyon (Picardy)</td>
<td>108</td>
<td>141</td>
<td>1.3 (Fourth-)</td>
</tr>
</tbody>
</table>

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Two sizes of pots of the same shape, Pommiers en Forez (Auvergne) (Ch Delomier, in « archéologie du son », 2012) Tune in fourth (estimation)
Dependence to the volume

- The number of pots increases with volume
- The tendency is the same for the Monastic churches but the evolution is more regular (less dispersion)
- 2 kind of pots are more present in large churches

<table>
<thead>
<tr>
<th>Churches</th>
<th>One kind of pot</th>
<th>Two kind of pots</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2500 m³</td>
<td>7</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>&gt; 2500 m³</td>
<td>3</td>
<td>8</td>
<td>11</td>
</tr>
</tbody>
</table>

The idea to act on the acoustic field is confirmed by these results

Conversely to first results on 25 churches, the dependence between volume and mean frequency is not confirmed with 40
Some remarks on distribution of pots

- In a large part of the studied churches, the pots are spread in the whole church (2/3)
  - Nevertheless with a large majority for parish churches

<table>
<thead>
<tr>
<th>Churches</th>
<th>Choir transept and first bays of the nave (liturgical choir)</th>
<th>Nave and spread in the whole church</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monastic</td>
<td>7 (41%)</td>
<td>10 (59%)</td>
<td>17</td>
</tr>
<tr>
<td>Parish</td>
<td>4 (22%)</td>
<td>14 (78%)</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>11 (31%)</td>
<td>24 (69%)</td>
<td>35</td>
</tr>
</tbody>
</table>

Some differences occur in monastic church in comparison of parish ones

- The use of two pots is frequent everywhere but is little bit more in monastic churches

<table>
<thead>
<tr>
<th>Churches</th>
<th>One frequency pots</th>
<th>Two frequency pots or more</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monastic</td>
<td>4</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Parish</td>
<td>6</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>

Pot position under the stalls, Pommiers en Forez (Ch Delomier, in archeology du son, 2012)
Some remarks on distribution of pots

- In small churches with one frequency pot (<2500 m³), mainly parish, the pots are divided into **two lines** on the vaults or on the walls.

- When the church have two frequencies' pots, the **high frequencies** are upper (in position), the **low frequencies** are below (5 churches on 8).

- In Noyon (XVI\textsuperscript{th}), low frequency pots are mainly in North and West and high frequency in South: link with polyphonic music?
Summary of evidences as a conclusion

- **Voice and song are the main target of the pots**
  - The choice of the pot frequencies are close to the *pitch* and first *harmonics* of the voice
  - This feature is more pronounced for monastery churches
  - In many churches pots are tuned in *fourth* or *fifth*
  - Symbolism are always linked to music and sound

- **The idea of control the sound is present**
  - The tradition from the antiquity (Aristotle, Stoics, Vitruvius …) still continues: effect of « hollow body »
  - The idea of *improvement of sound and/or amplification* (resonance in the old meaning) is in the heart of the problem
  - The number of pots increases with the volume of the churches
  - The use of “two frequency pots” are mainly use in larger churches (action on a larger frequency band)

- **Position and repartition of pots**
  - The pots in small churches with only one frequency (usually parish) are often arranged in two lines into the vaults or in the upper part of the walls.
  - The spatial repartition follows some rules in each church (for instance, high/low, of north/south) but it is difficult to deduce a general rule

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**Existence of a technical “culture” where the voice and the problem of listening of sound seems to be in the heart of the preoccupation of builders**
Thank you for your attention