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# **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 11<sup>th</sup>—17<sup>th</sup>-century churches in France.**

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## **Introduction**

The history of Western acoustics has yet to be written, let alone the history of acoustic practices. For one thing, current knowledge is based on the great philosophical texts of antiquity, their transmission during the Medieval and Modern periods (respectively, the fifth to fifteenth centuries and the sixteenth to seventeenth), and the works of the first scientists (eighteenth and nineteenth centuries). For another thing, experiments in sound obviously do not leave archaeological traces, and we know of only a few historical objects whose deliberately acoustic functions are certain. Among these objects, acoustic pots are a rare example whose use is confirmed by texts, although the ‘theoretical’ bases underlying their installation still elude our full comprehension. An improved understanding of the intentions underlying the choice of pots and their insertion into religious buildings’ walls and vaults will help us to discern the foundations of acoustic practices of the time.

In this article, we will first present our findings from fifteen years of measurements and observations conducted in some fifty churches in France and adjacent countries (Switzerland Germany). We will compare these results with the major historical texts on the subject and previous studies in France and neighbouring countries. We will then analyse how such pots are distributed in the liturgical space according to the function of the building, focusing particularly on the practice of frequency-tuning the pots, their placement in the building, and their association with decorative paintings related to angelic singing and the harmony of spheres.

## **Prior knowledge**

Scholars and scientists rediscovered the technique of acoustic pots in the nineteenth and twentieth centuries, and were quick to offer interpretations of both their hypothetical function and historical origin. In our earlier publications (Palazzo-Bertholon and Valière 2012, Valiere *et al.* 2013) we commented extensively on most authors’ assertion that the practice spread as a result of the circulation of a text by the Roman architect Vitruvius ([1<sup>st</sup> c. BC] 2009)<sup>1</sup>. Although his writings influenced the spread of pots as a technical concept during the Middle Ages, there is thus far no concrete evidence that medieval pots were directly modelled on Vitruvius’

description. There are indeed examples of pots dating from the first centuries of the Christian era in the Mediterranean basin (Zakinthinos and Skarlatos 2007, Barone 2015), but recent studies show that pots only seem to have emerged in Western Europe (notably in France) at the end of the ninth century (Carolingian period)<sup>2</sup>, with a revival between the fourteenth and sixteenth centuries before their use was gradually abandoned. According to recent studies in Italy (Barone 2015), there is no proven temporal continuity between the Byzantine-influenced Sicilian churches with pots and those in the north of Italy, which may be more influenced by Western European building practices. Similarly, the remaining examples in Serbia are related to construction techniques of the Dalmatian coast (Croatia) influenced by northern Europe, with no association with ancient traditions (Đorđević Z. 2016)<sup>3</sup>. Proving a direct relationship between building practices in south-eastern and north-western Europe that progressively spread across Western Europe may not seem to be the most pertinent approach today, but this line of enquiry is still being actively pursued and could prove the source of new results in years to come.

For the purposes of this article, we will concentrate only on French and European examples that have been studied in the last sixty years (Palazzo-Bertholon and Valière, 2012)<sup>4</sup>. Our recent research, whose early findings have already been published, will serve as the basis for the analysis that we offer here. In sum, we have identified more than 400 buildings in Europe, and in France we have measured over 1000 pots in 41 churches (out of 50 visited). We conducted an archaeological survey of each building and collected any related available documents.

The guiding principle of our research is uncovering the technical knowledge that led contractors, builders, architects, or religious authorities (monks, canons, bishops) to insert pots in buildings. This knowledge was probably rooted in classical texts by Aristotle and Vitruvius that were read and discussed in the Middle Ages and in oral traditions (Anonymous 1432). The first architectural treatises (Alberti 1485) and translations of classical texts (Vitruvius 1547, Alberti 1553) are likely to have fostered the final resurgence of the technique in the Renaissance and Modern times, when the emergence of polyphonic singing was likely another important factor in their revival.

Analysis of these sources and comparison with the data we collected in the studied churches leads us to interpret acoustic pots according to three dimensions that we will refer to using the Latin terms *Vox*, *Locus*, *Transitus*.

The spoken or sung voice (*Vox*) is undeniably the builders' primary focus in pot placement. All studies, historical or scientific, agree on this fact, and there is no lack of evidence. In the first place, the texts are very explicit, as evidenced by one dating from 1432 found in Metz by scholars in the nineteenth century (Anonymous 1432) and others found in Switzerland (Desarnaulds 2002). From an acoustic point of view, the pots' resonance frequencies are always between 100 and 500 Hz (average 209 Hz), and for the most part between 100 and 200 Hz, meaning the lower frequencies of the human speaking voice or the most solemn notes of the singing voice. Pots were likely selected according to their vocal resonance frequency because every text on the subject since antiquity has attempted to explain the amplification of sound as a result of cavities. The explanation given by Saint Thomas Aquinas, picking up on Aristotle (2001 [4th c. BCE]), is very explicit: "Hollow bodies give out sound very well, when struck, because they hold the air in, and, as this air first set in motion cannot at once come out, it disturbs the rest

of the air, and thus by repercussion the impact and the sounding are multiplied” (Aquinas [1268] 1994, p. 141).

Our second line of interpretation suggests that the pots were inserted to have a potential impact on the place (*Locus*). It is first of all important to distinguish between the two dimensions – the acoustic source (the voice, discussed above) and the place – because, given the understanding of acoustics at the time, it is conceivable that the pots were intended to improve perception of the voice, independent of placement. The hypothesis that pots were installed to act on buildings’ acoustics is subject to debate, with solid arguments for and against<sup>5</sup>. One prominent claim in favour came from some twentieth-century acousticians that argued that the pots were an early technique for making what came to be known as a Helmholtz resonator, a low-frequency absorber used to improve the acoustics of small rooms such as recording studios. This is a point of strong contention. Regardless, today we know that the amplifying capacity of pots has been known since Aristotle, as seen in the quotation from Saint Thomas Aquinas. On the other hand, no text mentions the role of an absorber of acoustic energy.

Another point of contention lies in the fact that ancient texts rarely document the sound qualities of specific places, especially with reference to inserted pots (they only mention the resonance of the voice). In more recent analyses, reverberation (wrongly referred to as ‘resonance’) is often seen as beneficial to singing, rather than an impediment. This perspective is probably greatly influenced by recent enthusiasm for plain-song and the practice of religious singing outside of the liturgical sphere or by specialized monastic chorales (such as Ligugé or Solesme in France).

References in classical and medieval literature nevertheless point to a search for improving the sound quality of places. Vitruvius, for example, classifies places into four categories according to their sonority: resonant (with echoes), dissonant (damping), consonant (amplifying the sound) and circumsonant (reverberant). He takes an especially negative view of the latter type, saying that circumsonant places prevent a good understanding of speech (Valière et al. 2013). Later, in the period when pots were installed in many churches in Europe, the Italian architect Alberti (2004) indicated in his treatise that wooden ceilings make it easier to hear the voice of the priest than the stone vaults of a church. Understanding speech in voluminous (and thus highly reverberant) places was a widespread problem that many tried to address, but the question remains as to whether pots can be understood as being such an attempt. No text sheds any light on this point, and it is reasonable to wonder about the builders’ intent.

Our measurements produced some particularly compelling elements for consideration. The most important point is that the number of pots increases overall with the size of the building. It is also interesting to note that sometimes two groups of pots with two different central frequencies were chosen. These frequencies are often separated by a fourth or fifth interval, which is consistent with medieval and renaissance musical theories. The reason for using two (or more) tuned pot frequencies is subject to speculation. One explanation is the considerable influence of Vitruvius in the Middle Ages, who claimed that the acoustic resonators in Greek theatres (called *echea*) were tuned by fourth, fifth, octave, and double octave. The development of polyphonic singing during these periods could be a second explanation. If we apply the medieval conception of acoustics, it is plausible that the pots were inserted to amplify the voice, and that each group of

pots was to stand for a group of voices. Obviously, as we indicated previously, this would be a misunderstanding of the real function of such resonators.

Nevertheless, our surveys show that this frequency-related technique is predominantly present in the larger churches of our sample, which can be interpreted as the pursuit of a more dramatic impact in larger buildings. In addition, a text on the Abbey of Montvilliers in Normandy indicates that the vault was lowered to ‘relieve the voices’ of the nuns<sup>6</sup>. Pots were inserted in this lowered vault, showing that an architectural action was associated with the acoustic intent of the pots.

The last dimension, which we refer to as ‘*Transitus*’, represents the symbolism of pot placement relative to the connection between secular and divine in medieval thought. They are sometimes arranged in the form of a cross or a triangle manifesting patterns of Christian symbolism, as seen in the church of Oberwinterthur in Switzerland (Palazzo-Bertholon, 2012).

Moreover, acoustic pots are iconographically associated with cosmic representations of the celestial vault: the stars and planets painted in Asbeck and Baidt churches (Germany) are scattered with acoustic pots. In the choir of San Severin of Cologne, the trumpets of angels painted above the stalls have acoustic pots inserted in each bell centre. Moreover, it is probably no coincidence that the acoustic pots placed at the horns’ mouths are located above the stalls, since throughout the Middle Ages the voice was a metaphor for the spirit. The Church Fathers, and especially Saint Augustine, established that the relationship between humans and the heavens was built on song. Later, many medieval authors, including Amalarius of Metz (ninth century) or Regino of Prüm (tenth century), emphasized the idea that human music imitates angelic choirs. According to Guillaume Durand, bishop of Mende in the thirteenth century. ‘the two choirs of singers reflect the angels and the spirits of elected men who praise God with a reciprocal and mutual desire to do good’. In his theological view, God is the composer of all music and Christ is the conductor. The Holy Spirit provides the Divine breath that keeps the musical order in the worlds of Heaven and Earth. For Ugolino of Orvieto (1380-1457), ‘all earthly music is a symbol of heavenly harmony’.

In addition, the study of the symbolism of acoustic pots follows a path signalled by one of the great theologians of the twelfth century, Hildegard von Bingen. In a letter to Elisabeth von Schönau, a Benedictine nun with whom she was friendly and corresponded regularly, Hildegard makes a comparison between humans and clay pots, saying that although both are fragile, the resonance of each is nonetheless associated with divine inspiration: “I am a miserable little clay vase. This, I do not say of myself but in thanks to the true light: Man is a vessel which God created for himself and filled with his inspiration in order to accomplish his work”<sup>7</sup>. As composer and author of “The Symphony of the Harmony of Celestial Revelations”, Hildegard probably knew the ancient theories of the harmony of the spheres (Palazzo-Bertholon, 2016).

Blending medieval concepts, the acoustic pot is thus simultaneously an object useful for strengthening the voice in places whose sound quality is deemed unsatisfactory and a medium symbolizing the link between the temporal and the spiritual. With these three lines of general interpretation in mind, we will now consider the relationship between pots and liturgical space.

In order to make the discussion clearer, *Vox* will be used to refer to voice-related interpretations, *Locus* for those related to place, and *Transitus* for those associated with the symbolic.

## **Spacing and arrangement of pots**

### *Variations according to church function*

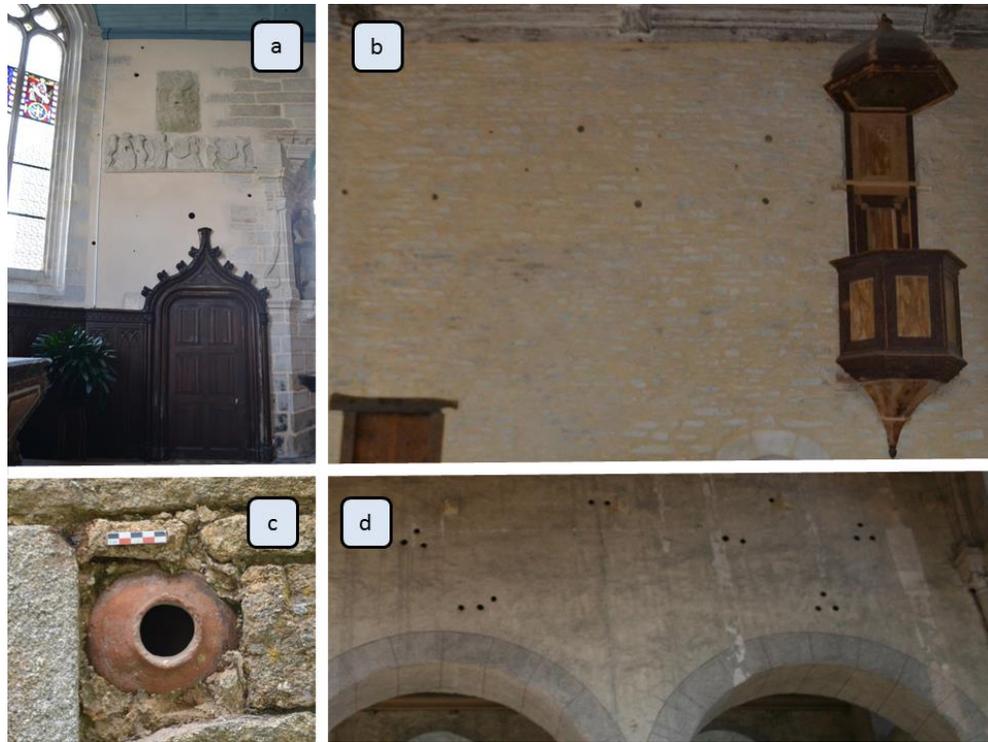
Let us emphasize first of all that acoustic pots are found in both parish and monastic churches. There are, however, statistical differences between location types. For one thing, we found that the trends described in the previous section are stronger in monastic or canonical churches than in parish churches. For example, pots with frequencies in the 100-200 Hz range are statistically more common in monastic churches. Similarly, the technique of associating pots of two frequencies, observed in half of our sample, is more frequent in monastic churches.

Thus far, findings from our current sample indicate that no monastic order predominates in the use of pots, which were found in churches of the Benedictines (Pommiers-en-Forez, Auvergne), Cordeliers (Notre-Dame des Anges, Brittany), and the Cistercians (Abbey de l'Epau, Loire Region). Similarly, churches of women's convents (Montivilliers, Normandy) are as concerned as monasteries for men. As a result, at this stage our analysis will only distinguish between monastic churches and parish churches, because, despite the magnitude of our study, findings do not permit us to identify specific patterns relating to particular monastic orders.

### *Heights*

As a rule, pots are inserted as high as possible in the buildings: preferably at the top of walls, the base of vaults, or in vaults themselves (Floriot, 1964). This observation corresponds perfectly to a *Transitus* interpretation, in the sense that the amplification of sound (in intention, rather than reality) is essentially localized in the upper parts of the building. But it is not incompatible with an intention to act on the place (the *Locus* interpretation), since the overall effect of the pots is related to their number. It is for this reason that twentieth-century acousticians hypothesised that the pots placed in church masonry could be Helmholtz resonators, a more recently discovered acoustic device, and this conviction is strengthened by the fact that the number of pots increases with the volume of the church.

On the other hand, although the pots are tuned to the voice, it would be surprising if they were designed to amplify the audience's perception of the priest's voice like a sounding board, although period texts seem to credit this hypothesis.



*figure 1*

- a) Church of Saint-Pierre-et-Saint-Paul of Melgven (Finistère). The 17 acoustic pots are inserted in the sixteenth-century walls of the choir, above the woodwork and close to the priest.
- b) Ancient collegiate church of Kersaint (Landunvez, Finistère), dating from the fifteenth century. The acoustic pots are inserted in three superimposed lines, here under the pulpit. Other pots are arranged in front of the pulpit, along the nave, and in the northern chapel.
- c) The ancient abbey church of Notre-Dame des Anges (Landéda, Finistère), dating from the beginning of the sixteenth century. Detail of an implantation: the acoustic pots are inserted in the granite facing.
- d) Abbey church of Saint-Chef-en-Dauphiné (Isère), dating from the twelfth century, consisting of acoustic pots arranged in groups of two, three, or four in a triangular or square arrangement. Pots are located in the walls of the first bays of the nave (liturgical space).

*Positioning with reference to the liturgical space*

The placement of pots relative to the liturgical floor plan presents some interesting characteristics. We identified two distinct groups, the first (A) concerning churches whose pots are installed in the liturgical space (including the choir, the transept and the first bay of the nave), and the second (B) comprising churches in which the pots are dispersed throughout the building, especially in the nave.

Although pots are distributed almost everywhere in most churches (25 of the 36 churches surveyed) (group B), group A has a higher concentration of monastic churches (7/11) than parish churches (4/11). In contrast, group B contains a large majority of parish churches, meaning that they have more widely dispersed pots (15/25) relative to monastic churches (10/25). This situation is compatible with the *Locus* interpretation in the sense that the pots were thought to amplify the voice, so they act on the space where the faithful or monastics assemble.

For monastic churches, in many cases the pots are unsurprisingly located in the liturgical space (group A) (7/11). The most significant examples in France are in Pommiers-en-Forez and Montivilliers, where the pots are located just above the places where monks or nuns would have been positioned. In many monastic churches, they are placed behind the chancel separating monks from the faithful. It is not systematic in monastic churches, however: in Lavaudieu (Auvergne) and in the Abbaye de Mercoire (Auvergne), for example, the pots are distributed along the length of the nave (group B). It is likely that such churches were used exclusively by the congregation.

In the great majority of parish churches, distribution is quite regular: either in two lines in the vaults, or at the top of the walls and along the nave in particular. In addition to the symbolic interpretation already mentioned (*Transitus*), this regular distribution can also be associated with a better distribution of sound throughout the building (*Locus*).

#### *Positioning frequency and tuning of pots*

We have already mentioned the fact that pot frequencies were chosen deliberately and pots were attuned in many churches where two pot frequencies were chosen. But beyond the choice of frequencies, is their distribution in the church space consistent with a rationale of voluntary implantation?

In general, pots are aligned along the walls or in the vault, and each row may consist of pots of a particular frequency. At Saint-Blaise d'Arles, in Provence, the low frequency (220 Hz) is on the upper line, while the high frequency (330 Hz, a fifth higher) is in the lower line, in a relatively counter-intuitive placement. In Pommiers-en-Forez, the pots are arranged roughly along three lines, the low frequency being in the median position. In Ploaré (Brittany), the vast majority of low-frequency pots (141 Hz) are set in the lower line in the nave, while the upper line contains only higher-frequency pots (184 Hz, i.e. the top quartet). Although this is not a general rule, there are other cases where the high frequencies are placed at a height, which can be explained by a link between musical and pot frequency. This characteristic is found in various configurations. In Saint-Martin d'Angers, the low-frequency pots (100 Hz) are set in the lower portion of the church, while the high-frequency pots (150 Hz) are placed in the vaults. In the subterranean chamber of the cathedral of Noyon (also called a "caveau phonocamptique"), the higher frequencies are also mostly placed in the upper part of the walls.

The distribution of pots also follows a logical orientation within churches. Thus, in the Romanesque vault of Montivilliers<sup>8</sup>, the low-frequency pots (143 Hz) are placed to the south and west, while the high-frequency pots (199 Hz) are placed in the north and east walls. In Saint-Victor de Marseille, the low frequencies (143 Hz) are also in the north, and the high frequencies

(199 and 280 Hz) more to the south. A distribution according to the points of the compass is found in the Noyon vault, where the low frequencies are arranged in the north and west walls, while more high frequency pots are placed to the south. During the emergence of polyphonic religious music, it is likely that pot distribution was related to the direction of the singing voices, so the low frequencies were located in a northerly direction, facing the choir. Note, however, that the chapel of Mercoire (seventeenth century) does not follow this rationale. Indeed, the pots are placed at the same level in the vault and tuned in fifth: the low-frequency (181 Hz) pots are located to the south and the east, while the high-frequency (279 Hz) ones are placed to the north and west. But the orientation of the chapel suggests that the altar was in fact located to the north, which would ultimately mean that the distribution of frequencies in the liturgical space fits the same pattern as the other examples.

### *Geometric patterns and association with painted scenes*

In a previous article, Palazzo-Bertholon (2012) associates the geometric organization of pots with Christian symbolism. They are sometimes arranged in the shape of a cross or a triangle, as can be seen in Oberwinterthur, Switzerland, where the pots form a complex pattern on the wall that not only takes the forms of crosses and triangles, but also lines of numbers (7, 10, 11) whose Christian symbolism could be expanded upon. This arrangement, which to our knowledge is unique, is found in the church choir.

Acoustic pots were moreover associated with wall decorations (paintings and stuccoes) in Switzerland and Germany. In the churches of Asbeck and Baidt, pots are at the centres of painted stars representing the celestial vault. In these churches, the stars and heavenly bodies make celestial music ‘too perfect to be perceived by human ears, according to Plato, or too deafening to be understood by men, according to Aristotle and Macrobe’ (Palazzo-Bertholon, 2012).

Elsewhere pots are associated with angelic music. In the churches of Villette and Gelterkinden in Switzerland, the pot-associated murals represent angels. In Oetenbach monastery in Zürich and that of Gelterkinden (Switzerland), the pots are arranged in lines surrounded by a crown of painted points that seem to express the divine sound that escapes. At Saint-Severin in Cologne, two paintings face each other over the stalls in the liturgical space, and four angels blowing horns are depicted at each corner, framing the crowning and ascension of the Virgin Mary. The bell end of each angel's trumpet contains an acoustic pot that opens into the church space.

### **Synthesis and conclusion**

The research presented in this article comes from the largest survey of acoustic pots in Europe, based on the work of previous researchers and including those from neighbouring countries. Archaeological, historical and acoustic data were systematically recorded in nearly fifty churches throughout France, and the included buildings covered a long historical time span, from the eleventh to the seventeenth centuries.

Survey results for France revealed that during the studied period, understandings of acoustics included several elements associated with geometry and music, two disciplines of the

quadrivium. Medieval authors established a constant relationship between architecture and music, following the classical tradition inherited from Vitruvius. Architectural beauty depended on symmetry, eurythmy, and decoration. Symmetry corresponded theoretically and objectively to the musical symphony: all parts of a building should harmonize according to the law of exact proportionality. This definition of 'purely rational and rigid' beauty can also be applied to music that is created on the basis of mathematical and geometrical relationships. Interpretation of these results is a delicate business, as the study of acoustic pots has suffered (and still does) from overly hasty analyses that began with the earliest observations in the nineteenth and early twentieth centuries and continued in the first acoustical approaches in the mid-twentieth century. The interpretation that pots were used as absorbers, in a kind of intuitive medieval pre-science, is not supported by texts on the subject, but neither does it rule out the possibility that builders intended to act on the acoustics of the place.

Prior knowledge and our own research first of all made it possible to confirm that pots were clearly implanted to act on the voice, and the sung voice in particular (*Vox*). We then demonstrated that the pots carried multiple strong spiritual and symbolic messages (*Transitus*) through their spatial arrangement and association with paintings and decoration. Finally, the improvement of the sonority of the place was probably another objective (*Locus*). We focused analysis in this article on the location of the pots within the building, taking other parameters such as height, frequency, orientation, and symbolism into account.

Our research has led to several significant findings. The pots are mostly arranged according to the place's use and function. In many monastic churches, the pots are placed above the officiants or in a horizontal line all along the nave, linking the assembly of the faithful with the liturgical space. The fact that pots are arranged according to frequency suggests a connection between their position (high / low) and the voice (high / low), referring to the usual representation of music (*Vox*), but also to symbolism (*Transitus*). Further study is needed to interpret this arrangement, especially with regard to the musical symbolism in images (Charles-Dominique, 2007). Analysis of the positioning of pots according to compass points reveals that most low-frequency pots are positioned to the north, and high-frequency pots to the south. With the emergence of polyphony, there could be a link between the musical use of the place and the arrangement of singers within the space; this possibility requires further research, based on particular buildings with surviving documentation of musical and liturgical practices. Lastly, the spatial distribution and ornamental arrangement of the pots relative to wall decorations requires further study in order to understand the variants and their symbolism.

To conclude, the three dimensions that we propose for interpreting acoustic pots (*Vox*, *Locus*, *Transitus*) provide a general framework for improving our understanding of what guided builders of the time, whilst avoiding the pitfalls of oversimplification or anachronism. Further research into the musical and scientific knowledge of the concerned periods is essential for accurate and complete interpretation of the data. Our research irrefutably shows that the intention was to act on the voice in a way that is dependent on the form and function of the place, together with the symbolism characteristic of the Medieval and the Renaissance periods.

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## Notes

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<sup>1</sup> Among the chapters of the book edited by Palazzo-Bertholon and Valière (2012), focused mainly on Germany, Italy (around Genoa), Spain, Croatia, Switzerland, and France, is a broad survey of acoustic pots in Europe and an exhaustive bibliography of old and recent publications. For an earlier summary in English, Arns & Crawford (1996) is a good starting point. See also Desarnaulds et al. (2001), Mijic and Sumarac-Pavlovic (2004), Zakinthinos and Skarlatos (2007).

<sup>2</sup> The oldest identified in Western Europe is the Abbey of Meschede (Germany) according to Kottmann (2015).

<sup>3</sup> Zorana Đorđević's article on this specific point is in publication. The original source was published by Djuric (1967).

<sup>4</sup> In our study we also used the published data of Floriot (1964), Fontaine (1979) and Desarnaulds (2002).

<sup>5</sup> See for instance Tallon (2016), for whom a deliberate attempt to 'improve' the sound of the church is anachronistic. Clearly, even if some pots have a limited impact on sound quality in large churches, it does not mean that builders were not trying to improve the building's acoustics. Indeed, there is evidence that this was their intention, but based on Medieval and Renaissance conceptions of acoustics.

<sup>6</sup> Recently discovered in the chronicle of the abbey of Montvilliers uncovered by Pauline Carvalho, who gives a complete description of the abbey (2012).

<sup>7</sup> Ed. L. van Acker, CCCM, 91°, p. 456. In G. Iversen, *Chanter avec les Anges. Poésie dans la messe médiévale, interprétations et commentaires*, Paris, 2001, p. 250.

<sup>8</sup> There are also two sets of pots at Montvilliers: one two-frequency set in the Romanesque vault, which were probably retroactively inserted (probably in the fifteenth or sixteenth century, the dating is in progress), and another set of pots of identical frequency in the seventeenth-century vault.