ACOUSTIC RESONATORS IN SERBIAN ORTHODOX CHURCHES

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ABSTRACT

Research in a number of Serbian medieval churches during their reconstruction or archeological investigation revealed the presence of acoustical resonators. To clarify their function laboratory experiments were organized with several resonators found and removed from some old churches. Resonant curve and reverberation time of the resonators were measured under simulated real conditions (embedded in massive material, plaster around the resonator aperture). The most of tested resonators have resonant frequencies below 100 Hz, i.e. too low for any acoustical effect during the acapela Orthodox service. Reverberation time of the resonators is 0,4-0,9 s, i.e. shorter than reverberation time in churches where the resonators were found.

INTRODUCTION

Function of acoustic resonators is a default topic in room acoustics literature [1,2,3]. In the course of investigation of Serbian medieval churches carried out to date by historians of art, archeologists and representatives of institutes for the protection of cultural heritage, acoustic resonators have been found built into the vaults, walls and floors of some monuments. Some of these churches exist even today in an unchanged form while others stand only as ruins and are the subject of archeological investigation. In some of the preserved churches, still active in the cult, the openings of resonators have been covered by mortar in the course of past reconstruction. For this reason, they were stumbled upon mostly by chance in the course of static sanations and architectural reconstruction. Discoveries of acoustic resonators in Serbian churches have been published in the works of art historians, archeologists and architects dealing with the reconstruction of church buildings [4,5].

With the exception of one recent case where a resonator was discovered in the course of constructional sanation of a church building [6], these discoveries were never accompanied by an appropriate acoustical analysis. That means that nothing was done to determine their possible contribution to the acoustical properties of the churches within which they were found. Therefore, there are only hypotheses regarding the real acoustical effects of the discovered resonators published in the papers of those who made the discoveries, i.e. of professionals outside the field of acoustics. The lack of any acoustical analysis to date leaves open the field for various assumptions and often also for wrong conclusions regarding their actual function in the worship spaces of Serbian Orthodox churches.

Some of the earthenware vessels that have been taken out of the walls of different churches where they were used as acoustical resonators are kept today in museums and collections. That gives the possibility of an objective laboratory analysis of their acoustical properties. Furthermore, this opens the possibility of evaluating the significance of such resonators in the acoustic response of the churches in which they were found.

This paper offers a brief review of discoveries of resonators made to date in Serbian churches based on the published works of authors who made the discoveries. Some examples of ceramic vessels taken out of church walls were subjected to laboratory analysis. Measuring procedures were developed which enable the assessment of basic acoustic parameters: resonant frequency, bandwidth and reverberation time of resonators. Based on this information, conclusions could be made regarding the possible acoustical influence of the resonators in the churches in which they were found and also regarding the possible impact of resonators in Orthodox worship spaces with all its specific characteristics.

RESONATORS FOUND TO DATE

The data published in papers dealing with presentations of architectural features of church buildings and their reconstruction enables to determine the locations at which acoustic resonators have been found to date. It has, thus, been concluded that resonators have been found in 24 Serbian churches and chapels. An analysis of these finds leads to the conclusion that discoveries were made in one of four different ways:

1. as a result of archeological explorations made on locations of ruined old churches, when parts of earthenware vessels assumed to have been used as resonators were found;
2. as chance finds in walls in the course of architectural reconstructions of churches when the apertures of resonators were covered with mortar so that their presence had not previous been noted;
3. in the course of tearing down of old churches for the purpose of building new structures in their place;
4. based on visible evidence of the existence of resonators in churches actively used today (apertures of built-in resonators visible on the wall surface or free-standing ceramic vessels in the attic space of the church)

It is interesting that among the 24 churches in which resonators have been found the least number of discoveries came as a result of visible apertures on the walls, which also implies that it is possible to evaluate their effect on the acoustic response of the church. In two wooden churches, in which vessels have been found, they were not built into the walls but rather hung freely in the attic space. The greatest number of discoveries was made by the first method, as a result of archeological investigation of ancient, nowadays ruined churches. In some cases, there is either mention of only parts of vessels being found or statements regarding the existence of indentations in the walls where ceramic vessels are assumed to have been located. A significant number of resonators finds was made in the course of architectural restorations when, following the depletion of a layer of mortar, complete ceramic vessels built into the walls were found.

The number of 24 churches known now to have had resonators is by no means the final score because it is realistic to assume that they had also been built into churches which are now completely ruined, and traces of their existence thus erased, and that they still exist in number of others, standing today, under layers of mortar, implying that they could be discovered in the course of some future sanation of these old buildings.

In all the known Serbian cases, the acoustic resonators used in churches were made out of baked clay (ceramics, earthenware). Some vessels, historians assume, could have been made specifically for acoustical purposes but in most cases the vessels found in function of resonators were originally intended for holding and transporting liquids in everyday life. Some have outer surfaces decorated with ornaments which offers additional proof of their original function. The most common shapes of discovered vessels are presented on the scheme of Figure 1. The height of the found vessels ranged between 25 – 45 cm. The figure also shows two basic means of forming the acoustic inductivity of resonator: by piercing an opening on the bottom of the vessel (the right part of the figure) or by using an existing opening of the vessel (the left part of the figure).

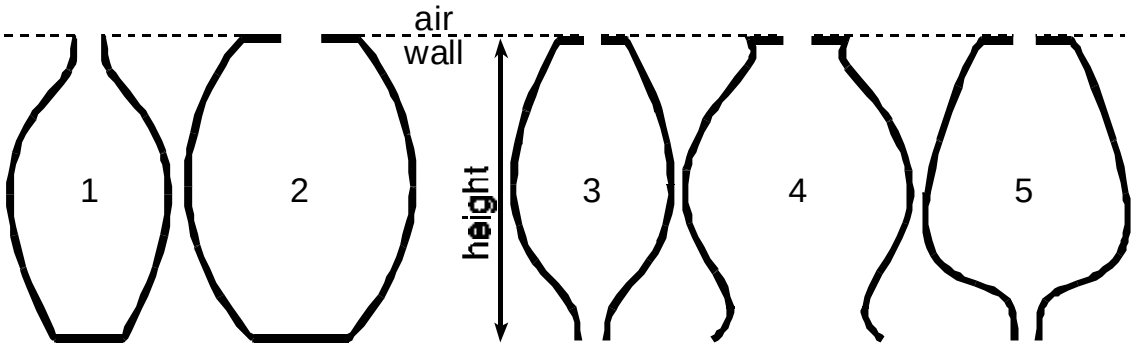

Fig. 1 - General forms of ceramic vessels found in Serbian churches.

Some of the found ceramic vessels were taken from museum collections to the laboratory for the purpose of measuring their basic acoustic characteristics. Figure 2 shows photographs of some of the vessels taken at the laboratory. Figure 2a and 2b show two resonators taken from the vaults of the Church of the Introduction of the Virgin in the Temple at Sremski Karlovci (built in the 17th century). It is obvious that they are actually water containers turned into resonators by piercing holes in their bottoms. Figure 2c shows a photograph of two resonators taken from the ruins of an old church in the village of Komarane (dating unknown).

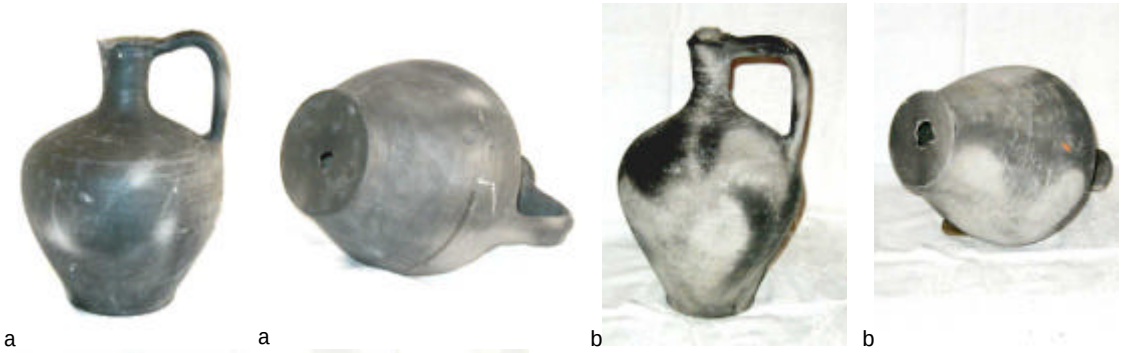

Fig. 2 - Photographs of resonators analyzed in the laboratory: a and b – two resonators taken from the vaults of the Church of the Introduction of the Virgin in the Temple, Sremski Karlovci, c – two resonators taken from the walls of the ruined medieval church from the village of Komarane

In many churches it was impossible to determine the total number of built-in resonators. In ruined churches, the reason lies in the fact that parts of their walls are missing. In some extant churches where some of the resonators have been found, the symmetry of the architectural structure offers basis for assumptions that similar resonators, the openings of which are covered by mortar decorated with fresco paintings, are to be found in other parts of those churches too.

METHOD OF MEASUREMENT

Acoustic analysis of a resonator implies the measurement of parameters relevant to describe the resonant process in it. That involves: resonant frequency, bandwidth and intrinsic reverberation time (or decay constant of resonant process). For that purpose an appropriate setup were prepared in the laboratory, as shown at Fig. 3.

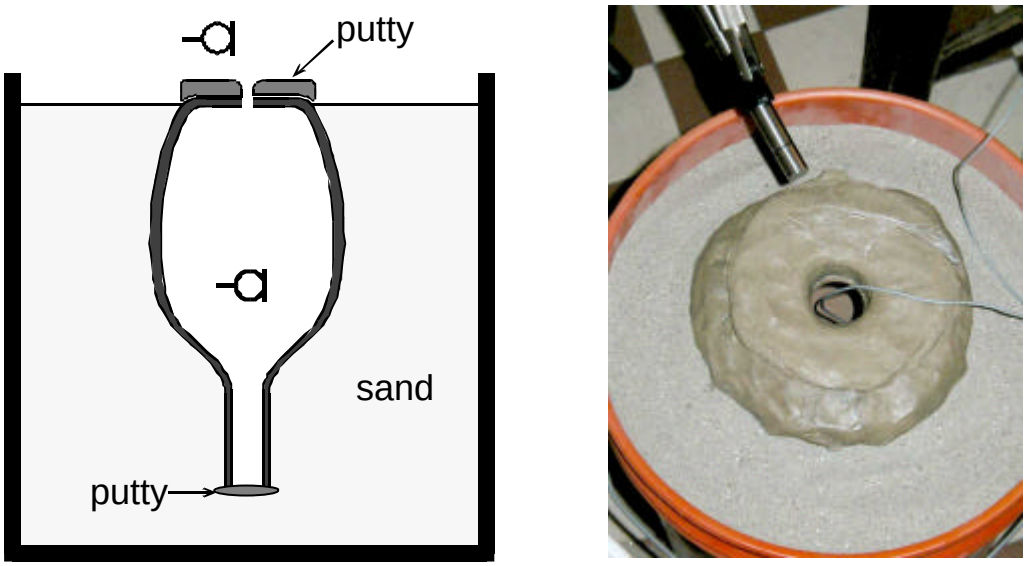

Fig. 3 - Laboratory setup for the measurement of acoustical parameters of the ceramic vessel if used as the resonator.

The large plastic container was used for ceramic vessel placement in all measurements. Inside the container the tested vessel is embedded in sand to achieve the environment as it was originally in church wall. It was estimated that ceramic walls of vessel are too transparent at frequencies as low as can be expected for its resonant frequencies. At resonators equivalent circuit such transparency can be modeled by a wall impedance parallel to the acoustic capacity. When the vessel is removed form the wall and stands freely in the air, influence of low wall impedance value causes some changes in decay constant, and according to that, in resonator's intrinsic reverberation time. To prevent this effect ceramic vessel is embedded in sand during all measurements. Some preliminary tests in the laboratory revealed changes in reverberation time values up to 20% when the ceramic vessel is removed from sand.

Round shaped piece of putty about 2 cm thick is applied around the resonator's hole, as shown at figure 3. During the measurements it simulates mortar originally present over resonators when built in church walls and vaults. The thickness of 2 cm is estimated as the least possible mortar layer thickness when applied on church walls. The thickness of vessel wall around the hole is 4-5 mm. So, 2 cm of plaster should have strong influence on resonant frequency value. Testing of possible mortar influence upon resonator performance was also carried out, Some results obtained are presented at fig 4. Significant lowering of resonant frequencies with mortar around resonators aperture is obvious.

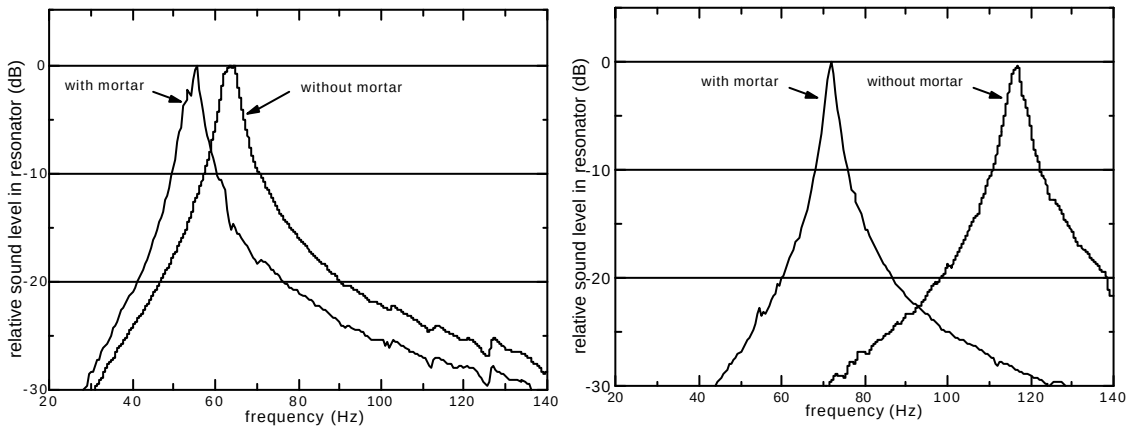

Fig. 4 - Two examples of measured resonant curves showing the mortar influence on resonant frequency: left - vessel no 1, right - vessel no 2 (all from Church of the Introduction of the Virgin in the Temple, Sremska Kamenica).

Two microphones were used for the measurement. The first, a standard laboratory microphone, is placed outside the resonator, in the vicinity of its aperture. The second microphone is placed inside the vessel through its aperture. For this purpose a special, very small microphone is used, taken from a hearing aid. This microphone is connected to the measurement system by a very thin cable in order to minimize its influence on the size of the aperture area, as visible at Fig. 3.

The measurements of the resonant curves were carried out in the reverberation chamber. White noise was reproduced in the chamber by standard laboratory loudspeaker, and resonators placed there were exposed to wideband diffuse sound field. The resonant curve was obtained as the difference of outside and inside sound level. It is expressed by relative sound level inside the vessel volume, normalized to its maximum. For measurement of the reverberation time the whole setup was moved to the anechoic chamber. Decay curve is obtained from inside microphone signal after the sound source, also placed in the anechoic chamber, is switched off. Intrinsic reverberation time of the resonator is evaluated from that curve.

RESULTS OF RESONATORS MEASUREMENTS

Eight original ceramic vessel was prepared for laboratory research. Six of them originate from the vaults of the Church of the Introduction of the Virgin in the Temple, Sremski Karlovci (S.K.), and two from ruins of the village church in Komarane (KO). Measured values of resonant frequency, bandwidth and intrinsic reverberation time for all these resonators are shown in Table 1. Resolution in frequency measurement was 0,5 Hz.

Table 1 - Measured values of resonant frequency, bandwidth and reverberation time for eight ceramic vessels if used as acoustic resonators: S.K. - vessels form Church of the Introduction of the Virgin in the Temple, Sremska Kamenica, KO - Church in Komarane.

no.	ceramic vessel	f_o (Hz)	B (Hz)	T (s)
1	G.C. vessel no 1	55,5	2,5	0,71
2	G.C. vessel no 2	72,5	2,5	0,86
3	G.C. vessel no 3	72	2,5	0,81
4	G.C. vessel no 4	72	4	0,44
5	G.C. vessel no 5	82	4	0,64
6	G.C. vessel no 6	102,5	1,5	0,99
7	KO. vessel no 1	124	2,5	0,64
8	KO. vessel no 2	131	2	0,86

Several statements follows from data presented in Table 1:

1. Resonant frequencies of all tested resonators are lower or equal to 131 Hz. Vessels from the Church of the Introduction of the Virgin in the Temple, with form shown at Fig. 2.a and 2.c, have very low resonant frequencies, between 72 and 102 Hz, while another two vessels, shown at Fig. 2.c, have it lower or equal to 131 Hz.
2. Bandwidths of resonant process in all resonators are lower or equal to 4Hz (resolution of measurement was 0,5 Hz). The lowest measured value were 1,5 Hz. All vessels were empty during the measurement due to the fact that they were empty where found in place.
3. Intrinsic reverberation time is in the interval 0,44-0,99 s. Again, all vessels were empty during the measurement.

The resonant frequency measurements were done with putty around the aperture in a layer of approximately 2 cm. It was estimated that this value represents a minimal thickness of mortar on church walls. If thicker, mortar would produce further reduction of resonant frequency values than those in table 1, due to the increase of acoustic inductance.

CONCLUSION

The characteristics of acoustic resonators found in old Serbian churches can be summarized in two main facts: very low value of resonant frequencies and very narrow bandwidth. Service in Serbian Orthodox churches consists of acapela chorus singing and preacher's chanting, without any musical instruments. Due to that fact, any resonator in a church working on frequencies below 100 Hz can't be excited by such sound field present in the church space. Even if working at higher frequencies, very narrow bandwidth of resonant process, below 4 Hz, typically 2 Hz, results that probability of resonators exciting by sound field during service is very low, even its resonance is higher than fundamental frequency of singing voices.

Data from literature shows that a relatively small number of resonators was discovered even in churches with volumes larger than 1000 m^3. In four smaller churches, with volumes less than 600 m^3, only four resonators were found in each of them. In two small worship spaces only two resonators found built to the walls, and there is a wooden church with only one resonator found.

In conclusion, the building of ceramic vessels into church walls and domes of Serbian churches is the result of orally transmitted tradition, without any real knowledge of their function. There are assumptions that, apart from the acoustic, the demand for building in of resonators also had a religious component. Finally, there are some observations that ceramic vessels, under the circumstances of an ambiguous acoustic function, were also used as constructional elements, something like a forerunner of present-day hollow bricks. As such they were also used in buildings other than churches. There is a note that the dome of the Bayrakli mosque in Belgrade consists of a large number of built-in ceramic vessels, like those from fig. 2, supposedly for reasons of static, due to the small overall weight of such a construction [4].

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