

# ACOUSTIC VESSELS AS AN EXPRESSION OF MEDIEVAL MUSIC TRADITION IN SERBIAN SACRED ARCHITECTURE\*

---

*Zorana Đorđević*<sup>1</sup>

Institute for Multidisciplinary Research, University of Belgrade

*Kristina Penezić*<sup>2</sup>

Centre for Digital Archaeology, Faculty of Philosophy, University of Belgrade

*Stefan Dimitrijević*<sup>3</sup>

School of Electrical and Computer Engineering of Applied Studies, Belgrade

Received: 15 February 2017

Accepted: 1 June 2017

Original scientific paper

## ABSTRACT:

Archaeoacoustics is a multidisciplinary field of research focused on the history of the relatedness of the field of sound and architecture. The architectural history of Europe, from Antiquity to the modern period, is abundant in the findings of vessels, which are considered to have an acoustic purpose. This paper addresses these acoustic vessels embedded in the massive walls of sacred architecture in medieval Serbia (15 churches). We considered the wide context of current archaeoacoustic research, in order to argue that this practice can be regarded as an expression of a certain medieval musical tradition.

\* The paper is a result of research on the project *Society, spiritual and material culture and communication on the Balkans in prehistory and early history of Balkans* (No. 177012) and the project *Theory and practice of science in society: multidisciplinary, educational and intergenerational perspectives* (No. 179048). The Ministry of Education, Science and Technological Development of the Republic of Serbia finances both projects. We are grateful for the help that we received from Jean-Christophe Valière from the University of Poitiers and Emilija Pejović from the Republic Institute for Protection of Cultural Monuments, Belgrade.

<sup>1</sup> [zoranaadjordjevic.arch@gmail.com](mailto:zoranaadjordjevic.arch@gmail.com)

<sup>2</sup> [kpenezic@gmail.com](mailto:kpenezic@gmail.com)

<sup>3</sup> [stefan.dimitrijevic@viser.edu.rs](mailto:stefan.dimitrijevic@viser.edu.rs)

KEYWORDS: Acoustic vessels, archaeoacoustics, sacred medieval architecture, medieval Serbia

Research into sound in architecture deserves a special place in studies of cultural heritage. There are two main reasons for this: (1) as well as visually, humans also reveal the surrounding space by using the sound (Reznikof 2005) while (2) the sense of hearing is more sensitive than the eyesight.<sup>4</sup> Archaeoacoustics, or the archaeology of sound, is a multidisciplinary field of research focused on the history of the relatedness of the field of sound and architecture. Because of the complexity of archaeoacoustic questions, it is necessary to develop a holistic approach and team research, which brings together archaeologists, acousticians, architects, musicologists, linguists, etc. Those different disciplines arrived at valuable conclusions concerning the history of the acoustics of sacred spaces in Europe (Baumann 1990; Arns & Crawford 1995; Carvalho et al. 2002; Desarnaulds 2002; Cirillo & Martellotta 2007; Zamarreño et al. 2008; Martellotta et al. 2008; Howard & Moretti 2009; Navarro et al. 2009; Crunelle 2009; Suarez et al. 2013, 2015; Elicio & Martellotta 2015; Alvarez-Morales & Martellotta 2015), and also in Serbia (Mijić 2000; Mijić & Šumarac Pavlović 2004; Пено 2008; Đorđević 2016; Đorđević et al. 2016).

This paper presents the results of multidisciplinary research into acoustic vessels built into the massive stone walls of sacred architecture in medieval Serbia. The main goal was to place the findings from Serbia in the context of current archaeoacoustic research and thus include them on the archaeoacoustic map of medieval Europe and the following interpretations of the historical relations of sound and architecture. Since medieval principles of building were considered as a secret of a craft, there are no detailed documents on the acoustical intentions of builders. Consequently, the research question is: Could the practice of embedding acoustic vessels in sacred architecture be considered as the expression of a musical tradition of medieval Serbia? To answer this question it is important to discuss four main groups of research questions related to this issue:

- (1) Where did the tradition originate and how was it transmitted? What were the possible ways of adopting the tradition of acoustic vessels in the building process of various parts of Europe throughout history?
- (2) What was the main intention of the builders or the founders? What did they strive for or believe they were accomplishing by installing the acoustic vessels?
- (3) What are the physical characteristics of the acoustic vessels found in the sacred architecture? Is there any positioning pattern? How were they installed?
- (4) What is the objective acoustical efficiency of the acoustic vessels in the architectural spaces?

Research into the acoustic vessels in architectural heritage was focused on three periods: (1) Antiquity, with special interest in the recommendations of Marco Pollio

<sup>4</sup> Relation of the frequency range for sight is 1:2, and for the hearing sense is 1:1000. Relation between the weakest and the strongest sound a human can sense is over 120 dB, while the sensitivity to light is 90 dB.

Vitruvius and theatre acoustics, (2) medieval times and sacred architecture, and finally (3) the modern period and the use of resonators in auditoriums and sacred spaces (Arns & Crawford 1995).

The first part of the paper considers the general usage of acoustic vessels in medieval Europe, starting with the main thoughts from Vitruvius's *Ten Books on Architecture*, the oldest document in which acoustic vessels are described, then presenting a short review of relevant archaeoacoustic studies and finally illustrating the acoustic intentions with several quotations. The second part of the paper addresses the acoustic vessels in sacred edifices of medieval Serbia. This includes the historical framework, an overview of previous research, and a census of the acoustic vessels in fifteen sacred edifices and related acoustic studies. In the third part of the paper the main points of the research are discussed – the physical characteristics of acoustic vessels, their distribution, positions and orientation in the walls, acoustical efficiency, etc. We subsequently draw conclusions and make suggestions for further archaeo-acoustic examination.

## ACOUSTIC VESSELS IN SACRED ARCHITECTURE IN MEDIEVAL EUROPE

### THE RECOMMENDATIONS OF MARCUS POLLIO VITRUVIUS

The oldest known source on acoustic vessels is the treatise *Ten Books on Architecture* by Marco Pollio Vitruvius, an architect from the period of Julius Caesar (1<sup>st</sup> century B.C.). Vitruvius considered architecture as the precursor of all other sciences. Writing about building practice, in several places he considered the issues of perceiving sound phenomenon and space acoustics. He described the voice as “a flowing breath of air [which] moves in an endless number of circular rounds like the innumerable increasing circular waves which appear when a stone is thrown into smooth water” until it is interrupted with an obstacle from which it reflects back, breaking up the formation of those which follow (Vitruvius 1914, 138–9). In other words, the laws of reflection were known in Antiquity, as well as the effect of reverberation<sup>5</sup> due to uncontrolled reflections of sound, which significantly disturbed the intelligibility of speech from the stage. Therefore, Vitruvius stressed the importance of the geometry and proportions of theatres for their acoustics, explaining that the geometry of theatres needs to follow the natural laws of sound movement and thus enable the voice not to be obstructed. As a key for solving these building tasks Vitruvius pointed out the significance of *mathematical theory* and *musical laws* for sound reinforcement. The ancient architects, “by means of the canonical theory of mathematicians and that of musicians, endeavoured to make every voice uttered on the stage come with greater clearness and sweetness to the ears of the audience” (ibid., 139).

As the key solution for achieving adequate acoustics in theatres, Vitruvius recommended the installment of bronze vessels “in niches under the seats in accordance

<sup>5</sup> The reverberation means that the production of multiple reflections of sound in a space, so more acoustic energy reaches the ears of the listener (Johnston 2009: 161–2).

with musical intervals on mathematical principles” (ibid., 9). In the fifth chapter of the fifth book – *Sounding Vessels in the Theatre* – he presented detail instructions on how to install sounding vessels on mathematical principles, so that when touched they would produce among themselves the tones of a fourth, a fifth and up to the double octave. All of this in such a way that “the voice, uttered from the stage as from a centre, and spreading and striking against the cavities of the different vessels, as it comes in contact with them, will be increased in clarity of sound, and will wake an harmonious note in unison with itself” (ibid., 143). Although he did not write in what way acoustic vessels impact the space acoustics, Vitruvius recommended the accurate disposition of acoustic vessels in the auditorium and their specific tuning according to musical intervals. He wrote that acoustic vessels should be facing the stage and arranged in the hollow niches between seats of the theatre, so “they nowhere touch the wall, but have a clear space all round them and room over their tops” (ibid.).

Vitruvius stressed that acoustic vessels are more suitable for theatres “built of solid materials like masonry, stone, or marble, which cannot be resonant” (ibid., 145). Although the number of niches and bronze vessels found in ancient theatres is inconclusive (Arns & Crawford 1995), a relation between Vitruvius’s description and the medieval practice of installing acoustic vessels may be found in the following recommendation:

Besides, many skilful architects, in constructing theatres in small towns, have, for lack of means, taken large jars made of clay, but similarly resonant, and have produced very advantageous results by arranging them on the principles described (ibid.).

Thus, this could be the essence of medieval thinking on architectural acoustics – acoustic vessels should be used if building in solid materials, and the vessels could be ceramic, not necessarily bronze.

#### ARCHAEOACOUSTIC STUDIES

Until the second half of the 20<sup>th</sup> century, researchers into acoustic vessels, mostly archaeologists or conservators (Vachez 1886, Јовановић 1909, Петковић 1909, Дероко 1930), were collecting data on physical characteristics, number, position and means of embedding vessels into the massive walls of sacred architecture. The vessels were reputed to have an acoustical function. The census of the findings is constantly modified. This significant contribution produced archaeoacoustic studies of 54 churches in Europe (Arns & Crawford 1995), 200 churches in Switzerland (Desarnaulds 2002) and about 200 medieval cathedrals in France and 320 in total all over Europe and the Near East (Palazzo-Bertholon & Valière 2012). Nevertheless, none of these wide-ranging studies included findings from Serbia.

Over the last several decades, research into acoustic vessels has drawn the attention of acousticians. There are two acoustic approaches amongst published multidisciplinary archaeoacoustic studies: (1) laboratory analysis of acoustic vessels (Carvalho

et al. 2002; Mijić & Šumarac-Pavlović 2004), and (2) *in situ* acoustic measurements on the localities where acoustic vessels are still in the original positions (Arns & Crawford 1995; Desarnaulds et al. 2001; Desarnaulds 2002; Zakinthinos & Skarlatos 2007; Valière et al. 2013, 2014). Their common goal is to examine the acoustic parameters, such as time of reverberation, clarity, definition, speech intelligibility, etc. Without exception, the studies showed that it is quite difficult to determine any significant acoustic effect of the inbuilt ceramic vessels. It is shown that there is no uniform pattern of embedding acoustic vessels in medieval sacred architecture (Palazzo-Bertholon & Valière 2012). Nevertheless, researching relations between type, number and positions of the vessels found with the building style, volume and height of the space, produced some indicative results. Valière et al. (2013) argued that builders had a vast empirical knowledge of acoustical laws, so they understood that the effect of acoustic vessels was cumulative. In other words, the number of vessels increased with the volume of a sacral space. In addition, the vessels were tuned in the frequency range with the longest time of reverberation.<sup>6</sup> Since the resonating frequencies of the vessels under research are in the range from 100 to 500 Hz, they contribute to shortening the time of reverberation of the frequencies usually excited by the speaking voice. The authors also noticed the attempt to adjust the dimensions of the vessels in order to absorb low frequencies for which the absorption of wooden furniture (iconostasis, benches, etc.) and textile was less effective. Two types of vessels were often used in churches, whose resonant frequencies are in the ratio of the musical intervals of a fourth and a fifth (Valière et al. 2013, 75–79). This indicates the relation with musical theory and the tuning of acoustic vessels that Vitruvius wrote about.

Beside the intention to determine the effect of inbuilt vessels on church acoustics, there are also theories concerning their symbolic applications, based on ancient philosophy and the belief that musical tones elevate the human soul (Arns & Crawford 1995). Consequently, acoustic purposes can be considered as a secondary intention of the builders, while the primary goal was the comprehensive representation of the universe in which each vessel represents a planet and its sphere, emitting a characteristic noise. Thus, the system of acoustic vessels is part of a more general theory of spheres, developed in Antiquity and specifically valued in the Middle Ages (Poulle 2000).

#### THE ACOUSTIC INTENTIONS OF MEDIEVAL BUILDERS

The awareness of the possible improvement of acoustic effects inside sacred spaces is expressed in Francesco Giorgi's Memorandum for S. Francesco della Vigna from the year 1535: "I recommend having all the chapels and the choir vaulted, because the word or song of the minister echoes better from a vault than it would from rafters. But in the nave of the church, where there will be sermons, I recommend a ceiling ... coffered with as many squares as possible... because they will be very convenient for preaching: this the expert knows and experience will prove it" (Wittkower 1971: 156).

<sup>6</sup> The time of reverberation is the time it takes the volume to drop to 1/1000000 of its initial value or, put another way, it is the length of time required for sound to decay 60 dB from its initial level. This acoustical parameter is the most important one for music (Johnston 2009, 161–162).

Throughout the Middle Ages acoustic vessels were incorporated in the massive walls of sacred edifices – the greatest architectural achievement of the time which expressed the symbolism of the internal value of overall order (*ibid.*). A comprehensive study on the tradition of acoustic vessels in medieval sacred architecture has not yet been published. However, there are two main positions: (1) the tradition is passed on as a continuous practice from Antiquity to Byzantine builders, and further, to the Middle Ages (Vachez 1886, Valière et al. 2013) or (2) the book of Vitruvius is credited with the revival of this acoustical tradition in medieval Europe (Godman 2006, Чанак-Медић 2006). Nevertheless, the effectiveness of acoustic vessels was constantly questioned throughout history. The oft-cited record on this scepticism, which also illustrates the acoustic intentions of medieval builders, is from the Chronicle of the Celestins de Metz from 1432:

He made and ordered the pots to be placed in the choir of the church thinking that they would make for better singing and would resound more loudly (...)  
I don't know whether one sang better than one would have without having done this (Baumann 1990).

During the reconstruction of the Dominican convent of Strasbourg in 1743, the architect Salomon found acoustic vessels dating from the 14<sup>th</sup> century. Regarding these findings, he wrote:

When demolishing the walls of the great choir of the temple-Neuf (begun in 1307, completed in 1345), I found earthen jars around the ogives of windows and buried in the masonry, the opening being flushed and open to the inside. I managed to extract some intact. These pots are in grey earth... Belief in the effectiveness of these pots for acoustics has been abandoned long ago, because all the holes were sealed and the roughcast covered them completely. Around each ogive were nine pots, one at the top and four on each side (...). Apparently these pots were used to raise the tone of the voice when the monks sang in chorus (Valière et al. 2013).

This passage implies that the intention of the builder was to provide the desired acoustic properties inside of the church. However, there are no written records as to how builders understood the influence of the vessels to church acoustics.

## ACOUSTIC VESSELS IN THE SACRED ARCHITECTURE OF MEDIEVAL SERBIA

### HISTORICAL FRAMEWORK

Sacred architecture had the highest significance in medieval Serbia. The architectural design of the church, as the most important element of the structure of the monastery,

was thoroughly thought through and imbued with Christian symbolism (Поповић 1993). Each of the rulers of the Nemanjić dynasty endeavored to erect at least one monumental endowment, as an expression of power, greatness and spiritual commitment. The seignorial foundations commenced with the strengthening of the nobility in the 14th century (Дероко 1962, 9). The most respected builders were invited to build and paint the churches. Therefore, medieval sacred architecture in Serbia represents the highest peak of art of the time. It is considered to be the foundational point in Serbian modernity, upon which national identity was developed (Валтровић & Милутиновић 2006).

Medieval Serbian monuments of sacred architecture may be researched within the framework of stylistic groups, such as: (1) Pre-Nemanjić period (to the 12<sup>th</sup> c.), (2) the Raška style group (12<sup>th</sup> – end of 13<sup>th</sup> c.), (3) the Byzantine style group (13<sup>th</sup> – 14<sup>th</sup> c.) and (4) the Moravian style group (end of 14<sup>th</sup> – mid 15<sup>th</sup> c.). Besides changes in the stylistic characteristics of architectural monuments, monasteries were erected in certain regions according to the shifts of state borders in medieval Serbia. Here we present the findings concerning acoustic vessels from all the above-mentioned building periods.

#### PREVIOUS RESEARCH

During the first period of research into acoustic ceramic vessels in Serbia, at the beginning of the 20<sup>th</sup> century, they were consequently referred to as “acoustic pots” (Петковић 1909, Јовановић 1909). Thus, in the journal *Starinar* from 1909, Vladimir Petković wrote about the findings in Žiča monastery, and Kosta Jovanović’s subheading referred to the “function of the acoustic pots of baked clay.” The next wave of interest in the subject<sup>7</sup> occurred in the 1960s (Ненадовић 1960, Дероко 1962), when Slobodan Nenadović published the first census of churches and description of the ceramic vessels found, their positions and the manner of their installation. In this census, the author concluded that vessels were found in the architectural monuments erected throughout the Middle Ages<sup>8</sup> (Ненадовић 1960). Researchers have dealt sporadically with the subject up to the present day, remaining within the frame of their own research disciplines (Бајаловић Хаџи-Пешић 1981; Чанак-Медић 2006; Мијић & Šumarac Pavlović 2004). The exception was the multidisciplinary approach taken in research into acoustic vessels found in the monastery Davidovica (Булић & Црнчевић 2010).

The function of these vessels was always questioned. However, researchers supported their acoustic function without exception. Thus, Petković wrote: “... the function of these pots is not quite clear. It is problematic to explain their use as being

<sup>7</sup> Acoustic vessels found in the walls of medieval architecture were also mentioned in publications from the third decade of the 20th century. See also: Дероко 1930: 128–155; Тагић 1929: 132.

<sup>8</sup> In addition to sacred architecture, acoustic vessels have been found in the medieval cities of Soko-grad and Куриново (Бајаловић Хаџи-Пешић 1981: 25–32).

part of constructional necessity, and perhaps it would be suitable to understand them in the role of resonators” (Петковић 1909: 104). Jovanović believed that in case of ancient buildings there was an awareness of the need for adjusting the acoustics of sacred spaces, but on account of their size and disposition in more recent buildings, he concluded that the tradition began merely to be passed on, without any understanding of the function of acoustic vessels; thus he wrote:

There seems to be no doubt that their usage came with the manner of building of the East, where they certainly used to have a common role as an instrument for increasing resonance. However, later on, especially in this region, it seems that this function was completely overlooked so their use was more a result of inherited building traditions than a consciously understood need for better resonance in churches (Јовановић 1909: 136).

Nenadović emphasized that Serbian medieval churches were usually consider “acoustical.” In addition to research into acoustic vessels, he also considered the role of the geometry of the church, suggesting that acoustic vessels were positioned in order to prevent direct reflections of sound towards the speaker, standing in a semi-circular apsidal choir. In other words, they played the role of the resonators that make sound spread evenly throughout the space, so the speaker cannot hear himself enhanced (Ненадовић 1960: 10). In contrast to that, Deroko believed that the acoustic vessels “were used for space to echo better.” Consequently, he wrote on their function: “When those vessels were built in such a way that their openings could be seen, their cavity enhanced the sonority of the space, like, for example, the openings and cavities in the guitars and other musical instruments” (Дероко 1962: 26).

The period of the use of acoustic vessels in medieval Serbia was initially questioned. Petković considered the vessels as a “characteristic sign” of 13<sup>th</sup>- and 14<sup>th</sup>-century churches (Петковић 1909: 104), while at the same time Jovanović claimed they were used in early as well as late medieval church building in Serbia (Јовановић 1909: 138). Today it is the accepted position that the embedding of ceramic vessels in church walls was common in all building periods of medieval Serbia, through the influence of Byzantine culture (Јовановић 1909; Бајаловић Хаџи-Пешић 1981) or as a consequence of the knowledge passing through the building groups from Dalmatia (Булић & Црнчевић 2010).

#### CENSUS OF THE ACOUSTIC VESSELS

In accordance with published papers, we present the findings of the acoustic vessels in the sacred architecture of medieval Serbia, in fifteen churches found today in the territory of the central Serbia, Kosovo and Metohija and Hilandar Monastery on Mount Athos (Table 1, Figure 1). For each church, we indicate its founder, the date of building and the importance of the edifice at the time of building, if any. There is also a description of the organization of space and of the system of construction, because this is important for understanding the positioning pattern of acoustic vessels. Finally, we give the position and the manner of installation of acoustic vessels, their physical

characteristics and, in cases where vessels are extracted from the walls, we indicated the Museum where they are preserved today.

**The Church of the Holy Apostles Peter and Paul near Novi Pazar** is the oldest preserved monument of medieval architecture in Serbia, dating from the Pre-Nemanjić period. According to the organization of space, construction and stylistic elements, this church belongs to pre-Romanesque architecture (Нешковић & Николић 1987: 17). Until the establishing of the first Serbian archbishopric at Žiča Monastery, St Peter's Church represented the centre of Church life in Serbia. The plan of the church is a circle with an inscribed cross with four conches. The dome is over squinches supported by four pilasters. Around this central space, a semicircular corridor and narthex with the gallery were built in the same period. The southern part of the edifice is from the later period. Eleven acoustic vessels are found in the central area, inbuilt 40 cm below the dome cornice, with distances among them from half a meter to one meter. They were also found in the apse, where they were inbuilt in one horizontal line. In addition, there are two vessels in the corners of each conch— eight vessels in total. They are about 30 cm in height with an opening of about 3,5 cm. All the vessels are inbuilt in the horizontal position, in such a way that the mouth opening is oriented towards the inner space of the church (Figure 3). These holes are visible today, since they were not covered with a layer of mortar in the past (Ненадовић 2003).<sup>9</sup>

**The Church of Sts Peter and Paul in Stara Pavlica Monastery near Brvenik** dates from the 12<sup>th</sup> century – the Pre-Nemanjić period or the very beginning of the rule of the Nemanjić dynasty. The church, with the dome still standing, is today in ruins. The plan of the church is a three-nave basilica with inscribed cross. The dome is in the centre of the cross, supported by the four columns and pendentives. The narthex is on the west side of the church. Eight acoustic vessels are equidistant in the area where the dome covers the drum. The acoustic vessels, about 25 cm in height, are positioned horizontally in the stone wall (Ненадовић 1960). The mouth opening is oriented towards the interior of the church, and the bottoms of the vessels are in the wall. Since parts of the walls are missing today, the bottoms of the vessels are visible from the outside of the church. The radius of the vessels at their widest is 15 cm, and the radius of the bottom is 10 cm. The openings were mortared over with the fresco mortar. Acoustic vessels, 30 cm radius at their widest, were also found in each of the “barely distinguished pendentives” (ibid.). In short, there are two dimensions of acoustic vessels in the church of Stara Pavlica Monastery – the eight in the drum are smaller, and the four in the pendentives are larger. All of the vessels found were made of baked clay, vermilion in color and not enamelled (ibid.). These vessels are considered to be intentionally made for acoustic purposes (Булић & Црнчевић 2010).

**The Church of St Nicholas near Kuršumljia** is one of the first endowments of Stefan Nemanja, the founder of the Nemanjić dynasty. The church was erected between 1152 and 1168. After gaining the autonomy of the Serbian Church in Nicaea

<sup>9</sup> St Peter's church near Novi Pazar is the only example of this type of sacred building in Serbia, but analogies may be found in Dalmatia. Therefore, it is important to bear in mind the discovery of acoustic vessels in the churches of the Dalmatian coast. See: Jurković & Turković 2012, Marasović 2003.

in 1219 this monastery became the centre of the newly formed episcopacy of Toplica (Томовић 2000). The church is a single-nave basilica with a sliced dome and three-part altar. King Stefan the First-Crowned added the narthex with two towers on the west side of the church, and king Milutin erected a chapel on the north side. Four acoustic pots are found in the pendentives under the central dome (Бајаловић Хаџи-Пешић 1981). One is well preserved and it is preserved in the National Museum in Belgrade. Its height is 31.7 cm, the radius at the widest zone is 23–24 cm and the radius of the bottom is 13.5 cm. The thickness of the ceramic walls is 5–8 mm. The mouth opening is about 12 cm. The pot is made of baked clay, an uneven red-yellow colour and not enameled. The vessel is decorated with three stripes and several lines in the upper zone. It was inbuilt horizontally, so the mouth opening of the vessel was orientated towards the inner space of the church and the bottom was installed in the mass of the wall (Ненадовић 1960). These pots are considered to be intentionally made for acoustic purposes (Булић & Црнчевић 2010).

**The Church of the Transfiguration of Christ in the village of Pridvorica** used to be part of the monastery complex. The characteristics of its style date it to the end of the 12<sup>th</sup> century – the period of the Raška style in sacred architecture. The church has a single nave, a central dome, transept and a spacious narthex. Two acoustic vessels were found under the rebated arches on east and west sides that support the central dome. They are horizontally positioned. The bottoms of the vessels are in the wall and the mouth is orientated towards the inner space of the church. The height of the vessels is about 35 cm, and the opening is about 10 cm in radius.

**The Church of the Ascension of Christ in Žiča Monastery** is an endowment of Stefan The First-Crowned, erected at the beginning of the 13<sup>th</sup> century. Credit for the building also belongs to St Sava, the first Archbishop of the Serbian Church. After the Serbian Church became autonomous in 1219, Žiča Monastery became the centre of the Serbian Archbishopric. The church is built in the Raška architectural style, and so has one nave, dome, transept, a side chapel, a wide apse on the east side and an inner and outer narthex with a tower on the west side of the church. Findings of acoustic vessels were reported, positioned under the main dome: in the wall of the north apse at the height of the beginning of the rebated arch – one on each side, in the diaphragm under the western rebated arch at the same height as the northern side, two on each side; and in the north wall under the rebated arch, two on each side (Ненадовић 1960). It is assumed that acoustic vessels were installed in the opposite walls on the analogous places, but that they were mortared over at some point in history (Ненадовић 2003). The vessels are positioned horizontally, so the openings are turned towards the interior of the church. The height of the vessels found in western wall is 38 cm and those found under the dome as much as 43 cm. The openings of these pots are in the range of 13 to 15 cm (*ibid.*),<sup>10</sup> so this is a case of two different dimensions of vessels in the same church.

<sup>10</sup> Vladimir Petković also wrote about the acoustic vessels found in Žiča Monastery. In the drawings of Valtrović and Milutinović from 1871–1884 (Валтровић & Милутиновић 2006) there are circular openings on the arch under western pendentives. They correspond to those described by Nenadović (1960).

**The Church of the Holy Apostles at the Patriarchate in Peć** is a spiritual centre and the mausoleum of Serbian archbishops and patriarchs. Archbishop Arsenije I founded the church, in the third decade of the 13<sup>th</sup> century. Nenadović (1960) presented a sketch of the positions where acoustic pots were embedded in the walls, under the upper rebated arches on the north, west and south sides. In this case, it is also assumed that pots might have been positioned in the eastern side, analogously to the present positions. However, the eastern side is totally covered by a layer of mortar, so there are two possibilities: the mortar is covering the openings of the pots or the whole wall was rebuilt and the pots were destroyed at some point in the past. The openings of the extant pots are 10 cm wide. In other churches of the Patriarchate in Peć – St Dimitrije, the Holy Virgin and St Nicholas, and in the narthex of Archbishop Danilo II there were no signs of the acoustic vessels in the walls (Ненадовић 1960). Bajalović Hadži-Pešić mentioned the fragments of a jug from the 14<sup>th</sup> century found at the Patriarchate in Peć, of the same type as those found at Mileševa Monastery (Бајаловић Хаџи-Пешић 1981).

**The Church of the Ascension of Christ in Mileševa Monastery** was built in the third decade of the 13<sup>th</sup> century, as the endowment of King Vladislav Nemanjić. After the death of St Sava at Trnovo, and the translation of his relics in 1236, the church gave rise to the cult of St Sava. The church is built in the Raška style, with one nave and a dome over the section of the nave and transept. The outer narthex with side chapels was erected in 1236. Under the arches that support the dome were found twenty jug-like acoustic vessels. They were adjusted for this purpose in the sense that before they were built into the walls their mouths and their handles were broken off and a hole was centrally pierced at the bottom. These were larger jugs, with narrow long necks, one handle, a rounded body and the largest radius down from the middle zone (Бајаловић Хаџи-Пешић 1981: 60–61). It is important to emphasize that these jugs were horizontally positioned, but with the bottom orientated towards the inner space of the church. Nenadović (2003) wrote that fresco mortar was found on the bottoms of the vessels, but it was formed precisely around the openings of the vessels, leaving them exposed. Initially they were jugs for water, made of clay that stayed white after baking. One of the vessels extracted, enamelled in green, is conserved in the National Museum in Belgrade (Figure 4). There are traces of stripes on its surface on account of the production process on a winch and a decoration of tiny impressed dots. The vessel is 23.5 cm in height, the radius of the bottom 11 cm, the radius of the opening at the bottom 4.5 cm and the radius of the widest zone 17 cm (Бајаловић Хаџи-Пешић 1981; Ненадовић 2003). Jugs of this type from the 13<sup>th</sup> century had a ring-like bulge, horizontal engravings on the body and a clearly-marked foot with profiled edge (Бајаловић Хаџи-Пешић 1981).

**The Church of the Theophany of the Davidovica Monastery** near Brdarevo on the River Lim, is an endowment of Dimitrije Nemanjić, son of Vukan. In the book of the Dubrovnik Municipality, a contract from 1281 was found between old David (the monastic name of Dimitrije Nemanjić) and the mason Desina de Risa from Dubrovnik who was obliged to build the church in Brodarevo (Ђурић 1967). The artisan used older monuments in Raška style as a model. Therefore, the church

of Davidovica Monastery has one nave, a narthex, a dome supported by arches and pilasters, rectangular side chapels and domes on eight-sided drums. Although it is mentioned in the literature that there were four acoustic vessels initially built in (Нешковић 1961: 96), during *in situ* archaeological research of the space under the dome in 1997 there were found two ceramic acoustic vessels built into the western wall under the dome (Булић & Црнчевић 2010), where the rebated arch touches the pendentives (Ненадовић 1960). The vessels were horizontally positioned, with their bottoms installed in the mass of the wall and the openings orientated towards the interior space of the church (ibid.). The bottom of the first vessel is concave on the inside and flat on the outside, with the radius of 9 cm. The radius at the widest zone of the vessel is 15 cm. There is a perforation on the body of the vessel. It is assumed that it was pierced in order to prevent further breaking of the vessel. This could also suggest that the vessels were used acoustically only secondarily. Both vessels were produced in the same manner, but the second one has a slightly wider bottom of 10.6 cm. It also preserves a small handle with a button-shaped widening at the top. The outer surface of the vessel has a dark red color. There is a technical mark of the winch on the bottom of both vessels – a central circular recess, 2.5 cm in radius, and three imprints equidistant at 4.5 cm. This suggests that the vessels were produced in the same workshop (Булић & Црнчевић 2010: 116).

**The Church in the village of Trg, near Žagubica** is consecrated to the Nativity of the Theotokos (previously to St Nicholas). Since it was erected at the end of the 13th or at the beginning of the 14th century (Чанак-Медић 2006), it belongs to the younger monuments of the Raška architectural style. The church is a single-nave basilica with a semicircular altar apse, the dome supported by the pillars, narthex and exonarthex built at the end of the 14th century. The church is “well built ... and its whole is carefully composed” (ibid.). Although signs of acoustic vessels were noticed at the beginning of the 20th century (Петковић 1909), it was only recently proved to be one of the best-preserved findings. All nine acoustic pots, found in the north wall of the aisle of the church, were extracted and analyzed. It was found that the same pots were built into the south wall, but they were severely damaged during the wall reconstruction, as also in the ruined west wall. The acoustic pots found are of the same type and approximately the same dimensions (Figure 5). They have a flat bottom, round body, short neck with bent brim and decorative stripes. They were built in at a height of 3.75 m from the floor. The distinctive characteristic of these findings is that those pots were installed in the vertical position upside down, thus the opening of the vessels was orientated towards the floor (Чанак-Медић 2006). One of the pots has a hole pierced in its body. These nine pots are now preserved in the National Museum in Požarevac.

**The Church of the Presentation of the Holy Mother of God in Nova Pavlica Monastery, near Brvenik**, is the endowment of Stefan and Lazar Musić, nephews of prince Lazar Hrebeljanović. The church, built at the end of the 14th century is a monument of the Moravian architectural style. The plan is a triconch with a developed inscribed cross and a dome over a cubical pedestal, supported by freestanding columns. One acoustic vessel is found in each pendentive. They are positioned horizontally in the walls, with the opening orientated towards the interior of the church.

The openings are today blocked by wooden cylinders with a radius of approximately 8 cm. The height of the vessels ranges from 40 to 46 cm, and the radius of the opening is 10 cm (Бајаловић Хаџи-Пешић 1981).

**The Church of the Holy Mother of God in Donja Kamenica, near Knjaževac** was founded by an unknown Bulgarian nobleman, in the first quarter of the 14<sup>th</sup> century. The plan of the church is in the shape of an irregular cross, with dome and a one-storey narthex with two smaller bell-towers above. When the church was built, this region was not part of Serbia. One acoustic vessel is found in the south-west and one in the south-east pendentive (ibid.). The height of the vessels was reported to be 20 to 25 cm, but after the dome collapsed, none of the vessels was preserved (Ненадовић 2003).

**The Church of the the Ascension of Christ in Ravanica Monastery** is an endowment of the prince Lazar Hrebeljanović, erected in the eighth decade of the 14<sup>th</sup> century. After his death in the Battle of Kosovo in 1389, the relics of Prince Lazar were conveyed to the Ravanica Monastery. Subsequently, the monastery became a place of pilgrimage and the centre of the cult of St Lazar and the Martyrs of Kosovo. The church is built in Moravian architectural style. The plan is triconch with an inscribed developed cross, five domes on cubical pedestals and an open narthex built in the later period. One pitcher, mentioned as an acoustic one, was found during the conservation works (Бајаловић Хаџи-Пешић 1981).

**The Church of the village of Komarane** is ruined today. The exact date of construction is unknown. However, two ceramic vessels were found in the remains of the church. The vessels are 22 cm in height, the radius of the bottom 12.5 cm and the radius of the top 13 cm, with a central hole of 3 cm in radius. The widest dimension of the vessel is 18 cm. The thickness of the ceramic walls is approximately 5 mm. The pots are red colored and not enameled. They are considered to have been originally produced for this purpose (Ненадовић 2003; Булић & Црнчевић 2010). These acoustic pots are today preserved in the Faculty of Architecture University of Belgrade.

**In the domed chapel in the Tower of Saint George** in Hilandar Monastery, built in the 15<sup>th</sup> or 16<sup>th</sup> century, ceramic acoustic vessels were found in the north-east and north-west pendentives. The vessels were positioned horizontally, with the openings pointing towards the interior. The radius of the openings is 1–2 cm, with the mortar rounded at their edges. The height of the vessels is about 40 cm (Ненадовић 1960). The acoustic vessels are also found in the Chapel of Hilandar Monastery – behind the room where icons are stored. The space, 4.6 by 3.2 m, is vaulted with an irregular dome. One acoustic vessel is found in each south pendentive. Their height is about 50 cm. They are positioned horizontally and the opening is orientated towards the interior of the Chapel.

## ACOUSTIC STUDIES

The generally accepted view in Serbian literature was that ceramic vessels were inbuilt in the stone walls of medieval churches “for better acoustics” (Дероко 1930: 133). In other words, the vessels were considered to play the role of absorbing resonators, thus influ-

encing the equal distribution of the concentrated reflected sound on concave surfaces (Ненадовић 1960). Numerous factors affect the sound field in an interior space; these include the volume of the space, its geometry and the finishes of the interior surfaces (Mijić 2000). Apart from the differences in building styles, in the case of church architecture in medieval Serbia it may be generally stated that the walls are massive, built in stone, with a few relatively small openings, fresco-mortared from the inside with the icons made in *alfresco* technique (Ненадовић 1960), and the floors paved in stone tiles (Дероко 1962: 26). Acoustic vessels are only one way of regulating church acoustics.

At the beginning of the 21<sup>st</sup> century, acousticians and multidisciplinary archaeo-acoustic teams began systematic research into the acoustic vessels found and acoustic examination of the spaces in which they were found. All the acoustic vessels from the period of medieval Serbia belong to the Helmholtz type of resonators (Mijić & Šumarac-Pavlović 2004), which means that the vessels have a relatively small opening comparing to the radius of the widest part of the vessel. Helmholtz resonators are stand-alone sound absorbers with emphatically resonant behavior. Their main characteristic is the air enclosed by a solid partition, which is connected with the surrounding area by the narrow hole. These two parts are the volume and the neck of the Helmholtz resonator, respectively. The basic assumption is that the size of the whole Helmholtz system is small comparing to the sound wave length. Moreover, this system has only one resonant frequency in the relevant range. The resonant frequency of the Helmholtz resonator depends on the size of the opening, the length of the neck and the volume of the resonator. On this frequency, absorption is maximal. The value of the resonant frequency does not depend on the shape of the resonator. Besides the resonant frequency, important characteristics of Helmholtz resonators are the width of the absorption range and the declining rate of sound in the resonator. The resonant frequency is regulated by the volume, the length or the size of resonator's neck opening. However, the absorption range depends on the adhesion inside the resonator. A low value of resonant frequency is often reflected in the narrow absorption range of only several Hz. For maximal efficiency, Helmholtz resonators should be positioned in the zones of the space in which the standing wave effect is strong on the certain frequency.

The first acoustic research into the medieval ceramic vessels of Serbia, based on the calculations of acoustic parameters on available drawings of the vessels, were published in 1984 for two acoustic vessels found in the church of the village of Komarane from the 14<sup>th</sup> century (Kalić 1984). Laboratory measurements on the same vessels (Mijić & Šumarac Pavlović 2004) showed significantly lower resonant frequencies (124 Hz and 131 Hz) compared to Kalić's calculations (166 Hz). The divergence is on account of the thickness of the final layer of mortar, which was not part of Kalić calculations but was added to the opening of the resonator in the laboratory measurements in order to simulate the original state of the inbuilt resonator. That way, the effect of the *elongated neck* of the Helmholtz resonator was obtained, so it produced lower resonant frequencies. Based on these results, the authors argued that the acoustic vessels in medieval churches in Serbia did not contribute to the acoustic quality of the interior space, because the churches have small volumes, and thus the additional

absorption, or in other words the decrease of the already short time of reverberation (2 to 3 seconds), has no importance. The number of inbuilt vessels per church is small, so they could not make a significant difference in the church sound field. In addition, the resonant frequency of the vessels is too low, and the frequency range too narrow, to be aroused by the human voice dominant in Orthodox services. For all these reasons, the authors concluded that acoustic vessels were used as part of an orally transmitted tradition, without any comprehension of their acoustical function (Mijić & Šumarac-Pavlović 2004).

## DISCUSSION

Acoustic vessels were found in fifteen sacred edifices from medieval Serbia (Table 1), today in the territory of the central Serbia (12), Kosovo and Metohija (1) and Hilandar Monastery on Mount Athos (2). The map (Figure 1) shows all the monasteries in which acoustic vessels are reported. Different colors indicate the architectural style of the monuments. Thus, it is clear that two churches belong to the Pre-Nemanjić period (2/15), seven to Raška style group (7/15), three to Moravian style (3/15) and for three churches the building period is not yet established (3/15). In other words, the largest number of acoustic vessels is found from the Raška period, 12th and 13th centuries. It is important to notice that there is no evidence of acoustic vessels in the monuments belonging to the Byzantine style group. Also, acoustic vessels were found in only three churches from the Moravian period when they were built exclusively into the pendentives under the central dome. These data do not correspond to the above-mentioned belief that acoustic vessels were equally used in all periods of church building in medieval Serbia.

The findings of acoustic vessels in Serbia suggest that ceramic vessels such as pots, jugs and pitchers were used in Middle Ages. They were in general secondarily used for acoustic purposes. The rare examples of ceramic vessels intentionally produced for acoustic function are found in the church of Stara Pavlica Monastery near Brvenik, St Nicholas church near Kuršumljija and in the church in the village of Komarane.

The exact number and the positions of originally built-in acoustic vessels is impossible to determine. There are many reasons for this: the churches were partly or completely damaged during the course of history, during the reconstruction works some of the vessels were broken, and the openings of the vessels are often covered with mortar due to rebuilding or repainting works in the past. The largest number – 20 acoustic vessels – was found in the Mileševa Monastery. There are approximately seven vessels per church. Their height is in the range of 20 to 50 cm. In each church the acoustic vessels are similar in shape, with one or two different dimensions per church. Other archaeoacoustic studies also point out the consistency in the dimensions of the inbuilt vessels of medieval Europe (Valière & Palazzo-Bertholon 2014).

One of the acoustic vessels found in Davidovica Monastery and one in the church of the village of Trg have a pierced hole in the body of the vessel. It is explained that these holes were made in order to prevent further breaking of the vessel (Булић & Црнчевић 2010), but it can also suggest searching for the appropriate frequency.

The acoustic vessels in medieval Serbia were inbuilt in linear or triangular disposition. They were predominantly found in the pendentives, drums under the dome, in the zone of rebated arches and similar spherical surfaces. Jovanović wrote that they could be noticed “especially at the beginning of pendentives, their arches, drums of the domes where they exist, and generally in the walls around the altar...” (Јовановић 1909: 135). The acoustic vessels were horizontally embedded with the mouth opening orientated towards the interior of the church (Figure 2A). In the case of the Mileševa monastic church, acoustic vessels were also in horizontal position, but the pierced bottom was turned towards the inner space and the mouth was deep inside the wall (Figure 2B). The only exception to the horizontal positioning of acoustic vessels is in the church of the village of Trg where the vessels were positioned vertically, with the mouth orientated downwards.

One of the main questions considers the origin and the transmission of this acoustic tradition in the regions of medieval Serbia. Monuments of medieval sacred architecture developed combining various building and artistic understandings that came from Byzantine and Western cultures (Ђурић 1967: 87). With the shifting of Serbian medieval state borders (12<sup>th</sup> – 15<sup>th</sup> centuries), geographical boundaries occasionally included spiritual centres of the Adriatic coast – Duklja and Dalmatia – belonging to the Latin Church. In addition, artisans from the coast worked in Serbia and included architectural elements of Byzantine tradition, but also the environment accepted building characteristics that masons brought from Western Europe (Ђурић 1967: 92–93).

As has been shown, the builders had empirical knowledge of the acoustic laws, thus they understood that the effect of acoustic vessels was cumulative (Valière et al. 2013). In several cases in Serbia, the vessels were extracted from the walls during conservation works and afterwards stored in museums. Therefore, today is only possible to conduct acoustic measurements on those vessels in the laboratory or build corresponding three-dimensional models of the vessels and the entire space and thus examine acoustics through virtual acoustic simulation. The only acoustic study on acoustic vessels from medieval Serbia, based on the laboratory measurements of a single artifact, showed that the vessel was tuned to low frequencies (Mijić & Šumarac-Pavlović 2004), on which the absorption of usually wooden furniture (iconostasis, icon stands, pulpit, etc.) is less effective (Valière et al. 2013: 78). The results of this study were not enough to arrive at a general conclusion concerning the effectiveness of acoustic vessels in sacred architectural practice in medieval Serbia.

## CONCLUDING REMARKS

Multidisciplinary archaeoacoustic teams endeavor to illuminate regularities in the installing of acoustic vessels in the massive stone walls of medieval sacred architecture as well as to explain the motives behind this practice. This paper enabled the findings from medieval Serbian architecture to be included in the archaeoacoustic map of Europe and thus contribute the understanding of the relatedness of sound and architecture throughout the history of building. We addressed the oldest docu-

ment in which acoustic vessels are mentioned – *Ten Books on Architecture* by Vitruvius, and then overviewed the relevant archaeoacoustic studies and the acoustic intentions of medieval builders in Europe. Furthermore, we considered the findings of acoustic vessels from medieval Serbia – previous research, a census of the findings and acoustic studies – in order to discuss the research results in the context of archaeoacoustic interpretations.

We showed that a certain level of regularity occurs in the positioning of the vessels, as well as in their physical characteristics. Although they were predominantly embedded into the walls of churches built in the Raška architectural style (12th and 13th century), they are also found in other architectural periods with the exception of the Byzantine architectural style for which there are no reported findings of acoustic vessels so far. We also showed that the practice of acoustic vessels can be considered as a certain expression of musical tradition of sacred architecture in medieval Serbia. Nevertheless, it is necessary to conduct further research.

We pointed out that acoustic vessels, amongst other factors, influence spatial acoustics to a certain extent. In order to determine their range of influence it is necessary to continue with acoustical measurements *in situ*, acoustical examinations of computer models and laboratory research of the vessels. The results of only one piece of laboratory research – the acoustic vessels found in the church of the village of Komarane – has so far been published (Mijić & Šumarac-Pavlović 2004). However, there are several more vessels on which research could be done as well – the acoustic vessels from Mileševa Monastery and from the St Nicholas church near Kuršumljica are stored in the National Museum in Belgrade, and the vessels from the church in the village of “Trg” are stored in the National Museum in Požarevac. On the other hand, *in situ* measurements could be done in the churches in which acoustic vessels are still in their original positions, with the openings not covered with mortar. In this way the data collected would contribute to the understanding of acoustical regularities, if any, and the motives for this acoustical practice in medieval Serbia. Certainly, further research should not be predominantly acoustical, but have a multidisciplinary approach and offer deeper insights from the point of liturgy, religious iconography, archaeology and the transmission of building practice and the tradition of acoustic vessels through medieval Europe.

## Illustrations

**Table 1.** Overview of number, dimensions, orientation and the place of embedding of acoustic vessels found in churches of medieval Serbia

ACOUSTIC VESSELS IN THE CHURCHES OF MEDIEVAL SERBIA				
Church (founder, year)	No of vessels	Dimensions	Orientation	Position in the wall
The Church of the Holy Apostles Peter and Paul near Novi Pazar (8th c.)	11 + 8	D: 30 cm O: 3.5 cm	Horizontally embedded; orifice towards the church interior, not plastered	In the dome, 40 cm below the cornice, on the distance 0.5 – 1.0 m (11); in the apse are built in a row above the cornice and in the corners of the other conches (8) (Ненадовић 2003)
The Church of Sts Peter and Paul in Stara Pavlica Monastery near Brvenik (Pre-Nemanjić period, 12th c.; ruins)	8 + 4	D: 25 cm R1: 10–15 cm R2: 30 cm	Horizontally embedded; orifice towards the church interior, plastered; bottoms of vessels are seen from the outside	In the zone where the dome leans on the drum (wall) – 8 vessels on equal distances; one larger in each pendentive (Ненадовић 1960)
The Saint Nicholas Church near Kuršumljia (1168)	4	D: 31.7 cm O: 12 cm R: 13.5–24 cm	Horizontally embedded; orifice towards the church interior	One in the lower zone of each pendentive (kept in National Museum in Belgrade).
The Church of the Transfiguration of Christ in the village of Pridvorica (end of 12th c.)	4	D: 35 cm O: 10 cm	Horizontally embedded; orifice towards the church interior	Under the rebated arches that support the dome, two on the western and two on the eastern side (Бјаловић Хаџи-Пешић 1981)
The Church of the Ascension of Christ in Žiča Monastery (Stefan The First-Crowned, 13th c.)	11	O: 13–15 cm D: 38–43 cm	Horizontally embedded; orifice towards the church interior	Under the dome: in the wall of north choir is one at the height of the starting point of the rebated arch that supports the dome; in the western and northern diaphragm, under the western rebated arch (2); on the northern side, in the corner of western wall (1); in the pendentive of northern dome (1) * it is assumed that these vessels were initially in the opposite walls in the corresponding places, but they are now mortared over and covered with frescos (Ненадовић 2003)

ZORANA ĐORĐEVIĆ / KRISTINA PENEZIĆ / STEFAN DIMITRIJEVIĆ  
ACOUSTIC VESSELS AS AN EXPRESSION OF MEDIEVAL MUSIC TRADITION IN SERBIAN SACRED ARCHITECTURE

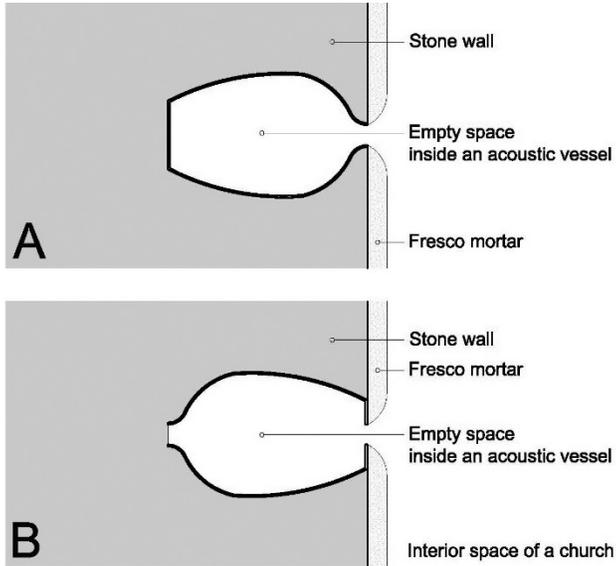
The Church of the Holy Apostles in the Patriarchate in Peć (first half of 13th c.)	4	O: 10 cm	/	Under the rebated arches on the northern, western and eastern sides (Бајаловић Хаџи-Пешић 1981)
The Church of the Ascension of Christ in the Mileševa Monastery (Stefan Vladislav, 13th c.)	20	D: 23.5 cm O: 2.5 cm R: 16.5–17 cm Ro: 1.2 – 4.5	Horizontally embedded; orifice towards the church interior, not plastered	Under the arches that support the dome; bottom of jugs is pierced; one jug is enamelled with green colour, kept in National Museum in Belgrade (Бајаловић Хаџи-Пешић 1981, Ненадовић 2003)
The Church of the Theophany of the Davidovica Monastery (Dimitrije Nemanjić, end of 13th c.; vessels dated to 1282)	2	R: 9–16 cm	Horizontally embedded; orifice towards the church interior; bottom is convex from the inside	Two pots are found in the western wall under the dome, where the arch touches the pendentive (not in the pendentive) (Булић & Црнчевић 2010)
The Church in the village of Trg near Žagubica (end of 13th –beginning of 14th c.)	9	/	Vertically embedded pots; orifice towards ground	Northern wall of northern aisle in the nave; same pots were built in the western and southern walls; kept in the National Museum in Rožarevac (Чанак-Медић 2006)
The Church the Presentation of the Holy Mother of God in Nova Pavlica Monastery (Musić brothers, end of 14th c.)	4	O: 10 cm D: 40–46 cm	Horizontally embedded; orifice towards the church interior;	One in each pendentive; today, the openings are closed with wooden logs of ~8 cm in radius (Бајаловић Хаџи-Пешић 1981)
The Church of the Holy Mother of God in Donja Kamenica (Bulgarian nobleman, end of 14th c.)	2	D: 20–25 cm	/	One in south-west and one in south-east pendentive (Бајаловић Хаџи-Пешић 1981); after the fall of the dome, none of the acoustic vessels were saved (Ненадовић 2003)

The Church of the Ascension of Christ in Ravanica Monastery (Prince Lazar Hrebeljanović, 14th c.)	1	/	/	The vessel was found during the conservation works (Бајаловић Хаџи-Пешић 1981)
The Church in the village of Komarane (year unknown; today in ruins)	2	D: 22 cm R: 12.5–18 cm / O: 3 cm		Pots were custom made (for this purpose only), red coloured without enamel (Ненадовић 2003); kept in the Faculty of Architecture University of Belgrade
Domed chapel in the Tower of Saint George of Hilandar Monastery (15th or 16th c.)		O: 1–2.0 cm D: 40 cm	Horizontally embedded; orifice towards the church interior, not plastered	In both northern pendentives (Ненадовић 2003)
The Chapel of Hilandar Monastery (year unknown)	2	D: 50 cm	Horizontally embedded; orifice towards the church interior	One in both southern pendentives

\* D: depth; O: orifice; R: radius of the widest part; RO: radius of the opening on the bottom of the vessel



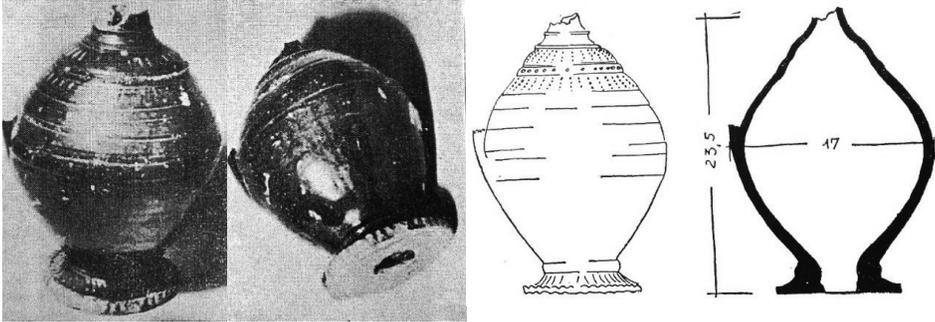
Map of acoustic vessels found in medieval Serbia



The horizontal position of the embedded acoustic vessel in the stone wall, with the opening towards the interior church space (A) and with the pierced bottom orientated towards the interior space (B)

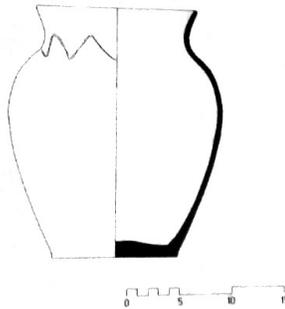


Openings of acoustic vessels in the Church of Sts Peter and Paul in Novi Pazar  
(Source: Нешковић & Николић 1987)



Acoustic vessel enamelled with green colour with a hole in the bottom, from Mileševa Monastery

(Source: Ненадовић 1960)



Acoustic pot from the Church in the village of Trg near Žagubica

(Source: Чанак-Медић 2006)

### LIST OF REFERENCES

- Alvarez-Morales, Lidia & Martellotta, Francesco (2015) "A geometrical acoustic simulation of the effect of occupancy and source position in historical churches." *Applied Acoustics*, 91: 47–58, <http://www.sciencedirect.com/science/article/pii/S0003682X14003119>
- Arns, Robert G. & Crawford, Bret E. (1995) "Resonant Cavities in the History of Architectural Acoustics." *Technology and culture* 36(1): 104–135.
- Бајаловић Хаџи-Пешић, Марија (1981) *Керамика у средњовековној Србији*. Београд: Музеј града Београда, 71–73 / Bajalović Hadži-Pešić, Marija (1981) *Keramika u srednjovekovnoj Srbiji*. Beograd: Muzej grada Beograda [*Ceramics in Medieval Serbia*].
- Булић, Дејан & Црнчевић, Дејан (2010) "Звук и грађење: примери акустичких судова из цркве манастира Давидовица." *Историјски часопис* књ. LIX, 103–130 / Bulić, Dejan & Crnčević, Dejan (2010) "Zvuk i građenje: primeri akustičkih sudova iz ckve manastira Davidovica." *Istorijski časopis*

- knj. LIX: 103–130 [“Sound and Construction: Example of Acoustic Resonators in the Church of the Davidovica Monastery.” *The Historical Review*].
- Baumann, Dorothea (1990) “Musical acoustics in Middle Ages.” *Early Music*, May 1990, 199–209.
- Carvalho, António, Desarnaulds, Victor & Loerincik, Yves (2002) “Acoustic behavior of ceramic pots used in middle age worship spaces – a laboratory analysis.” Paper presented at *Ninth international congress on sound and vibration ICSV9*, Orlando, USA, July 8–11.
- Cirillo, Ettore & Martellotta, Francesco (2007) “Acoustics and architecture in Italian Catholic churches.” In: *International Symposium on Room Acoustics: Satellite Symposium of the 19<sup>th</sup> International Congress on Acoustics*, Seville, 10–12 September 2007.
- Crunelle, Marc (2009) “Is There an Acoustical Tradition in Western Architecture?” In: *PROHITECH 09: proceedings of the International Conference on Protection of Historical Buildings*, Romem, 1115–1120.
- Дероко, Александар (1930) “У Бодиновој престоници.” *Сѝаринар V*: 128–151 / Deroko, Aleksandar (1930) “U Bodinovoј prestonici.” *Starinar V*: 128–151 [“At King Bodin’s Capital”]
- Дероко, Александар (1962) *Монументална и декоративна архитѝектѝура у средњовековној Србији*. Београд: Научна књига / Deroko, Aleksandar (1962) *Monumentalna i dekorativna arhitektura u srednjovekovnoj Srbiji*. Beograd: Naučna knjiga [Monumental and Decorative Architecture in medieval Serbia].
- Desarnaulds, Victor, Loerincik, Yves & Carvalho, António P. O. (2001) “Efficiency of 13<sup>th</sup> century acoustic ceramic pots in two Swiss churches.” *NOISE-CON 2001*, 29–31 October, Portland, ME.
- Desarnaulds, Victor (2002) *De l’acoustique des églises en Suisse – une approche pluridisciplinaire*. Doctoral thesis. Lausanne: Ecole Polytechnique Federale de Lausanne.
- Ђорђевић, Зорана, Ђале, Иван & Димитријевић, Стефан (2016) “Acoustical Heritage of Medieval Serbia: The Case of Two Moravian Style Churches.” Conference Proceedings *Archaeoacoustics II*, 30 October –1 November 2015, Istanbul, 51–60.
- Ђорђевић, Зорана З. (2016) *Принципи и историја односа архитѝектѝуре и акустике*. Докторска дисертација. Београд: Универзитет у Београду, Студије при Универзитету, Мултидисциплинарне докторске студије / Ђорђевић, Зорана З. (2016) *Principi i istorija odnosa arhitekture i akustike*. Doktorska disertacija. Beograd: Univerzitet u Beogradu, Studije pri univerzitetu, Multidisciplinarne doktorske studije [Principles and History of the Relatedness of Architecture and Acoustics. Doctoral thesis. Belgrade: University of Belgrade, Studies at the University, Multidisciplinary Postgraduate Studies].
- Ђурић, Војислав Ј. (1967) “Дубровачки градитељи у Србији средњег века.” *Зборник за ликовне уметности* 3. Нови Сад: Матица српска – одељење за ликовне уметности, 85–103 / Ђурић, Војислав Ј. (1967) “Dubrovački graditelji u Srbiji srednjeg veka.” *Zbornik za likovne umetnosti* 3. Novi Sad: Matica srpska – odeljenje za likovne umetnosti, 85–103 [“Builders from Dubrovnik in Medieval Serbia”].
- Elicio, Luigi & Martellotta, Francesco (2015) “Acoustics as a Cultural Heritage: The Case of Orthodox Churches and of the ‘Russian Church’ in Bari.” *Journal of Cultural Heritage* 1–6. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1296207415000254>.
- Godman, Rob (2006) “The enigma of Vitruvian resonating vases and the relevance of the concept for today.” *Working papers in art and design* 4. [https://www.herts.ac.uk/\\_\\_data/assets/pdf\\_file/0020/12377/WPIAAD\\_vol4\\_godman.pdf](https://www.herts.ac.uk/__data/assets/pdf_file/0020/12377/WPIAAD_vol4_godman.pdf)

- Howard, Deborah & Moretti, Laura (2009) *Sound and Space in Renaissance Venice – Architecture, Music, Acoustics*. New Haven and London: Yale University Press.
- Јовановић, Коста (1909) “Стара Павлица.” *Старинар* II: 135–136 / Jovanović, Kosta (1909) “Stara Pavlica.” *Starinar* II: 135–136 [“Old Pavlica”].
- Johnston, Ian (2009) *Measured Tones: The Interplay of Physics and Music*. Boca Raton: CRC Press Taylor & Francis Group.
- Jurković, Miljenko & Turković, Tin (2012) “La Croatie médiévale: état des lieux.” In: Bénédicte Palazzo-Bertholon & Jean-Christophe Valière (eds.), *Archeologie du Son: Les dispositifs de pots acoustiques dans les édifices anciens*. Paris: Supplément au Bulletin monumental n° 5, Société Française d’Archéologie, 133–139.
- Kalić, Dušan (1984) “Acoustic resonators in Serbian medieval churches.” II Joint meeting of Greek and Yugoslav Acoustical Societies Proceedings, 91–97
- Marasović, Tomislav (2003) “Patere i amfore u svodovima ranosrednjovekovnih crkava u Dalmaciji.” *Starohrvatska prosvjeta* III (30), 113–125 [“Pateras and Amphoras in the Domes of Early-Medieval Churches in Dalmatia”].
- Martellotta, Francesco, Cirillo, Ettore, Crociata, Sabrina della, Gasparini, Emanuele & Preziuso, Daniela (2008) “Acoustical reconstruction of San Petronio Basilica in Bologna during the Baroque period: the effect of festive decorations.” *The Journal of the Acoustical Society of America* 123(5). Available at: <http://scitation.aip.org/content/asa/journal/jasa/123/5/10.1121/1.2934787>
- Mijić, Miomir & Šumarac-Pavlović, Dragana (2004) “Analysis of Contribution of Acoustic Resonators Found in Serbian Orthodox Churches.” *Building Acoustics* 1(3): 197–212.
- Mijić, Miomir (2000) “Akustika pravoslavnih crkava – sinteza objektivnog i subjektivnog u akustičkim komunikacijama.” Telekomunikacioni forum TELFOR 2000, Beograd, Srbija, November 21–22 [“Acoustics of Orthodox Worship Spaces – A Synthesis of the Objective and Subjective in Acoustical Communication”], <http://www.telfor.rs/telfor2000/radovi/7-1.pdf>.
- Navarro, Jaime, Sendra, Juan & Muñoz, Salvador (2009) “The Western Latin church as a place for music and preaching: An acoustic assessment.” *Applied Acoustics* 70(6), 781–789. Available at: <http://dx.doi.org/10.1016/j.apacoust.2008.09.014>.
- Ненадовић, Слободан (1960) “Резонатори у црквима средњовековне Србије.” *Зборник Архитектонског факултета Универзитета у Београду* 5, 3–11 / Nenadović, Slobodan (1960) “Rezonatori u crkvama srednjovekovne Srbije.” *Zbornik Arhitektonskog fakulteta Univerziteta u Beogradu* 5, 3–11 [“Resonators in the medieval Serbian Churches”].
- Ненадовић, Слободан (2003) *Грађевинска техника у средњовековној Србији*. Београд: Просвета, 438–439 / Nenadović, Slobodan (2003) *Грађевинска техника у средњовековној Србији*. Београд: Просвета, 438–439 [Technique of Construction in medieval Serbia].
- (“)“: Републички завод за заштиту споменика културе Београд 89–112 / Nešković, Jovan (1961) “Crkva manastira Davidovice na Limu.” *Saopštenja Republičkog zavoda za zaštitu spomenika kulture* IV, Beograd: Republički zavod za zaštitu spomenika kulture Beograd, 89–112 [“The Church of the Davidovica Monastery on the River Lim”], [http://www.heritage.gov.rs/cirilica/Download/Saopstenja/Saopstenje-IV-1961/Saopstenje\\_IV\\_1961\\_Crkva\\_manastira\\_Davidovice\\_na\\_Limu.pdf](http://www.heritage.gov.rs/cirilica/Download/Saopstenja/Saopstenje-IV-1961/Saopstenje_IV_1961_Crkva_manastira_Davidovice_na_Limu.pdf).
- Нешковић, Јован & Николић, Радомир (1987) *Петрова црква код Новог Пазара*. Београд: Републички завод за заштиту споменика културе Београд / Nešković, Jovan & Nikolić, Radomir

- (1987) *Petrova crkva kod Novog Pazara*. Beograd: Republički zavod za zaštitu spomenika kulture Beograd [St. Peter's Church near Novi Pazar].
- Palazzo-Bertholon, Bénédicte & Valière, Jean-Christophe (eds.) (2012) *Archéologie du Son: Les dispositifs de pots acoustiques dans les édifices anciens*. Paris: Supplément au Bulletin monumental n° 5, Société Française d'Archéologie.
- Пено, Весна (2008) *Појачки зборници у српским рукописним ризницама од XV до XIX века*. Докторска дисертација (необјављена). Београд: Универзитет у Београду, Филозофски факултет / Peno, Vesna (2008) *Pojački zbornici u srpskim rukopisnim riznicama od XV do XIX veka*. Doktorska disertacija (neobjavljena). Beograd: Univerzitet u Beogradu, Filozofski fakultet [*Chanting Codices in the Serbian Manuscript Treasures from the 15<sup>th</sup> to the 19<sup>th</sup> Century*, Doctoral Thesis (unpublished). Belgrade: University of Belgrade, Faculty of Philosophy].
- Петковић, Владимир (1909) “Жича.” *Сѣаринар* IV, 27–106 / Petković, Vladimir (1909) “Žiča.” *Starinar* IV, 27–106 [“The Žiča Monastery”].
- Поповић, Светлана (1993) *Крст у кругу – архитектура манастира у средњовековној Србији*. Београд: Републички завод за заштиту споменика културе Београд / Popović, Svetlana (1993) *Krst u krugu – arhitektura manastira u srednjovekovnoj Srbiji*. Beograd: Republički zavod za zaštitu spomenika kulture Beograd [*The Cross in the Circle*].
- Pouille, Bruno (2000) “Les vases acoustiques du théâtre de Mummius Achaicus.” *Revue Archéologique*, Nouvelle série 1: 37–50.
- Reznikoff, Igor (2005) “On Primitive Elements of Musical Meaning.” *The Journal of Music and Meaning* vol.3, section 2, <http://www.musicandmeaning.net/issues/showArticle.php?artID=3.2>.
- Suárez, Rafael, Alonso, Alicia & Sendra, Juan (2015) “Intangible cultural heritage: The sound of the Romanesque cathedral of Santiago de Compostela.” *Journal of Cultural Heritage*, 16(2), 239–243. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1296207414000788>.
- Татић, Жарко (1929) *Трајом велике прошлости. Свештојерска њисма и монографске сјудуге сѣаре српске архитектуре*. Београд: издање аутора / Tatić, Žarko (1929) *Tragom velike prošlosti*. Beograd: izdanje autora [*Tracing the Great Past*].
- Томовић, Гордана (2000) “Топлица у средњем веку.” Зборник радова са научног скупа *Куршумлија кроз векове*, Пролом Бања / Tomović, Gordana (2000) “Toplica u srednjem veku.” Zbornik radova sa naučnog skupa *Kuršumljia kroz vekove*, Proлом Banja [“Toplica in the Middle Ages”].
- Vachez, Antoine (1886) “Des echea ou vases acoustiques dans le théâtres antiques et les églises du Moyen Age.” *Congres Archéologique*, Paris: 253–279.
- Valière, Jean-Christophe, Palazzo-Bertholon, Benedicte & Polack, Jean-Dominique (2013) “Acoustic Pots in Ancient and Medieval Buildings: Literary Analysis of Ancient Texts and Comparison with Recent Observations in French Churches.” *Acta Acoustica united with Acoustica* 99: 70–81. Available at: <http://www.ingentaconnect.com/content/dav/aaua/2013/00000099/00000001/art00011?crawler=true>.
- Valière, Jean-Christophe & Palazzo-Bertholon, Benedicte (2014) “Le dispositif acoustique du caveau de la cathédrale de Noyon (Oise).” CFA 2014, Poitiers, France, April 22–25.
- Валтровић, Михаило & Милутиновић, Драгутин (2006) *Валтровић и Милутиновић, документи 1, теренска грађа 1871–1884*. Ур. Тања Дамљановић. Београд: Историјски музеј Србије / Valtrović, Mihailo & Milutinović, Dragutin (2006) *Valtrović i Milutinović, dokumenti 1, terenska građa 1871–*

1884. Ur. Tanja Damljanović. Beograd: Istorijski muzej Srbije [*Valtrović & Milutinović, Documents 1, Field Work 1871–1884*].

Vitruvius, Marco Pollio (1914) *The Ten Books on Architecture*. Translated by Morris Hicky Morgan. Cambridge: Harvard University Press.

Wittkower, Rudolf (1971) *Architectural Principles in the Age of Humanism*. New York: W.W. Norton & Company.

Zakinthinos, Tilemachos & Skarlatos, Dimitris (2007) "The Effect of Ceramic Vases on the Acoustics of Old Greek Orthodox Churches." *Applied Acoustics* 68: 1307–1322.

Zamarreño, Teófilo, Girón, Sara & Galindo, Miguel (2008) "Assessing the intelligibility of speech and singing in Mudejar-Gothic churches." *Applied Acoustics* 69(3), 242–254. Available at: <http://www.sciencedirect.com/science/article/pii/S0003682X06002015>.

Чанак-Медић, Милка (2006) *Архитектура групе њоловине XIII века I*. Београд: Републички завод за заштиту споменика културе Београд / Čanak-Medić, Milka (2006) *Arhitektura druge polovine XIII veka I*. Beograd: Republički zavod za zaštitu spomenika kulture Beograd [*Architecture of the Second Half of the 13th Century I*].

*Зорана Ђорђевић, Кристина Пенезић и Стефан Димиријевић*

АКУСТИЧКИ СУДОВИ КАО ИЗРАЗ МУЗИЧКЕ ТРАДИЦИЈА СРПСКЕ  
 СРЕДЊОВЕКОВНЕ АРХИТЕКТУРЕ

(САЖЕТАК)

Истраживање звука у архитектури завређује посебно место у студијама културног наслеђа, захтевајући притом мултидисциплинаран приступ. Кроз градитељску историју Европе, од античког до савременог доба, коришћени су одређени судови, за које се сматра да су имали акустичку намену. Овај рад представља резултате истраживања акустичких судова уграђених у камене зидове сакралне архитектуре средњовековне Србије и одговара на питање да ли се ова пракса може сматрати изразом извесне музичке традиције. У првом делу рада сагледан је шири контекст археоакустичких истраживања средњовековне Европе. Представљени су кључни изводи из Витрувијевог дела *Десет књига о архитектури* – најстаријег документа са описом акустичких судова. Затим, дат је кратак преглед релевантних археоакустичких студија и извода који илуструју акустичке намере средњовековних градитеља. У другом делу рада представљени су налази акустичких судова из средњовековне Србије – историјски оквир истраживања, преглед истраживања ове теме код нас, попис налаза (из укупно 15 цркава) и досад спроведене акустичке студије. У трећем делу рада дискутована су физичка својства акустичких судова, њихов

распоред, позиција и оријентација у зиду, акустичке одлике, итд. Показано је да постоји одређени ниво правилности у постављању судова, као и у њиховим физичким својствима. Пронађени су у свим осталим градитељским периодима осим у византијској групи споменика (доминантно у Рашкој, XII-XIII век). Поред тога што је показано да се пракса узиђивања акустичких судова може сматрати извесним изразом музичке традиције сакралне архитектуре средњовековне Србије, такође је указано на неопходност даљих истраживања – акустичких мерења *in situ*, испитивања рачунарских модела или лабораторијских мерења судова. Поврх свега, овај рад омогућио је да се налази акустичких судова из српске средњовековне архитектуре позиционирају на археоакустичкој мапи Европе и тако допринесу разумевању односа звука и архитектуре кроз историју градитељства.

Кључне речи: акустички судови, археоакустика, сакрална архитектура средњег века, средњовековна Србија