

## Original Study

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# Archaeoacoustic Research of Ljubostinja and Naupara Medieval Monastic Churches

<https://doi.org/10.1515/opar-2019-0018>

Received February 18, 2019; accepted May 1, 2019

**Abstract:** The overall experience of religious practice is significantly affected by the acoustical properties of temples. Divine service is the most important act in the Orthodox Church, which equally demands intelligibility of speech for preaching and as well as adequate acoustics for Byzantine chanting as a form of a song-prayer. In order to better understand and contribute to unlocking the role of sound in these historical sacral spaces, this paper explores the acoustics of two well-preserved Orthodox churches, from Ljubostinja and Naupara monastery, built in the last building period of medieval Serbia (1371–1459). These represent two types of the Morava architectural style – triconch combined with a developed and compressed inscribed cross, respectively. Using EASERA software, we measured the impulse response for two sound source positions – in the altar and in the southern chanting apse, as the main points from which the Orthodox service is carried out. Thus obtained acoustic parameters (RT, EDT, C50 and STI) were further analysed, pointing out the differences in experiencing sound between naos and narthex, as well as how the position of the sound source influenced the experience of sound. Finally, we compared the results with previous archaeoacoustic research of the churches from the same building period.

**Keywords:** acoustic heritage, Orthodox Church acoustics, Morava architectural style, medieval Serbia, architectural heritage

## 1 Introduction

Although medieval architectural heritage seemed to provide only visual artefacts for further scientific research, recently auditory characteristics have been taken into account as an important source of information for architectural reconstructions, conservation works and above all to further understandings of sensory experience in specific surroundings. Each space works like a kind of a filter, *colouring* all the audio content in its specific *spectrum of colours*. Places of interest for archaeoacoustic research are those in which the sound (whether music or spoken word) defines its purpose throughout history – such as theatres, temples, music rooms, etc.

The published archaeoacoustic studies of Christian temples are overviewed by Girón et al. (2017), while Elicio and Martellota (2015) summarized the available acoustical data for Orthodox Christian churches in Europe. The sound in Byzantine churches is a focus of a multidisciplinary project, *Soundscapes of Byzantium*,

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**Article note:** This article is a part of the Special Issue on Unlocking Sacred Landscapes: Digital Humanities and Ritual Space, edited by Giorgos Papantoniou, Apostolos Sarris, Christine E. Morris & Athanasios K. Vionis

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that considers not only the acoustical parameters but also the live chant recordings and correlated imagery in Thessaloniki churches (Gerstel et al., 2018; Antonopoulos et al., 2017). The acoustics of Serbian Orthodox churches was researched in general (Mijić, 2000) and specifically for the medieval period (Đorđević et al., 2015, 2017; Nenadović, 2003).

This paper addresses the acoustics of Ljubostinja and Naupara monastic churches, built in the last period of the Serbian medieval state before it was conquered by the Ottoman Empire (1371–1459). The political circumstances in the second half of the 14<sup>th</sup> century led to the collapse of Serbian empire and the division of its territory among local rulers. Considering himself a successor of the previous royal Nemanjić dynasty, prince Lazar Hrebeljanović ruled the region around the Morava river that became the economic and cultural centre of the time. The monasteries had an essential role in this cultural development (Vulović, 1966), in which the authentic Morava architectural style arose. The acoustics of monastic churches were important as the chanting art also reached the peak of its development in this last period of the Serbian medieval state (Peno & Obradović, 2017).

A church built in the Morava architectural style has a narthex, a naos and an altar (from west to east). It is a triconch in plan, combined with a compressed or developed inscribed cross. Triconch plan implies three apses (conchas) – an altar apse in the east and chanting apses on north and south, circular on the inside and multi-sided on the façade. They are vaulted with a half-calotte. In the case of the developed cross plan, the central dome is supported by four columns (Ljubostinja church), while in the case of the compressed cross the weight of the dome is directly transmitted through pilasters on the walls (Naupara church). Considering both types, this paper compares the results of archaeoacoustic research for Ljubostinja and Naupara monastic churches that were built within a few years of each other, close to the capital fortification of Kruševac city from where prince Lazar ruled (about 30 km away from Ljubostinja and 13 km away from Naupara monastery) and built one of his endowments – Lazarica church.

**Ljubostinja Monastery** was founded between 1381 and 1388 as an endowment of the princess, Milica Hrebeljanović, wife of prince Lazar (Đurić, 1985). When their son, Stefan Lazarević, took over the rule in 1393, Milica retreated to Ljubostinja monastery where she later died as a nun, known as Evgenija.

Ljubostinja monastic church is consecrated to the *Uprising of the Holy Mother of God*. It represents a mature period of the Morava architectural style. Symmetry and harmony are the main principles of its architecture. Originally, there were symmetrical portals on each side of the narthex that was built simultaneously with the naos. The narthex has almost cubic form – a square plan with a blind calotte on pendentives and a cross-shaped roof. There is a low stone bench connected to the walls all around. The narthex and naos are divided by a massive wall with two doors – a central door and one smaller door close to the northern wall.<sup>1</sup> Almost square in plan, the naos is triconch combined with a developed inscribed cross (Đurić, 1985). The interior space of the naos is focused on the highest point of the dome – about 17.7 m. Massive pillars support the arches between which are the pendentives that support the cylindrical drum and the dome.

The church was built with five entrances (three in the narthex and two in the chanting apses), but over the centuries it was modified – side portals of the narthex were closed as well as the hidden staircase window. All interior wall surfaces were originally fresco-plastered. Today, the frescoes are significantly damaged and conservation works recommended covering the area between the remained frescoes with a new render (Figure 1).

**Naupara Monastery** was founded in the 14<sup>th</sup> century. Although there are no written documents relating to its construction, the charter of Drenča monastery from 1382 states that its founders – the monk, Dorotej, and his son, hieromonk Danilo – donated Naupara to the newly found Drenča monastery. Therefore, it is believed that the founders of Drenča monastery were also the founders of Naupara monastery. Regarding the architecture of monastic church, it is believed that Lazarica church in Kruševac was used as a role model, so the building of Naupara church is dated to between 1377 and 1382 (Popović & Čurčić, 2000).

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<sup>1</sup> Under the doorstep of central door between narthex and naos, the name of church builder is inscribed – “*Protomajstor Borovič Rad [Протомајстор Боровић Рад]*“. It is the only known name of Morava style builders (Ristić, 1996).

Naupara monastic church is consecrated to the *Birth of the Holy Mother*. The triconch plan of Naupara church is combined with a compressed inscribed cross. Naos and narthex are built simultaneously (Ristić, 1996). The narthex has two entrances – in western and northern wall. It is vaulted with a blind calotte, with a tower above that could be reached through staircases in southern wall. The narthex and the naos communicate through a massive stone portal. Four pilasters in the naos, connected with longitudinal walls, support the arches. As in Ljubostinja church, the arches are mutually connected with wooden tension ties. Between the arches, irregular pendentives act as a support for a cubic pedestal that is cylindrical from the inside and above which is an eight-sided drum and a dome.



**Figure 1.** Temple of the Uprising of the Holy Mother of God, Ljubostinja monastery: exterior view (top), view from the narthex towards naos (middle left), central dome (middle right) and view towards the altar and wooden iconostasis. Photo credits: Zorana Đorđević.

The church walls were built in three layers – two layers of partly-cut sandstone with two faces and the filling with smaller pieces of stone. The portals and rosettes (twelve in various dimensions) are cut in stone and the doors are made of wood. Roofs are covered with galvanized copper sheet on wooden planks. All interior church walls were originally painted in frescos that are today highly-valued Morava style paintings from the end of the 14<sup>th</sup> and beginning of the 15<sup>th</sup> century (Ristić, 1994). The iconostas (the icon screen that visually separates altar from the naos) is from the second half of the 19<sup>th</sup> century, made of wood. The church used to have *polijelej* – large chandeliers with many lights and icons, hanging under the central dome.

Naupara church was reconstructed in 1835 when, among other works, the dome with the drum was rebuilt. The monastery has been protected as cultural heritage since 1949. The preservation works in the nineties ordered the repair of the structure, conservation and part-restoration of the architecture and fresco paintings. Also, the original medieval horizontal alignment of floors was discovered and renewed (Popović & Ćurčić, 2000).

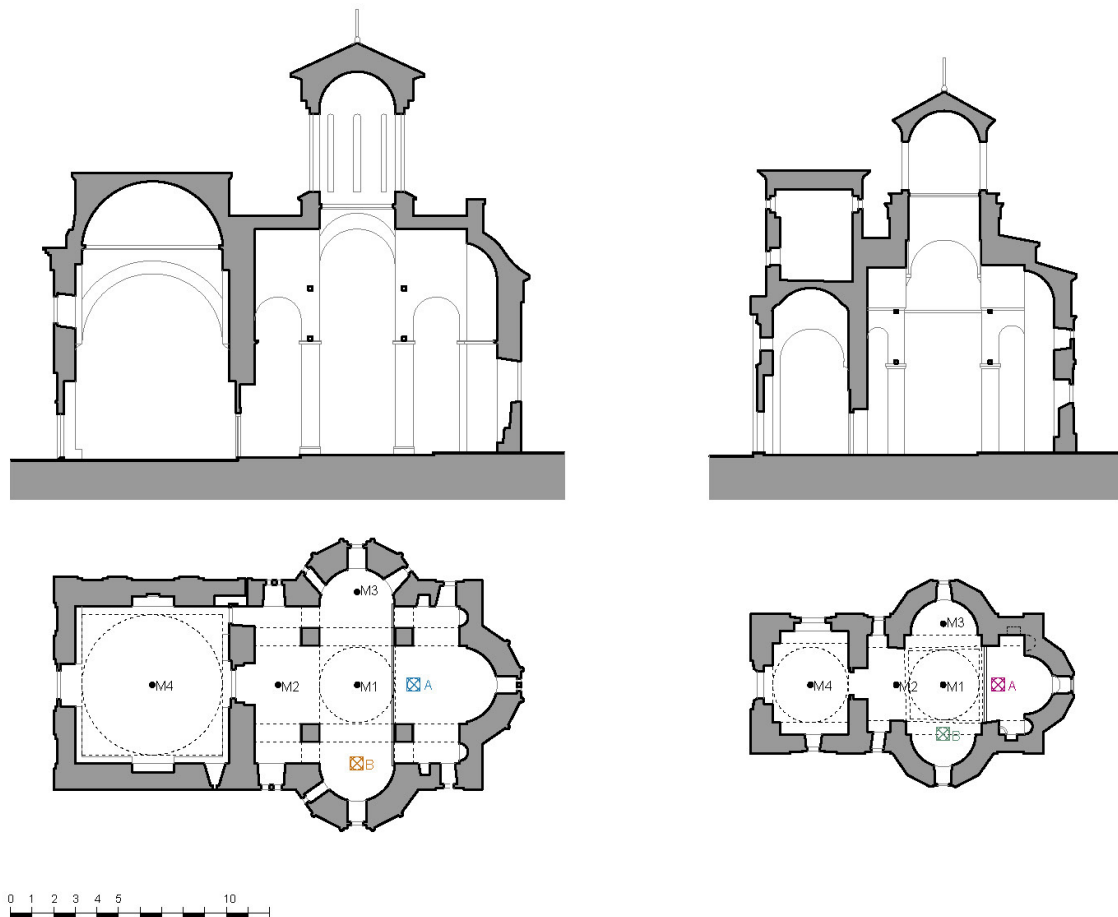


**Figure 2.** Temple of the Birth of the Holy Mother, Naupara monastery: exterior view (top) and interior view of the naos and central dome (bottom) where wooden iconostasis and fresco remains could be observed. Photo credits: Zorana Đorđević.

## 2 Methodology: On-Site Acoustic Measurement

The main intention of the conducted measurements was to investigate monophonic acoustic parameters defined by the ISO 3382 set of standards, as a starting point for further analysis of basic sound field properties. Due to the available equipment, the spatial aspect of sound field was investigated through separately-organized measurement sessions, based on recommendations made by Farina and Tronchin (2005). Having this in mind, only monaural measurements were undertaken. Measurement of impulse response was carried out in two monastic churches built in the Morava architectural style – Ljubostinja and Naupara church. A sine sweep signal in the range of 20 Hz to 20 kHz was used as excitation. EASERA software and the following equipment were used: laptop Fujitsu LIFEBOOK E Series, sound card *Digidesign Mbox2 mini*, active speaker *dB Opera 110* and measurement microphone *Behringer ECM 8000*.

Due to the Orthodox religious practice, we determined two speaker positions – in the altar (position A) and in the southern chanting apse (position B). Measurement points were distributed to cover the area where the faithful gather to attend the divine service. There are four of them for each church: (1) under the central dome, (2) in the western bay of the naos, (3) in the northern chanter apse and (4) in the centre of the narthex (Figure 3). The microphone was placed at a height of 180 cm.



**Figure 3.** The plan and longitudinal section of Ljubostinja (on the left) and Naupara monastic church (on the right) with marked positions of sound sources (A – in the altar, B – in the southern chanting apse) and measurement points (M1 – under the central dome, M2 – west side of naos, M3 – northern chanting apse, M4 – centre of the narthex).

### 3 Results

The most investigated acoustic parameter is Reverberation Time (T), often used for acoustic comparison of spaces with similar volume and purpose. Reverberation time (expressed in seconds) depends on the room geometry and absorption of surfaces in the room. It is defined as the duration required for the averaged sound pressure level in an enclosure to decrease by 60 dB after the source emission has stopped. It can be evaluated based on a smaller dynamic range than 60 dB and extrapolated to a decay time of 60 dB. In that case, it is labelled accordingly ( $T_{20}$ ,  $T_{30}$ ...). For the purposes of this paper,  $T_{30}$  values are used (ISO 3382-2, first edition 2008-06-15).

Additional information about acoustic field can be obtained by analysing the starting section of the sound energy decay curve. Early Decay Time (EDT) is a parameter defined by an interval of the first 10 dB decay. If the decay rate of very early energy is increased in relation to the later energy, the EDT will be shorter than  $T_{30}$ . In that case, clarity and intelligibility are increased even in rooms that are very reverberant otherwise. On the other hand, higher values of EDT (comparing to  $T_{30}$ ) can indicate speech intelligibility problems, especially in the more reverberant spaces, such are churches. In the results presented here, for example, such a situation appears in the case of sound field excitation from the altar.

**Table 1.** Mean values of Reverberation Time and Early Decay Time for Ljubostinja church and Naupara church.

Part of the church	T30 [s]	EDT [s]
Naos	1.79	1.41
	1.61	1.19
Narthex	2.35	2.80
	1.70	1.39

Figure 4 shows the  $T_{30}$  and EDT values in the octave range for Ljubostinja (on the left) and Naupara monastic church (on the right), obtained at 4 measurement positions for the cases of excitation from the altar and the chanting apse. All graphs show similar values for  $T_{30}$  and EDT values. A significant deviation can be observed only in the case of a measuring position M4, namely in the narthex of Ljubostinja church. This difference is not so pronounced for the same measurement positions in Naupara church. Measurement position M4 is in the middle of narthex, while the excitation sound source is in the chanting apse of naos. To better understand this result, we should consider that the narthex and the naos are two different rooms connected with a door, which makes them acoustically coupled spaces. It means that sound energy decay curve in the receiving room (room without the sound source – in this case narthex) can be expected to have a fairly slow early decay rate, followed by reverberation tail which is determined by the space with longer reverberation time (in this case it is naos) (Kurtović, 1990). Furthermore, the reason for such a pronounced difference between EDT and  $T_{30}$  values in Ljubostinja church could be that a greater amount of direct and early energy arrives from naos to narthex, followed by less energy in the later part of sound decay, as a consequence of the greater overall absorption (more wooden surfaces), existence of columns and longer average sound travelling paths (more air dissipation) in Ljubostinja than in the Naupara naos.

The Orthodox service consists of the spoken word, slowly chanted. Thus, it has a melodic quality, as well as the monophonic Byzantine chant performed by the chanters, standing in the chanting apses. Therefore, it is appropriate to examine acoustic parameters that refer to speech intelligibility, such as Speech Clarity (C50) and Speech Transmission Index (STI). Those parameters are valued with simple logic of “the greater the value of parameter – the greater the speech intelligibility”. STI is a numeric representation measure of communication channel characteristics whose value varies from 0 (bad) to 1 (excellent). On this scale, STI value of at least 0.5 is desirable for most applications.

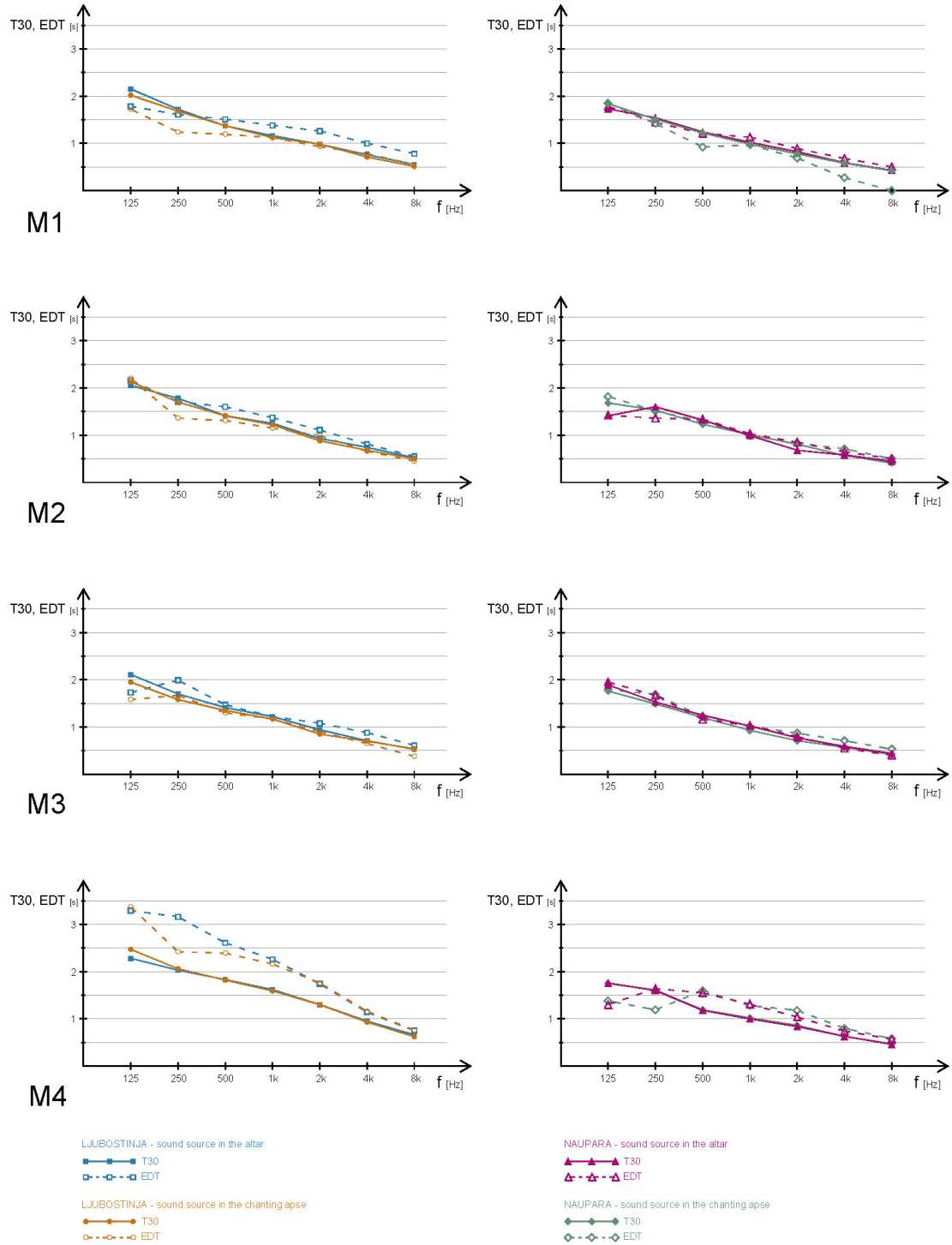


Figure 4. Graphs showing the Reverberation Time  $T_{30}$  and Early Decay Time EDT in the octave range for Ljubostinja (on the left) and Naupara monastic church (on the right).

According to the evaluation scale for STI (Table 2) speech intelligibility in Ljubostinja and Naupara church naos varies from fair to excellent, depending on the sound source position and the receiver position (Table 3). Excellent intelligibility is obtained under the dome of Naupara church when the sound source is in the chanting apse. This is expected, due to a lot of early reflections energy within ear integration zone as a result of a low position of the dome, that thus provides a small distance between the listener and the dome. Regarding intelligibility of speech in the narthex, in Naupara it is fair and in Ljubostinja poor, due to the more than double volume and the columns in Ljubostinja church producing sound diffraction effects in the audience area.

**Table 2.** Evaluation scale for the values of Speech Transmission Index STI.

STI value	Rate
0 - 0.3	bad
0.3 - 0.45	poor
0.45 - 0.6	fair
0.6 - 0.75	good
0.75 - 1	excellent

Parameter C50 implies the precision of received acoustic information. As expected, its values drop with increased source-receiver distance. Small values of C50, such are those when sound source is positioned in the altar (behind the iconostasis), signify the dominance of reverberation and they are not preferred for speech intelligibility. However, they strengthen the feeling of communion among the faithful. Due to the lack of direct sound, the listener has a hard time defining a singular sound source, feeling that sound is arriving from various directions.

**Table 3.** Acoustic parameters for Ljubostinja and Naupara monastic church.

Sound source	A: Altar				B: Chanting apse				
	Measurement points	M1	M2	M3	M4	M1	M2	M3	M4
Acoustic parameter	C50 [dB]	-5.2	-8.2	-7.5	-9.3	0.8	-1.9	0	-7.8
	STI	-4.8	-1.7	-1.8	-4.0	9	2.7	1.3	1.1
		0.500	0.532	0.526	0.437	0.612	0.577	0.616	0.441
		0.571	0.598	0.625	0.556	0.777	0.648	0.622	0.583

Table 3 shows that there is a consistent difference in speech intelligibility that depends on the source position. Speech intelligibility is much higher in the case of excitation from the chanting apse than from the altar. The reason for this lies in the fact that there is a high altar barrier (iconostasis) between the source in the altar and the measurement positions, while there is no such obstacle when the sound source is in the chanting apse. The most significant difference in the C50 parameter is observed at the M1 position (under the dome) in Naupara church (-4.2 dB from the altar and 9 dB from the apse excitation). The highest value of C50 (+9 dB) could be explained with the small distance between the sound source and the measurement position placed on the central sound source axis, which results in a high ratio of direct to reverberant energy. Furthermore, it can be observed that C50 values at M2 and M3 are smaller than in M1. This implies that the sound field in the naos is extremely non-homogeneous and that speech intelligibility is highly dependable on the listener's position.



## 4 Discussion

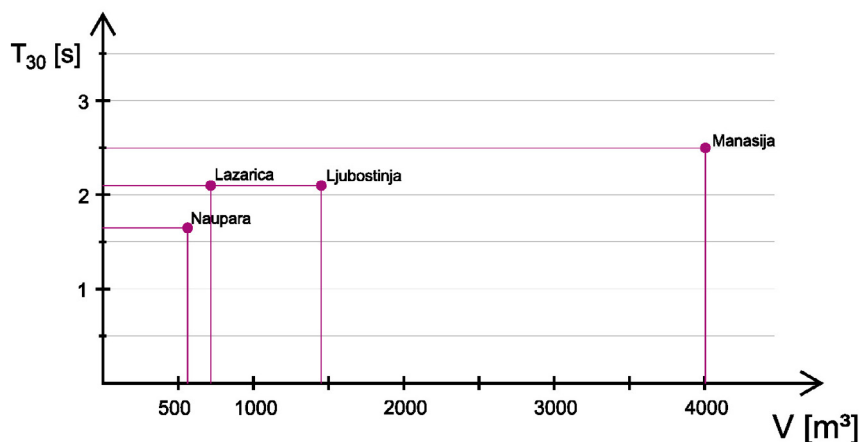
Although Ljubostinja church has a volume almost three times larger than that of Naupara, differences in average Reverberation Times between the two churches are not so pronounced. Overall difference in average Reverberation Times between each church's naos is only 10% (1.79 s in Ljubostinja comparing to 1.61 s in Naupara). At the same time, overall difference in Reverberation Times inside the narthex areas are noticeable larger – around 40% (2.35 s in Ljubostinja comparing to 1.7 s in Naupara). This can be explained by the fact that Ljubostinja has more wooden surfaces within the naos, which is an additional reason for the even higher average absorption coefficient of the Ljubostinja naos compared to the same area in Naupara.

The significantly shorter-than-expected Reverberation Time in Ljubostinja could be explained by the columns in the naos, as dominant acoustic diffraction elements. Sound diffraction exerts its own impact on shortening Reverberation Time, due to an overall shortening of the average path distance that sound waves pass. Such acoustical situation raise the possibility of significantly different behaviour in sound fields (that can result in shortening of Reverberation Time), which cannot be observed simply by comparing only overall volumes of two or more spaces (Šumarac Pavlović, 2004).

Although the similar Reverberation Times in both churches' naos might indicate similar values of acoustic parameters that describe speech intelligibility, this is not the case. Namely, all such parameters (C50 and STI) have much greater values for Naupara, indicating noticeably higher levels of speech intelligibility for this church. Such a situation can be explained by its smaller interior volume and the reduced path distances that sound waves pass in Naupara, resulting in the greater part of reflection energy arriving to the listener within the ear's integration time zone (first 50 ms after the arrival of direct sound). The sound energy that reaches listeners within this time zone is considered as *useful* in the sense of speech intelligibility. More energy that comes to a listener after this period of time, which is characteristic for Ljubostinja, actually distracts the speech recognition process, resulting in lesser values in speech intelligibility parameters. It is notable that the best speech intelligibility is under the dome of the Naupara naos, which is close enough to a listener to provide reflection that actually improves overall speech intelligibility.

Finally, acoustic parameters clearly indicate a significant reduction of speech intelligibility in case of sound field excitation from the altar. Singing in the altar area behind the iconostasis has a specific role in Orthodox divine service, with the main intention of encouraging the sense of the holy mystery, while the comprehensibility of spoken and sung text is not so important.

Lazarica church was used as an architectural role model for Naupara church (Popović & Ćurčić, 2000). Therefore, they have very similar geometry. Figure 5 shows the values of Reverberation Time at 500 Hz for Naupara and Ljubostinja churches, as well as two other churches – Lazarica and Manasija (Đorđević et al., 2016), all built in the same architectural style.



**Figure 5.** Graph showing a comparison of the Reverberation Time in relation to the total church volume for four churches built in the Morava architectural style.

## 5 Conclusion

In order to better understand how medieval people experienced the Orthodox service, it is crucial, among other things, to explore the acoustics of medieval temples. This research contributes to the wider picture of acoustic quality of churches built in the Morava architectural style. Both built in the end of 14<sup>th</sup> century, Ljubostinja and Naupara monastic churches are well preserved and remain in their original use today. To obtain their acoustic parameters, we conducted the on-site impulse response measurement using EASERA software. The analysis of acoustic parameters – such as Reverberation Time, Early Decay Time, Speech Clarity and Speech Transmission Index – showed how the experience of sound changes depending on the position of both the listener and the sound source, affecting two main acoustic demands for Orthodox churches – speech intelligibility (for preaching) and experience of chanting. On the other hand, this research also has provided additional input for future conservation works – an acoustical imprint as a reference of the current state.

**Acknowledgements:** The paper is a result of research on the project *Theory and practice of science in society: multidisciplinary, educational and intergenerational perspectives* (number 179048), financed by the Ministry of Education, Science and Technological Development of Republic of Serbia.

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