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THE ESTIMATION OF SPEECH INTELLIGIBILITY QUALITY IN ORTHODOX CHURCHES

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Abstract: This paper presents the estimation of speech intelligibility in unoccupied and occupied Orthodox churches "**Saint George**" in Žitnipotok and "**Holy Great Martyr Prokopija**" in Katun, Serbia, based on a comparative analysis of objective acoustic parameters: reverberation time, RT_{30}, and speech transmission index STI,and subjective acoustic parameters: subjective intelligibility of sentences, SI_{sent}, PB words, SI_{PB}, and CVC logotoms, SI_{CVC}. Correlation and regression analysis confirmed a strong relationship between the analyzed acoustic parameters of speech intelligibility and reverberation time. The estimation of the quality of speech intelligibility in churches was carried out using Standard IEC 60268 - 16.
Keywords: estimation quality speech intelligibility orthodox

I. INTRODUCTION

Churches are acoustically complex places. They are complex from a geometrical point of view, as their dimensions and shapes can be extremely diverse: from simple auditorium-designed churches to complicated baroque churches with curved walls, side chapels, vaults and domes that often represent partially joined volumes. The range of possible sound messages is also extremely diverse. During the same liturgical service, spoken words, organ music and congregational singing can be heard. In an Orthodox church, during the church service, there are complex sound contents that are the result of the permeation of very specific musical forms (chanting of the priest and polyphonic singing of the priest and choir) and speech (preaching) [1]. These two forms of sound have different acoustic requirements.

Today, in the field of indoor acoustics, there are great cognitions in the domain of the subjective experience of the sound field. The detailed foundations of the theory on the correlation between the subjective and the objective have been set up, which provides a good basis for looking at the acoustic properties of church space in general, including Orthodox churches. This paper presents an estimation of the quality of objective and subjective intelligibility of speech in two Serbian Orthodox churches: "**Saint George**" in ŽitniPotok and "**Saint Great Martyr Prokopius**" in Katun.The values of objective acoustic parameters, reverberation time RT_{30} and speech transmission index STI, were obtained by measuring acoustic impulse responses and using the ARTA software package in unoccupied churches. Then, the values of these parameters were also determined for occupied churches using the estimation algorithm [2]. By means of Standard IEC 60268 - 16, the percentage values and the quality of the subjective intelligibility of speech of sentencesSI_{sent}, PB wordsSI_{PB} and CVC logotoms SI_{CVC} in unoccupied and occupied churches were determined. The relationship between acoustic parameters of speech intelligibility and reverberation time was confirmed by correlation and regression analysis. The conclusion on the quality of speech intelligibility in acoustically treated churches. was based on the comparative analysis of the obtained values of the acoustic parameters. The structure of the paper is as follows: 1) in section II the experiment is explained and the results of the experiment are presented 2) in section III the analysis of the results is given and 3) section IV is the conclusion.

II. EXPERIMENTS

The aim of this paper is to estimate the quality of objective and subjective intelligibility of speech in Serbian Orthodox churches: "**Saint George**" in ŽitniPotok (Fig. 1) and "**Saint Procopius the Great Martyr**" in Katun (Fig. 2).

Fig. 1 Church **"Saint George"** in ŽitniPotok(Serbia)

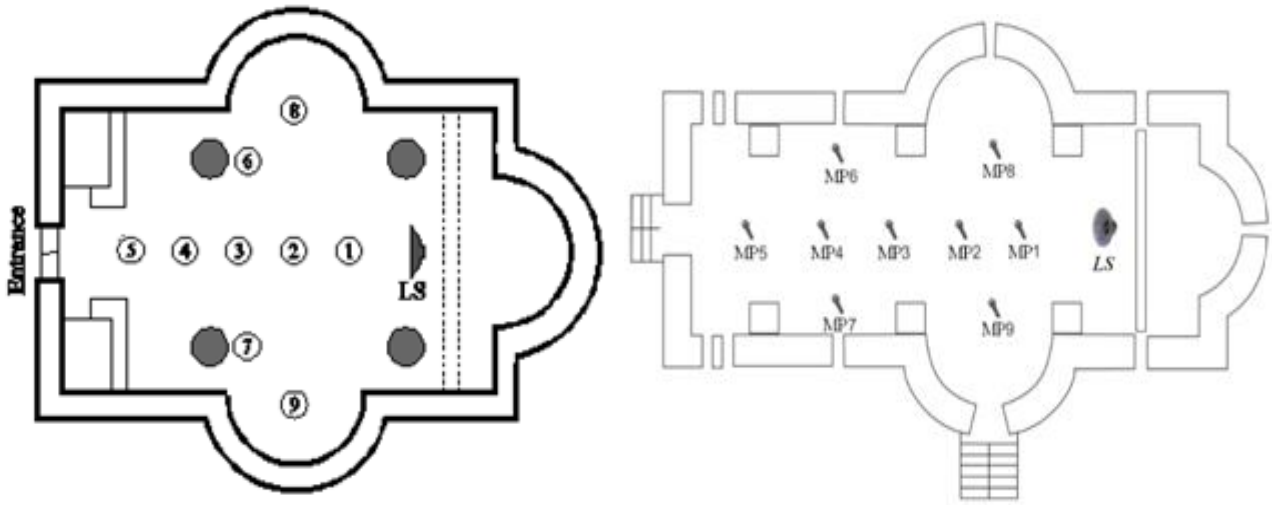
Fig. 2 Church **"Saint Procopius the Great Martyr"** in Katun (Serbia)

According to design, these Serbian Orthodox churches belong to the Moravian-Byzantine style [3]. In Serbian architecture during the Middle Ages, the Moravian style encompasses the period from the seventh decade of the XIV century up to 1459. This style was named after the river Morava, in the basin of which sacred objects were built. The main feature of this style is the trefoil foundation of the church. It has the shape of the cross, accompanied by an altar and two apses from south and north designed modeled by the monasteries of Sveta gora (Holy Mountain). The apses are half rounded in the attic level. The dome of the church has a relatively big diameter and large volume in relation to the greatness of the central area.

Church 1, the church of "Saint George" in ŽitniPotokhas a volume of V = 2163 m^3 and inner area is S = 167 m^2. Church 2, the church of "Holy Great Martyr Procopius" in Katun has a volume of V = 1659.68 m^3 and the area S = 646.68 m^2. In these churches, the interior walls and the ceilings are solid brick with a lime plaster finish (the coefficient of absorption = 0.02), and the floors the ceramic tiles (the coefficient of absorption = 0.015)[2]. The equippment used for the experiment as follows: (a) an omnidirectional microphone (PCB 130D20), having a diaphragm diameter of 7mm; (b) a B&K omnidirectional sound source type 4295 (dodecahedron loudspeaker); (c) a B&K audio power amplifier, rated at 100W RMS, stereo, type 2716-C; (d) a laptop, incorporating a Soundmax Integrated Digital Audio sound card from Analog Devices.The recorded acoustic impulse responses in the churches are the basis of the experiment. Both the recording procedure and the evaluation of the parameters were performed according to ISO 3382 standard [4]. Measuring of the impulse response was performed is using incentive log sweep signal with the duration of 5 s; sampling frequency was f_s= 44.1 kHz[2].Acoustic impulse responses were measured in MP = 9 measurement points in each church. Their arrangements in the churches are shown in Fig. 3. For each measurement point, 7 measurements were performed, which makes a total of 63 files for each church. Size values for unoccupied church 1 ($RT_{30unocc1}$and STI_{unocc1}) and church 2($RT_{30unocc2}$andSTI_{unocc2}) were calculated based on the recording of impulse responses and the use of the ARTA software package.

After that are:

1) for unoccupied churches: a) for each MP measurement position (based on the classification of the ratio of speech intelligibility and the STI parameter determined by the Standard [5]) certain speech intelligibility values of sentences ($SI_{sent\text{-}unocc1}$ and $SI_{sent\text{-}unocc2}$), PB of words ($SI_{PBw\text{-}unocc1}$ and $SI_{PBw\text{-}unocc2}$)and CVC logatoms($SI_{CVC\text{-}unocc1}$ and$SI_{CVC\text{-}unocc2}$) and b) for all measuring positions of MP in churches calculated mean values and standard deviations of these quantities and 2) for occupied churches: a) for each measuring position MP estimated values of reverberation time RT_{30occ1} and RT_{30occ2}[6] and speech transmission index parameters STI_{occ1} and STI_{occ2}[7], c) the value of speech intelligibility determined by the Standard: sentence $SI_{sent\text{-}occ1}$and $SI_{sent\text{-}occ2}$, PB words $SI_{PBw\text{-}occ1}$and $SI_{PBw\text{-}occ2}$ and CVC logatom $SI_{CVC\text{-}occ1}$ and $SI_{CVC\text{-}occ2}$ for all measuring positions of MP in churches and d) calculated mean values and standard deviations of these quantities for all MP measurement positions.



a b

Fig. 3 Positions of MP measurement points and LS sound sources when recording the impulse response in a) the church 1 and b) the church 2

Comparative analysis and estimation of quality of the speech intelligibility was performed for: 1) unoccupied churches, 2) occupied churches and 3) unoccupied and occupied churches. The performed evaluation of the quality of speech in churches was based on the Standard [5]. The strength of the relationship between the objective parameters RT_{30} and STI and the parameters that qualify subjective speech intelligibility: SI_{sent}, SI_{PBw} and SI_{CVC} for unoccupied and occupied churches, at f_c= 2 kHz, was determined using regression and correlation analysis.

A. The Results of the Experiment

Table I shows the values of the following acoustic quantities at the central frequency f = 2kHz:
1) $RT_{30unocc1}$, STI_{unocc1}, $SI_{sent\text{-}unocc1}$, $SI_{PBw\text{-}unocc1}$ and $SI_{CVC\text{-}unocc1}$ and
2) RT_{30occ1}, STI_{occ1}, $SI_{sent\text{-}occ1}$, $SI_{PBw\text{-}occ1}$ and $SI_{CVC\text{-}occ1}$ for each measuring position of MP in unoccupied and occupied churches 1, respectively.
Table II shows the mean values and standard deviations of these quantities for all measuring positions of the MPin unoccupied and occupied churches 1.
Table III contains the values of these quantities that refer to church 2, namely :
1) $RT_{30unocc2}$, STI_{unocc2}, $SI_{sent\text{-}unocc2}$, $SI_{PBw\text{-}unocc2}$ and $SI_{CVC\text{-}unocc2}$ for each measuring position of MP in unoccupied and occupied churches 2, respectively.
Table IV contains the mean values and standard deviations of these quantities for all MP measurement positions in unoccupied and occupied churches 2.

Fig. 4 - 5 show regression lines for sizes:

1) STI_{unocc1} and $RT_{30unocc1}$, $SI_{sent\text{-}unocc1}$ and $RT_{30unocc1}$, $SI_{PBw\text{-}unocc1}$ and $RT_{30unocc1}$ and $SI_{CVC\text{-}unocc1}$ and $RT_{30unocc1}$
2) STI_{unocc2} and $RT_{30unocc2}$, $SI_{sent\text{-}unocc2}$ and $RT_{30unocc2}$,$SI_{PBw\text{-}unocc2}$ and $RT_{30unocc2}$ and $SI_{CVC\text{-}unocc2}$ and $RT_{30unocc2}$ at the center frequency f_c = 2 kHz for unoccupied churches 1and 2, respectively.

Figures 6 - 7 show the regression lines for the sizes:

1) STI_{occ1} and RT_{30occ1}, $SI_{sent\text{-}occ1}$ and RT_{30occ1}, $SI_{PBw\text{-}occ1}$ and RT_{30occ1} and $SI_{CVC\text{-}occ1}$ and RT_{30occ1} and
2) STI_{unocc2} and $RT_{30unocc2}$, $SI_{sent\text{-}unocc2}$ and $RT_{30unocc2}$, $SI_{PBw\text{-}unocc2}$ and $RT_{30unocc2}$ and $SI_{CVC\text{-}unocc2}$ and $RT_{30unocc2}$ at the center frequency f_c = 2 kHz for occupied churches 1and 2, respectively.

III. ANALYSIS OF EXPERIMENT RESULTS

Based on the results shown in the Tables I – IV and the Figs 4. – 7.
The following can be concluded:

1) For the unoccupied churches:

a) the mean value of the reverberation time is expectedly higher for church 1 compared to church 2 due to its larger volume [ISO 12001 Standard]:$\overline{RT_{30unocc1,MP}}$= 2.14 ±0.09 s=2.05 ÷ 2.23 s and $\overline{RT_{30unocc2,MP}}$ = 1.53 ± 0.1 s = 1.43 ÷ 1.63 s.
b) due to the longer reverberation time, it is expected that church 1 has a lower value of the speech transmission index compared to church 2, and therefore a worse quality of speech. The mean values of this parameter are: for the church 1 $\overline{STI_{unocc1}}$= 0.49 ± 0.14 = 0.35 ÷ 0.63 and classifies objective speech intelligibility from poor to good, and for the church 2 $\overline{STI_{unocc2}}$= 0.57 ± 0.05 = 0.52 ÷ 0.62 and classifies objective speech intelligibility from fair to good;

c) the mean value of the subjective intelligibility of the sentences has an expected higher value and indicates a better quality of speech in church 2 than in church 1:$\overline{SI_{sent-unocc1}}$ = 67.78 ± 27.26 % = 40.52 ÷ 95.04 % classifies the subjective intelligibility of sentences from bad to good while$\overline{SI_{sent-unocc2}}$ = 92.78 ± 4.15 % = 88.63 ÷ 96.93 % classifies the subjective intelligibility of sentences from bad to excellent;

TABLE I: VALUES OF REVERBERATION TIME RT_{30}, OBJEKTIVE SPEECH TRANSMISSION INDEX STI, SUBJECTIVE SPEECH INTELLIGIBILITY SI (SENTENCE, PB WORDS AND CVC LOGATOMS) FOR THE UNOCCUPIED AND THE OCCUPIED CHURCH 1

MP	$RT_{30unocc1}$ (2 kHz) (s)	STI_{unocc1}	$SI_{sent-unocc1}$ (%)	$SI_{PBw-unocc1}$ (%)	$SI_{CVC-unocc1}$ (%)	RT_{30occ1} (2 kHz) (s)	STI_{occ1}	$SI_{sent-occ1}$ (%)	$SI_{PBw-occ1}$ (%)	$SI_{CVC-occ1}$ (%)
1	2.29	0.77	100	97	83	1.59	0.95	100	98	95
2	2.26	0.62	98	93	70	1.58	0.79	100	97	83
3	2.12	0.5	83	86	59	1.54	0.66	99	95	74
4	2.11	0.46	69	82	53	1.54	0.61	97	93	70
5	2.08	0.4	50	76	46	1.53	0.55	92	90	64
6	2.05	0.37	37	72	41	1.52	0.52	85	87	60
7	2.05	0.35	32	70	39	1.52	0.5	83	86	59
8	2.11	0.39	46	75	45	1.53	0.55	92	90	64
9	2.23	0.58	95	91	67	1.57	0.75	100	96	81

TABLE II : VALUES OF THEIR MEAN VALUES, STANDARD DEVIATIONS AND SPEECH QUALITY FOR THE UNOCCUPIED AND THE OCCUPIED CHURCH 1

$\overline{RT_{30unocc1,MP}}$ (2 kHz) (s)	2.14	$\sigma\left(\overline{RT_{30unocc1,MP}}\right)$ (2 kHz) (s)	0.09		-
$\overline{STI_{unocc1}}$	0.49	$\sigma\left(\overline{STI_{unocc1}}\right)$	0.14		poor - good
$\overline{SI_{sent-unocc1}}$ (%)	67.78	$\sigma\left(\overline{SI_{sent-unocc1}}\right)$ (%)	27.26		bad - good
$\overline{SI_{PBw-unocc1}}$ (%)	82.44	$\sigma\left(\overline{SI_{PBw-unocc1}}\right)$ (%)	9.81		bad - good
$\overline{SI_{CVC-unocc1}}$ (%)	55.89	$\sigma\left(\overline{SI_{CVC-unocc1}}\right)$ (%)	15	Rating	bad - good
$\overline{RT_{30occ1,MP}}$ (2 kHz) (s)	1.55	$\sigma\left(\overline{RT_{30occ1,MP}}\right)$ (2 kHz) (s)	0.03		-
$\overline{STI_{occ1}}$	0.65	$\sigma\left(\overline{STI_{occ1}}\right)$	0.15		fair - excellent
$\overline{SI_{sen-occ1}}$ (%)	94.22	$\sigma\left(\overline{SI_{sent-occ1}}\right)$	6.63		bad -excellent
$\overline{SI_{PBw-occ1}}$ (%)	92.44	$\sigma\left(\overline{SI_{PBw-occ1}}\right)$ (%)	4.39		good - excellent
$\overline{SI_{CVC-occ1}}$ (%)	72.22	$\sigma\left(\overline{SI_{CVC-occ1}}\right)$ (%)	12.14		fair -good

TABLE IIII : VALUES OF REVERBERATION TIME RT_{30}, OBJEKTIVE SPEECH TRANSMISSION INDEX *STI*, SUBJECTIVE SPEECH INTELLIGIBILITY *SI* (SENTENCE, PB WORDS AND CVC LOGATOMS) FOR THE UNOCCUPIED AND THE OCCUPIED CHURCH 2

MP	$RT_{30unocc2}$ (2 kHz) (s)	STI_{unocc2}	$SI_{sent-unocc2}$ (%)	$SI_{PBw-unocc2}$ (%)	$SI_{CVC-unocc2}$ (%)	RT_{30occ2} (2 kHz) (s)	STI_{occ2}	$SI_{sent-occ2}$ (%)	$SI_{PBw-occ2}$ (%)	$SI_{CVC-occ2}$ (%)
1	1.66	0.69	100	95	72	1.4	0.78	100	97	84
2	1.49	0.55	92	90	64	1.34	0.61	97	93	70
3	1.41	0.54	91	89	63	1.32	0.58	96	92	66
4	1.47	0.52	85	87	60	1.34	0.57	94	91	65
5	1.41	0.53	90	88	62	1.32	0.57	94	91	65
6	1.53	0.57	94	91	65	1.36	0.64	98	93	73
7	1.49	0.57	94	91	65	1.34	0.63	98	93	71
8	1.65	0.58	96	92	66	1.39	0.67	99	95	75
9	1.67	0.56	93	90	64	1.4	0.65	98	94	73

TABLE IV: VALUES OF THEIR MEAN VALUES, STANDARD DEVIATIONS AND SPEECH QUALITY FOR THE UNOCCUPIED AND THE OCCUPIED CHURCH 2

$\overline{RT_{30unocc2,MP}}$ (2 kHz) (s)	1.53	$\sigma\left(\overline{RT_{30unocc2,MP}}\right)$ (2 kHz) (s)	0.1		-
$\overline{STI_{unocc2}}$	0.57	$\sigma\left(\overline{STI_{unocc2}}\right)$	0.05		fair - good
$\overline{SI_{sent-unocc2}}$ (%)	92.78	$\sigma\left(\overline{SI_{sent-unocc2}}\right)$ (%)	4.15		bad - excellent
$\overline{SI_{PBw-unocc2}}$ (%)	90.33	$\sigma\left(\overline{SI_{PBw-unocc2}}\right)$ (%)	2.34		good
$\overline{SI_{CVC-unocc2}}$ (%)	64.48	$\sigma\left(\overline{SI_{CVC-unocc2}}\right)$ (%)	3.32		fair - good
$\overline{RT_{30occ2,MP}}$ (2 kHz) (s)	1.36	$\sigma\left(\overline{RT_{30occ2,MP}}\right)$ (2 kHz) (s)	0.03	Rating	-
$\overline{STI_{occ2,}}$	0.63	$\sigma\left(\overline{STI_{occ2,}}\right)$	0.07		fair - good
$\overline{SI_{sen-occ2,}}$ (%)	97.11	$\sigma\left(\overline{SI_{sent-occ2,}}\right)$	2.09		good -excellent
$\overline{SI_{PBw-occ2,}}$ (%)	93.22	$\sigma\left(\overline{SI_{PBw-occ2,}}\right)$ (%)	1.92		good - excellent
$\overline{SI_{CVC-occ2,}}$ (%)	71.33	$\sigma\left(\overline{SI_{CVC-occ2,}}\right)$ (%)	6.02		fair -good

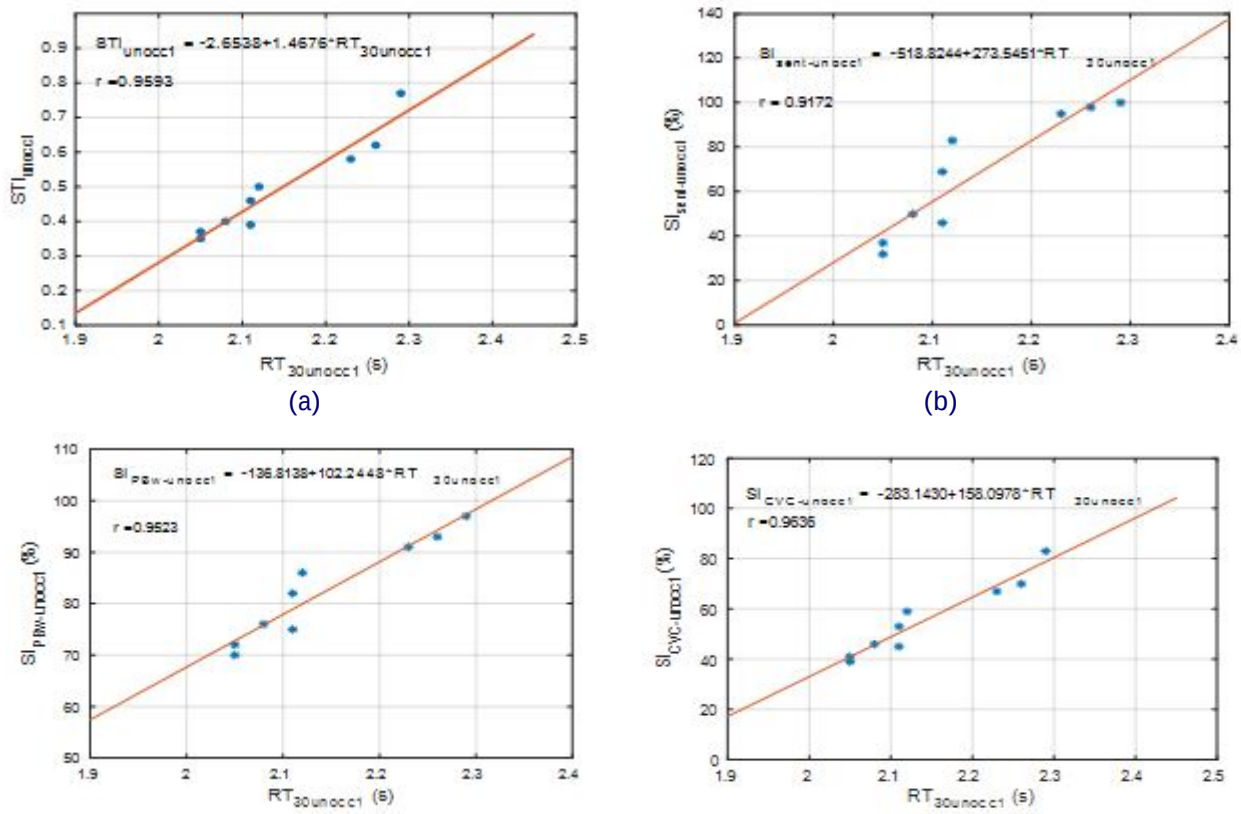


Fig. 4The regression line for: a) STI_{unocc1}i $RT_{30unocc1}$, b) $SI_{sent\text{-}unocc1}$i $RT_{30unocc1}$,c) $SI_{PBw\text{-}unocc1}$i $RT_{30unocc1}$i d) $SI_{CVC\text{-}unocc1}$i $RT_{30unocc1}$ for the unoccupied church 1 at f = 2kHz

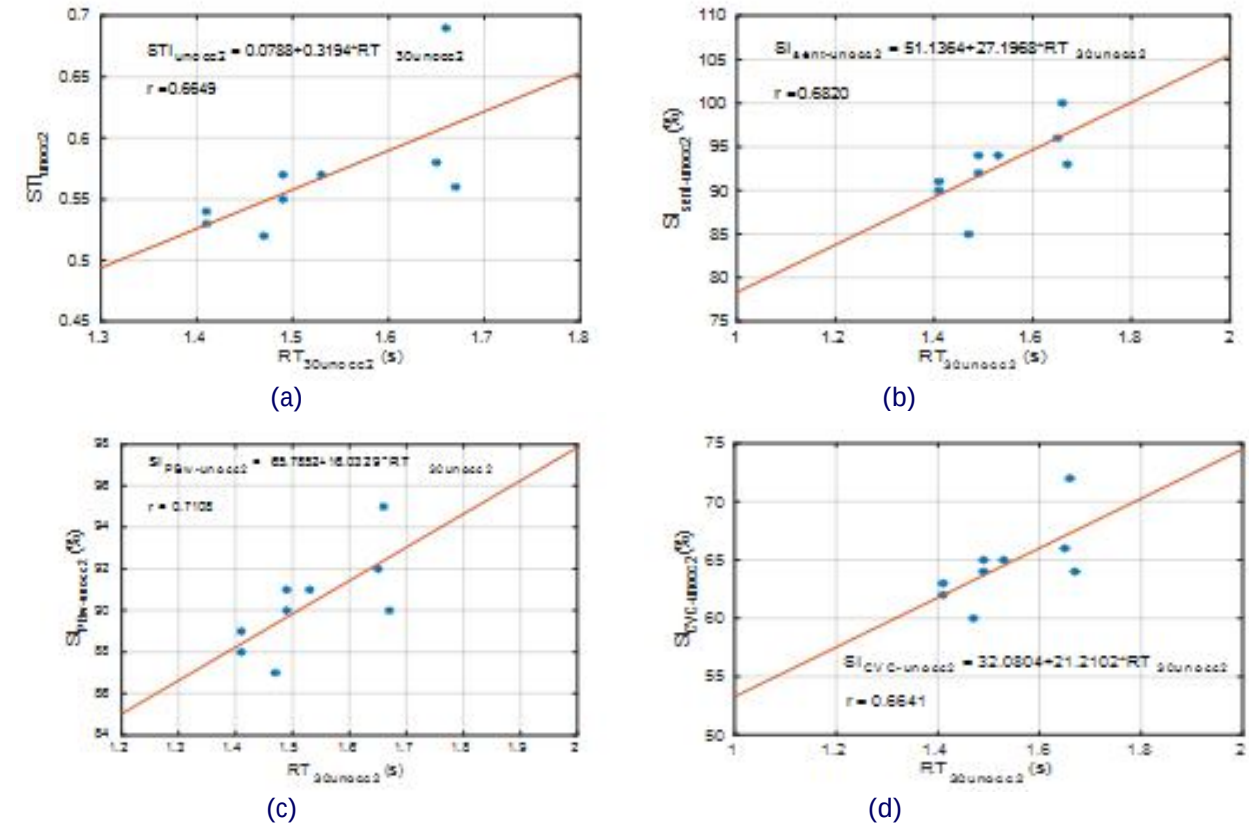
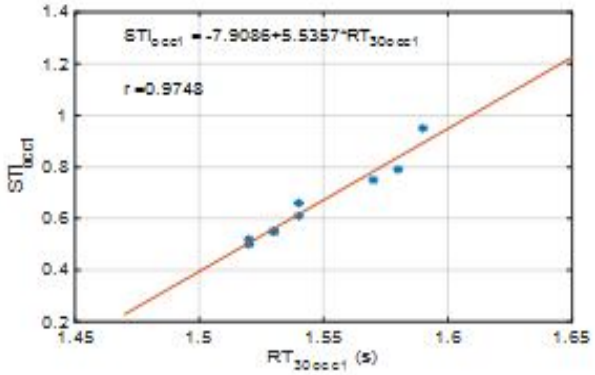


Fig. 5 The regression line for: a) STI_{unocc2}i $RT_{30unocc2}$, b) $SI_{sent\text{-}unocc2}$i $RT_{30unocc2}$, c) $SI_{PBw\text{-}unocc2}$i $RT_{30unocc2}$ i d) $SI_{CVC\text{-}unocc2}$i $RT_{30unocc2}$ for the unoccupied church 2 at f = 2kHz



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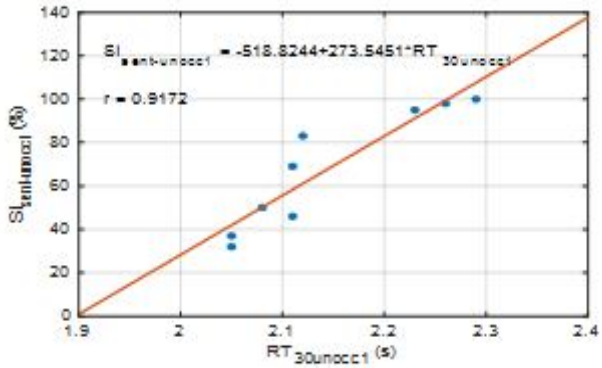

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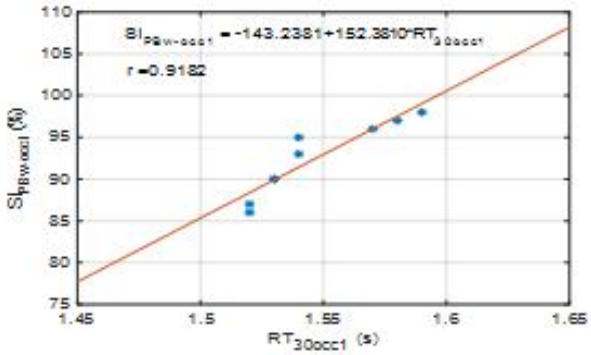

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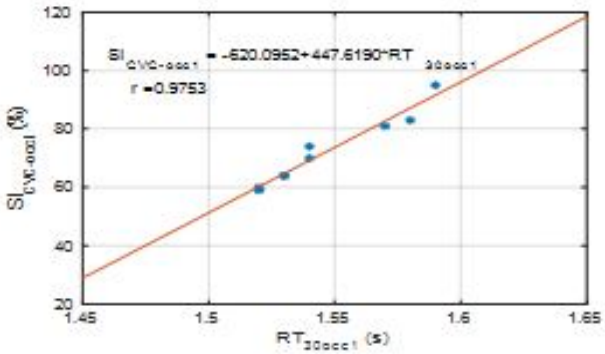
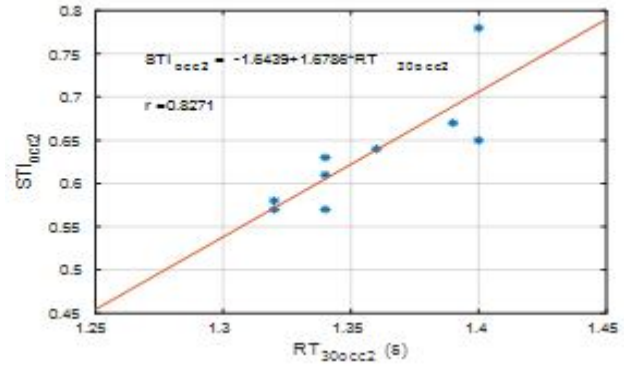


(d)

Fig. 6 The regression line for: a) STI_{occ1} i RT_{30occ1}, b) $SI_{sent\text{-}occ1}$ i RT_{30occ1},c) $SI_{PBw\text{-}occ1}$ i RT_{30occ1} i d) $SI_{CVC\text{-}occ1}$ i RT_{30occ1} for the occupied church 1 at f = 2kHz



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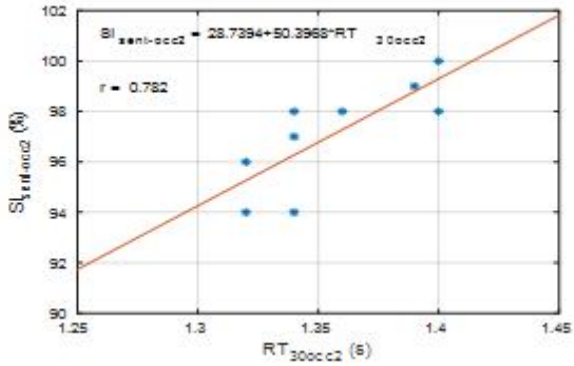

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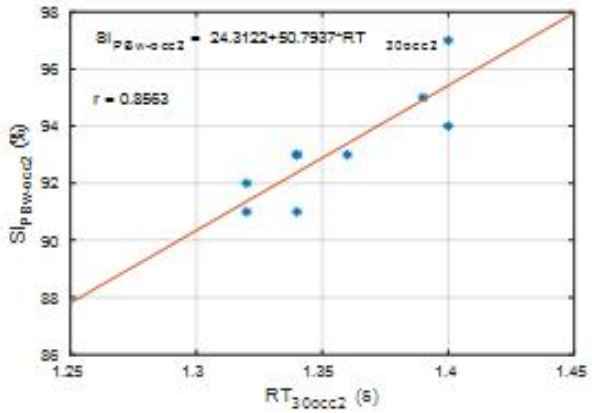

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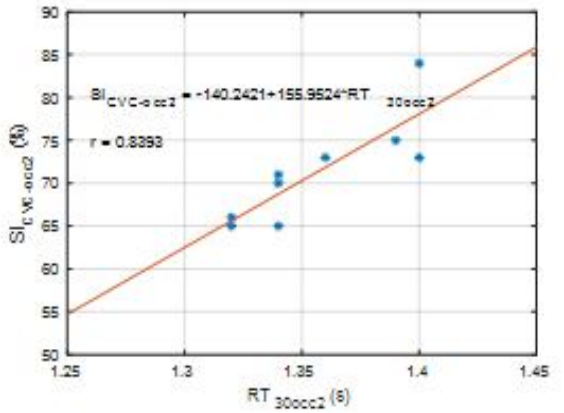

(d)

Fig. 7 The regression line for: a) STI_{occ2} i RT_{30occ2}, b) $SI_{sent\text{-}occ2}$ i RT_{30occ2},c) $SI_{PBw\text{-}occ2}$ i RT_{30occ2} i d) $SI_{CVC\text{-}occ2}$ i RT_{30occ2} for occupied church 2 at f = 2kHz

d) The mean value of subjective intelligibility of PB words shows better intelligibility in church 2: $\overline{SI_{PBw-unocc1}}$ = 82.44 ± 9.81 % = 72.63 ÷ 92.25 % classifies subjective intelligibility of PB words from poor to good and $\overline{SI_{PBw-unocc2}}$ = 90.33 ± 2.34 % = 87.99 ÷ 92.67 % classifies subjective intelligibility of PB words as good;

e) The mean value of the subjective intelligibility of the CVC logotoms indicates slightly better intelligibility in church 2: $\overline{SI_{CVC-unocc1}}$ = 55.89 ± 15 % = 40.89 ÷ 70.89 % classifies the subjective intelligibility of CVC logatoms from poor to good and $\overline{SI_{CVC-unocc}}$ = 64.48 ± 3.32 % = 61.16 ÷ 67.8 % classifies the subjective intelligibility of CVC logatoms from fair to good. Therefore, the results of the analysis confirm that both the objective and subjective intelligibility of speech is better in church 2. The reason is certainly the smaller mean value of the reverberation time.

f) Correlation and regression analysis for the unoccupied church 1 gave the following connections of speech intelligibility and reverberation time with the corresponding Pearson coefficients:

STI_{unocc1} = -2.6538 + 1.4676 $RT_{30unocc1}$, r = 0.9593;

$SI_{sent\text{-}unocc1}$ = -518.8244 + 273.5451 $RT_{30unocc1}$, r = 0.9172;

$SI_{PBw\text{-}unocc1}$ = -136.8138 + 102.2448 $RT_{30unocc1}$, r = 0.9523 and

$SI_{CVC\text{-}unocc1}$ = -283.143+158. 0978 $RT_{30unocc1}$, r = 0.9636.

This analysis shows that there is a statistically positive, very strong, linear relationship between these parameters. Correlation and regression analysis for the unoccupied church 2 gave the following connections between these quantities:

STI_{unocc2} = 0.0788 + 0.3194 $RT_{30unocc2}$, r = 0.6649;

$SI_{sent\text{-}unocc2}$ = 51.1364 + 27.1968 $RT_{30unocc2}$, r = 0.6820;

$SI_{PBw\text{-}unocc2}$ = 65.7852 + 16.0329 $RT_{30unocc2}$, r = 0.7108 and

$SI_{CVC\text{-}unocc2}$= 32.0804+21.2102 $RT_{30unocc2}$,r = 0.6641.

This analysis shows that there is a statistically positive, moderate, linear relationship between speech intelligibility parameters and reverberation time.

2) For the occupied churches:

a) The presence of believers in churches increases the sound absorption, as a result of which the reverberation time values decrease[8].For church 1 and church 2, the reductions in the mean values of the reverberation time are: $\overline{\Delta RT_{30\_1,MP}}$= 0.59 s and $\overline{\Delta RT_{30\_2,MP}}$= 0.17 s, respectively.Now their values are: $\overline{RT_{30occ1,MP}}$= 1.55 ± 0.03 s = 1.52 ÷ 1.58 s and $\overline{RT_{30occ2,MP}}$= 1.36 ± 0.03 s = 1.33 ÷ 1.39 s and for church 1 they again meet the Standard, while those values for church 2 are a little lower. Namely, the upper value of 1.39 s is at the limit of the range of values adopted by the Standard.

b) The objective intelligibility of speech is now increased in churches and that by: $\overline{\Delta STI_1}$ = 0.16 and $\overline{\Delta STI_2}$ =0.06. The mean values of the speech transmission index are: for the church 1 $\overline{STI_{occ1}}$= 0.65 ± 0.15 = 0.5 ÷ 0.8 and classifies speech intelligibility from fair to excellent and for the church 2$\overline{STI_{occ2}}$= 0.63 ± 0.07 = 0.56 ÷ 0.7 classifies speech intelligibility from fair to good. It can be seen that now in church 1 the objective intelligibility of speech is better.

c) The increase in the mean value of the subjective intelligibility of the sentences for the examined churches is: $\overline{\Delta SI_{sent1}}$= 26.42 % and $\overline{\Delta SI_{sent2}}$= 4.33%. For both churches it is $\overline{SI_{sent-occ1}}$ = 94.22 ± 6.63 % = 87.59 ÷ 100.85 % and classifies the subjective intelligibility of sentences from bad to excellent and$\overline{SI_{sent-occ2}}$ = 97.11 ± 2.09 % = 95.02 ÷ 99.2 % classifies the subjective intelligibility of sentences from good to excellent, respectively. Therefore, in the occupied church 2 the quality of the intelligibility of the sentences is better.

d) Mean values of subjective intelligibility of PB words are increased in churches for $\overline{\Delta SI_{PBw1}}$= 10 % and $\overline{\Delta SI_{PBw2}}$= 2.89 %. This increase classifies subjective intelligibility of PB words from good to excellentin both churches because they are: $\overline{SI_{PBw-occ1}}$ = 92.44 ± 4.39 % = 88.05 ÷ 96.83 % and$\overline{SI_{PBw-occ2}}$ = 93.22 ± 1.92 % = 91.3 ÷ 95.14 %.

e) the increase in the mean value of subjective intelligibility of CVC logatoms in churches is $\overline{\Delta SI_{CVC1}}$ = 16.33% and $\overline{\Delta SI_{CVC2}}$ = 6.85 %. Their values in churches $\overline{SI_{CVC-occ1}}$ = 72.22 ± 12.14 % = 60.08 ÷ 84.36 % and $\overline{SI_{CVC-occ2}}$ = 71.33 ± 6.02 % = 65.31 ÷ 77.35 % classifies the subjective intelligibility of CVC logatoms from fair to good. A greater reduction in reverberation time in occupied church 1 compared to church 2 led to a significant improvement in speech intelligibility in that church. A greater reduction in reverberation time in occupied church 1 compared to church 2 led to a significant improvement in speech intelligibility in that church. Therefore church 1 has a better quality of objective intelligibility of speech and equal quality of intelligibility of PB words and CVC logatoms with church 2. Church 2 has better sentence intelligibility quality.

f) Correlation and regression analysis for the occupied churches gave the following connections of speech intelligibility and reverberation time with the corresponding Pearson coefficients:

STI_{occ1} = -7.9086 + 5.5357 RT_{30occ1}, r = 0.9748;

$SI_{sent\text{-}occ1}$ = -222.4762 + 204.7619 RT_{30occ1}, r = 0.8172;

$SI_{PBw\text{-}occ1}$ = -143.2381 + 152.381 RT_{30occ1}, r = 0.9182;

$SI_{CVC\text{-}occ1}$ = -620.0952+447.619 RT_{30occ1}, r = 0.9753.

STI_{occ2} = -1.6439 + 1.6786 RT_{30occ2}, r = 0.8271;
$SI_{sent\text{-}occ2}$ = 28.7394 + 50.3968 RT_{30occ2}, r = 0.782;
$SI_{PBw\text{-}occ2}$ = 24.3122 + 50.7937 RT_{30occ2}, r = 0.8563 and
$SI_{CVC\text{-}occ2}$ = -140.2421+155.9524 RT_{30occ2}, r = 0.8393.

This analysis shows that for an occupied churches there is a statistically positive, strong linear connection between the subjective speech intelligibility: STI_{occ},$SI_{sent\text{-}occ}$, $SI_{PBw\text{-}occ}$ and $SI_{CVC\text{-}occ}$ and the reverberation time RT_{30occ}.

3) For the unoccupied and occupied churches:

a) The mean reverberation time values for unoccupied and occupied churches belong to the range of values: $\overline{RT_{30unocc}}$ = 1.43 ÷ 2.23 s and $\overline{RT_{30occ}}$ = 1.33 ÷ 1.58 s, respectively. These values satisfy the Standard's criteria.

b) The mean values of the objective parameter of the speech transmission index for occupied churches belong to a range of values that is greater than the range to which the values of this parameter belong for unoccupied churches, which implies better speech intelligibility. Namely, for full churches it is: $\overline{STI_{occ}}$ = 0.5 ÷ 0.8 and classifies objective speech intelligibility from fair to excellent, and it is for empty churches: $\overline{STI_{unocc}}$ = 0.35 ÷ 0.63 and classifies objective speech intelligibility from poor to fair.

c) For unoccupied and occupied churches, the mean values of the subjective intelligibility of sentences belong to the range of values: $\overline{SI_{sent-unocc}}$ = 40.52 ÷ 96.93 % and $\overline{SI_{sent-occ}}$ = 87.59 ÷100.85 % and classifies the subjective intelligibility of sentences from bad to excellent.

d) For unoccupied churches, the mean values of subjective intelligibility of PB words belong to the range of values:$\overline{SI_{PBw-unocc}}$ = 72.63 ÷ 92.67 % and classifies the subjective intelligibility of PB words of poor to good. For occupied churches, this parameter has higher values: $\overline{SI_{PBw-occ}}$ = 88.05 ÷ 96.83 % and classifies the subjective intelligibility of PB words good to excellent.

e) The subjective intelligibility of CVC logotoms is better for occupied churches than for unoccupied ones. Its mean values for unoccupied churches $\overline{SI_{CVC-unocc}}$ = 40.89 ÷ 70.89 %, classifies the subjective intelligibility as poor – good, while those for occupied churches $\overline{SI_{CVC-occ}}$ = 60.08 ÷ 84.36 % classifies the subjective intelligibility of CVC logatoms from fair to good.

f) Correlation and regression analysis for the occupied church and the unoccupied church 1 showed that there is a statistically positive, strong linear relationship between the objective and subjective intelligibility of speech and the reverberation time. For the unoccupied church 2, the relationship between these parameters is a statistically positive, moderate linear relationship.

IV. CONCLUSIONS

The aim of this paper is estimation the intelligibility of speech (objective and subjective) in two Orthodox churches: **"Saint George"** in Žitni Potok and **"Saint Great Martyr Prokopius"** in Katun, Serbia. It is shown by means of a comparative analysis of the obtained mean values of objective acoustic parameters: reverberation time RT_{30} and speech transmission index STI and subjective acoustic parameters: subjective intelligibility of sentences SI_{sent}, PB words SI_{PB} and CVC logatoms SI_{CVC} in 1) unoccupied, 2) occupied churches and 3) unoccupied and occupied churches. The quality of speech intelligibility in the analyzed churches was determined using Standard IEC 60268 – 16. For the analyzed Orthodox churches, it was shown that full churches have a better quality of speech intelligibility than empty churches, for: a) objective intelligibility of speech that qualifies from fair to excellent, b) subjective intelligibility of PB words that qualifies from good to excellent and c) subjective intelligibility of CVC logotoms that qualifies from fair to good. Unoccupied and occupied churches have the same quality of subjective intelligibility of sentences, from bad to excellent. Correlation and regression analysis confirmed a strong relationship between acoustic parameters of speech intelligibility and reverberation time for occupied churches.

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