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Byzantine Churches in Albania: How Geometry and Architectural Composition Influence the Acoustics

Silvana Sukaj [1], Antonella Bevilacqua [2], Gino Iannace [3,*], Ilaria Lombardi [4], Rosaria Parente [5] and Amelia Trematerra [3]

[1] Department of Engineering and Architecture, European University of Tirana (UET), 1000 Tirana, Albania; silvana.sukaj@uet.edu.al
[2] Department of Industrial Engineering, University of Parma, 43124 Parma, Italy; antonella.bevilacqua@unipr.it
[3] Department of Architecture and Industrial Design, University of Campania "Luigi Vanvitelli", 81031 Aversa, Italy; liatrematerra@libero.it
[4] Department of Engineering, University of Campania "Luigi Vanvitelli", 81031 Aversa, Italy; ilaria.lombardi@unicampania.it
[5] Benecon University Consortium, 80138 Naples, Italy; rosaria.parente@benecon.it
* Correspondence: gino.iannace@unicampania.it

Abstract: The Byzantine churches built between the 7th and the 15th centuries represent an architectural typology that has been developed along with other architectural styles. The evolution of the interior organization, to be composed of only a single nave for the oldest architecture and then developed with additional lateral naves, is one of the multiple aspects that characterizes this building type, studied mainly from an architectural perspective. The variety of roof morphology, being flat, double slope, vaulted or domed, contributes to determining the overall acoustics. This paper deals with the analysis of the acoustic characteristics related to five Byzantine churches located in Albania, specifically in Berat and Cete. A comparison of the impulse response (IR) measured inside each church was given by analyzing the most appropriate acoustic parameters and in line with ISO 3382. The acoustic surveys were undertaken with a minimal furniture and without any audience. The results highlight small difficulties in terms of speech understanding, especially under a speech clarity index found to be below the optimal range limit. This shortfall is attributed to the geometry of the volumes and to the reflecting materials applied to the surfaces that facilitate the build-up of sound energy.

Keywords: Byzantine church; acoustic measurements; architectural acoustics; church in Albania

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1. Introduction

The geographical position of Albania falls in the middle land located between the two Roman Empires, having the capital cities in Rome (west) and Istanbul (east). From a religious perspective, the spreading of the Christianism, although under cover during the first centuries AC, was strong in the Western Roman Empire, while the Eastern Roman Empire was mainly influenced by the Orthodoxy [1].

As such, the mixture of the two religions became strong in 731 when Albania was elected as part of the patriarchalism of Constantinople (the alternative name of Byzantium, nowadays Istanbul) [1]. Thereafter, the Balkan peninsula was controlled by the Venetian dominion until the 14th century, when Venice was one of the four maritime republics that managed the commercial trading with Asians, including the Chinese [2]. During this period the Catholic beliefs in Albania were closer to the Greek rituals, until 1478, when the Turkish invasion obliged the local habitants to undergo a religious conversion, specifically to the Ottoman faith [3]. The instability took place until the 20th century when Albania was declared an atheist country, precisely in 1967. Only after 1992 could the Catholic bishops give masses and undertake prayers publicly in churches.

The spatial compositions of Byzantine churches, which could be considered simple with the volume of a single-nave, and more complex for the multi-nave design and the introduction of domes, have been subject to extensive analyses from an architectural perspective [4]. The acoustics of the Byzantine churches matter for the late reflections due to the curved surfaces and to the reflecting materials applied to walls (plaster) and the floor (tiles), other than for the concave architectural elements (domes) that can unbalance the distribution of the sound waves across the volume [5–11].

This paper deals with the acoustic analysis of five Byzantine churches located in Albania and built during the 7th and 15th centuries [12]. Acoustic measurements carried out in different campaigns allowed the authors to compare the most appropriate acoustic parameters as outlined by ISO 3382 [13].

The geometry and the volume shape contribute to determining the direction of the sound rays, in combination with the poor level of absorption found at the finish materials [14].

The investigation was undertaken on five Byzantine churches with different volume sizes. Future research studies would introduce the digital models of the architecture herein selected to study some acoustic treatments that can be assessed before being tested on site.

Typology Plan Development between 7th and 15th Centuries

According to the literature, two main types of buildings have been developed for Byzantine churches: the structure based on a single nave and on multiple naves (called *basilica*) [15]. In addition, a third planning configuration appeared between the 11th and 12th century, identified as the cross shape surmounted by a dome in the center of the main volume [15].

The Byzantine churches are recognizable by some specific architectural elements, including their type of roof, that could comprise of a double slope composed of wooden beams and/or trusses, the vaulted closure and the dome usually located in the center of the cross-shaped plan layout [15].

The churches with a single nave are characterized by a rectangular plan, having a round apse on the eastern side wall [16]. The addition of lateral naves (configured as a *basilica*) is typical of the Hellenistic period (9th–11th century), by having the central nave higher and covered by wooden trusses [16]. The use of the barreled vault has been taking place to reduce the risks of fire that could be caused by candles used to highlight the indoor spaces. The sloped roof used for the *basilica* should also be contextualized in terms of financial availability, that was sometimes limited and dug to have a flat wooden ceiling in place [17].

The development of a cross-shaped plan is typical of the Mediterranean influence, characterized by a dome at the center of the axes [16]. In this type of plan configuration, the apse could be only one behind the altar, or three, located at the end of each edge of the cross except the entrance [17].

Besides these three main categories, in Albania there are also buildings that do not meet these architectural criteria and reach specific solutions dictated by other influence, as illustrated in Figure 1. This is the case of St Nicholas's church of Mesopotam, extensively analyzed in Section 2.

All the spatial typologies are shown in Figure 1.

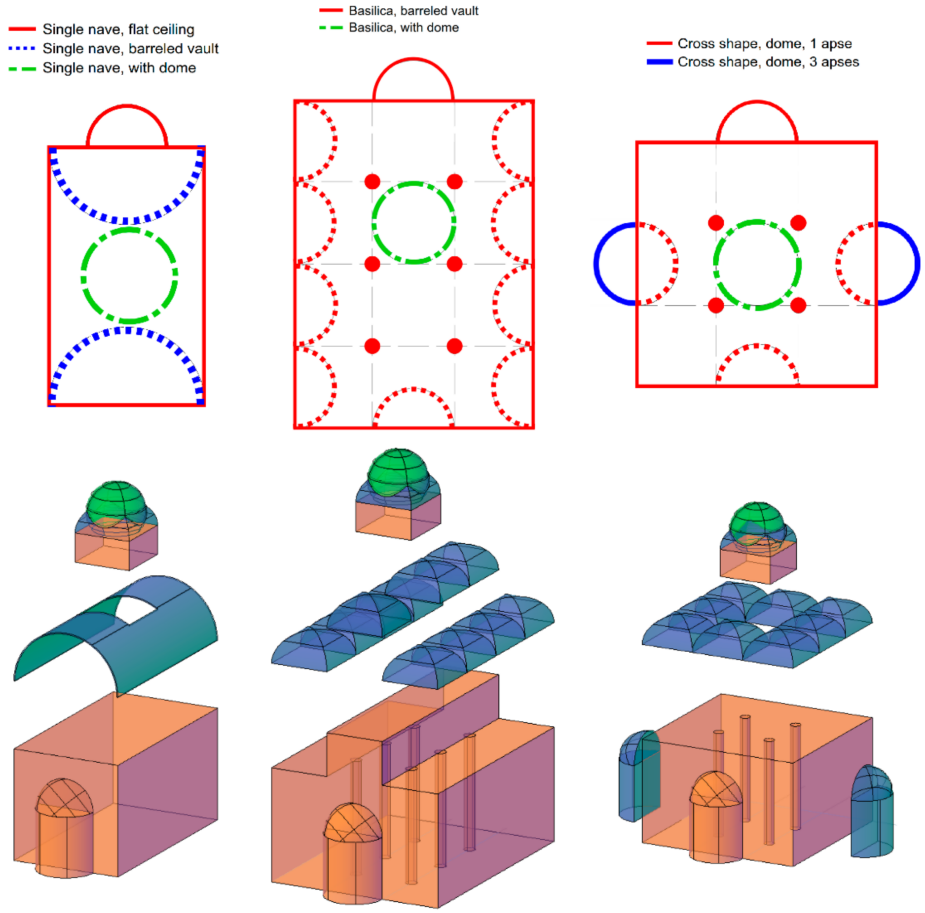

Figure 1. Drawn not to scale, different typologies of Byzantine churches. Plan layout (**above**) and 3D view (**below**).

2. History and Architectural Features

2.1. St Mary Assumption's Church of Berat

St Mary Assumption's sanctuary was built in Berat in 1797. This church is considered the building most representative of post-Byzantine architecture [8]. Based on archaeological studies, this church was built upon the foundations of an old church of reduced dimensions. In fact, the sacred estate is bounded by residential properties on four sides [18,19].

The construction elements of St Mary Assumption's church follow the rules of the *basilica* as a reference building type, having the internal dimensions equal to 21 m and 11.5 m (L, W). Additional structures have been added to the main hall, in particular a double-height porch on the west side and a narthex on the east side composed of columns and arches.

The entire volume is divided into three naves by two rows of columns running along the longitudinal axis. The central nave is characterized by two domes, with the central one hemispherical. Whereas the space defined by the columns is rectangular in plan, the vaults are elliptical. The hemispherical dome is maximum 9.5 m high at the center, increasing the entire volume to approximately 1800 m^3. Figure 2 reports the plan and the transversal section of St Mary Assumption's church.

The church is highlighted by natural light from small windows placed in the domes and by lateral windows built in the lateral walls [20]. The walls are composed of stone blocks up to 0.8 m high, and of bricks which are a lighter material for the elevated structure [21,22]. The interior design is composed of plastered walls and a roof, and tiles on the floor. Figure 3 shows some views of the St Mary Assumption's church.

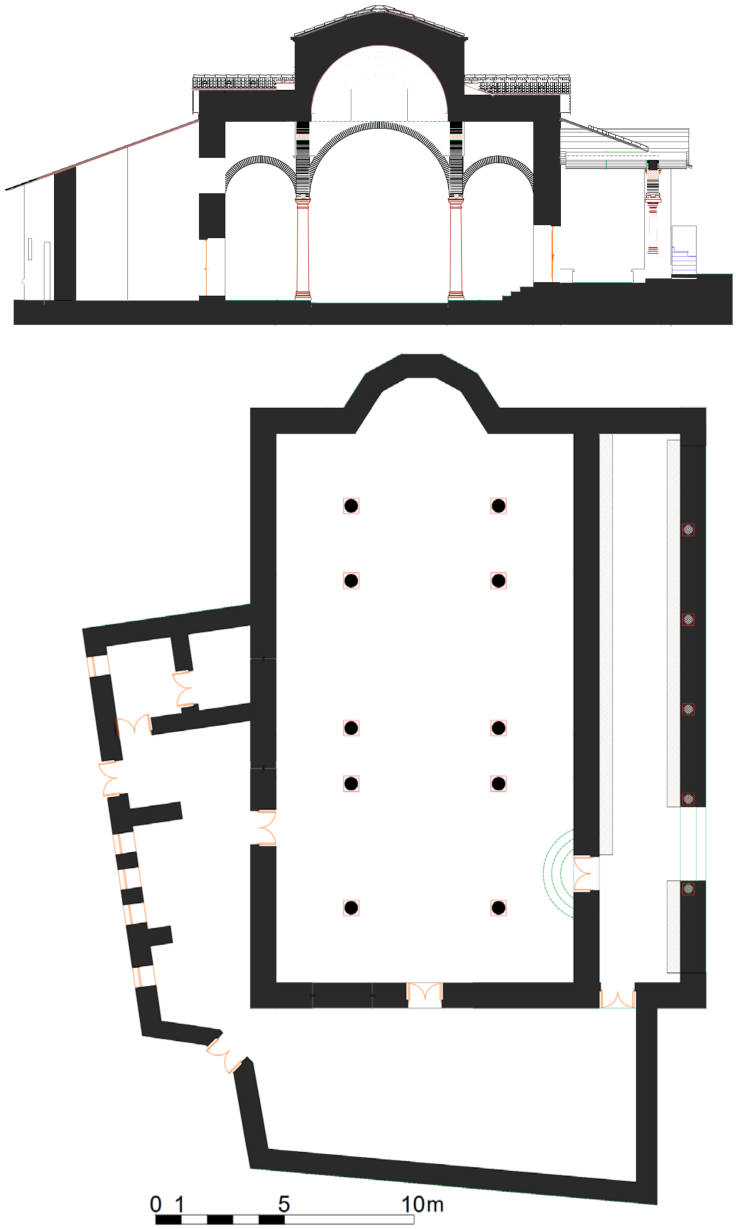

Figure 2. Plan layout and transversal section of St Mary Assumption's church. Provision courtesy of Arch. Arsim Murseli, UBT University, Pristina, Kosovo.

Figure 3. Internal (**left**) and external (**right**) views of the St Mary Assumption's church of Berat.

2.2. St Paraskevi's Church of Cete

St Paraskevi's church was built during the 13th century in Cete, a village on the eastern side of Kavaja. The church is composed of a unique nave where the altar is placed in a squared apse. Initially there was a wooden structure separating the altar from the nave, which now no longer exists [23,24].

Based on the workmanship of the walls, the church was realized by the human resources available in the village, sometimes to be extracted by the lower classes of society and who were not experts of this work. As such, the lack of expertise regarding construction techniques determined the dimensions of width and length, which do not reflect the Romanic-gothic style of that period.

The wooden roof provided with a double slope was restored in 1963. The internal dimensions of the plan layout are equal to 14 m and 5.1 m (L, W), having a total volume of approximately 460 m^3 when including the apse. The northern side is provided with three windows which highlight the room, while on the southern side a porch composed of seven arches represents a sort of narthex, to be preceding the main hall [25,26]. Figure 4 shows the plan and the longitudinal section of St Paraskevi's church.

Figure 4. Plan layout and longitudinal section of St Paraskevi's church in Cete. Provision courtesy of Arch. Arsim Murseli, UBT University, Pristina, Kosovo.

The original frescos on the walls inside the church are still preserved. The interior design follows the representation of the Bible, while the stone blocks are left to be visible, as shown in Figure 5.

2.3. St Nicholas Monastery of Mesopotamia

St Nicholas's church as part of the fortified monastery was built in 1224 on top of a hill circumscribed by two riverbeds of the Bistrica. The architectural characteristics are typical

of the Byzantine style, composed of only one volume divided by columns. Originally, this church was composed of two altars placed on opposite sides, for both Christian and Orthodox rituals [27–29]. Only in 1793 was the round apse built on one side.

The roof is characterized by four domes. The internal dimensions are equal to 11 m and 16.5 m (L, W), having a total volume of approximately 1700 m^3. Figure 6 shows the plan and the longitudinal section of St Nicholas's church.

Figure 5. Internal (**left**) and external (**right**) view of St Paraskevi's church of Cete.

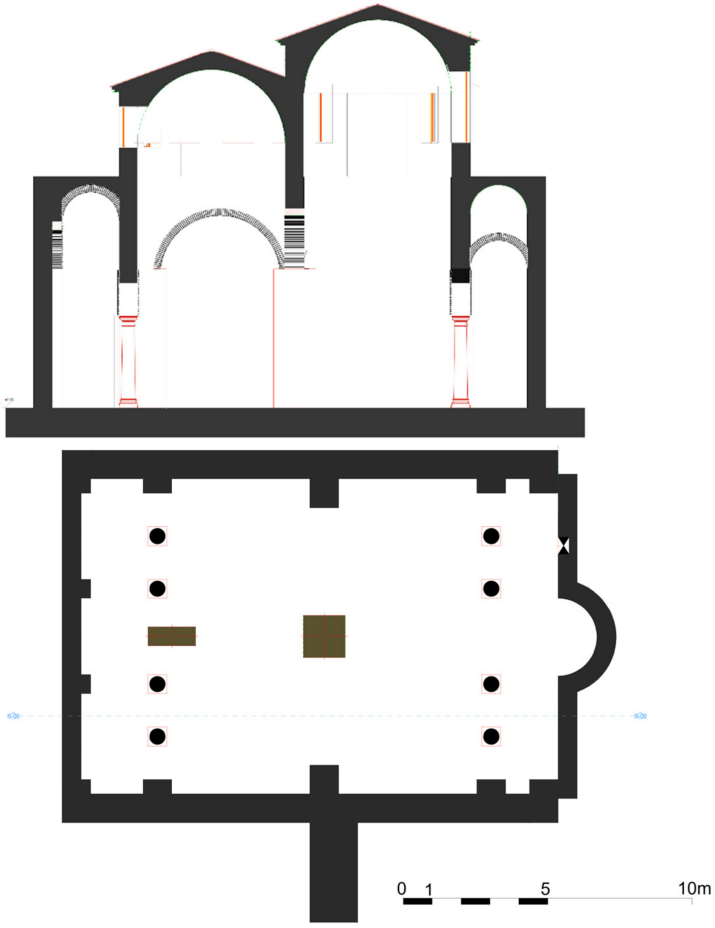

Figure 6. Plan layout and longitudinal section of St Nicholas's church of Mesopotamia. Provision courtesy of Arch. Arsim Murseli, UBT University.

The maximum height of the biggest dome is 13.5 m. The construction technique is identified in the *clausonage*, composed of slim bricks [30,31], while the basement is composed of squared stone blocks, as represented in Figure 7.

Figure 7. Internal (**left**) and external (**right**) views of St Nicholas's church of Mesopotamia.

2.4. Holy Trinity's Church of Berat

The Holy Trinity's church of Berat has been introduced into the list of UNESCO to become one of the cultural heritage subjects to be protected for future generations. The Byzantine church is located in the Kalaja district of the city, and it is characterized by a cross-shaped plan layout with equal length of the wings. At the junction of the wings there is a hemicircular dome highlighted by four windows opened in the octagon parallelepiped [32].

An inscription honored to Andronicus Paleologus, the governor of Berat between 1302 and 1326, indicates that the church mast was built between the end of the 13th century and the first half of the 14th.

The plan layout corresponds to a square having the dimension of the edge equal to 5.8 m, while the entire volume is approximately 300 m^3. Figure 8 shows the plan and the longitudinal section of the Holy Trinity's church.

The dome is 10 m high at its center. The interior design is characterized by two columns supporting capitals reused from classical ruins [33]. The layout is composed of a cross having wings of the same length, as shown in Figure 9.

2.5. St Mary of Blachernae Church of Berat

St Mary of Blachernae's church was built during the 13th century and in Berat it is well known for its frescos decorating all the interior walls. The name calls out the homonymous palace of Constantinople, and it is very likely that the church was built on existing foundations of the 5th century. The paintings belonging to the 16th century were realized by Nicholas Onufri [34,35].

The internal dimensions are equal to 6.6 m and 6 m (L, W), having a total volume of approximately 234 m^3. Figure 10 represents the plan and the longitudinal section of St Mary of Blachernae's church.

The maximum height is 5.9 m. The interior design is characterized by two stone pillars supporting the frames of the apse [36]. All the walls are decorated with frescos belonging to the 13th century, that are partially damaged by the humidity absorbed by the walls, as shown in Figure 11.

2.6. Overview of the Churches' Characteristics

From the previous information it can be noticed that only St Mary Assumption's church is composed of three naves. A comparison of the architectural characteristics has been made for all the churches, as indicated in Table 1.

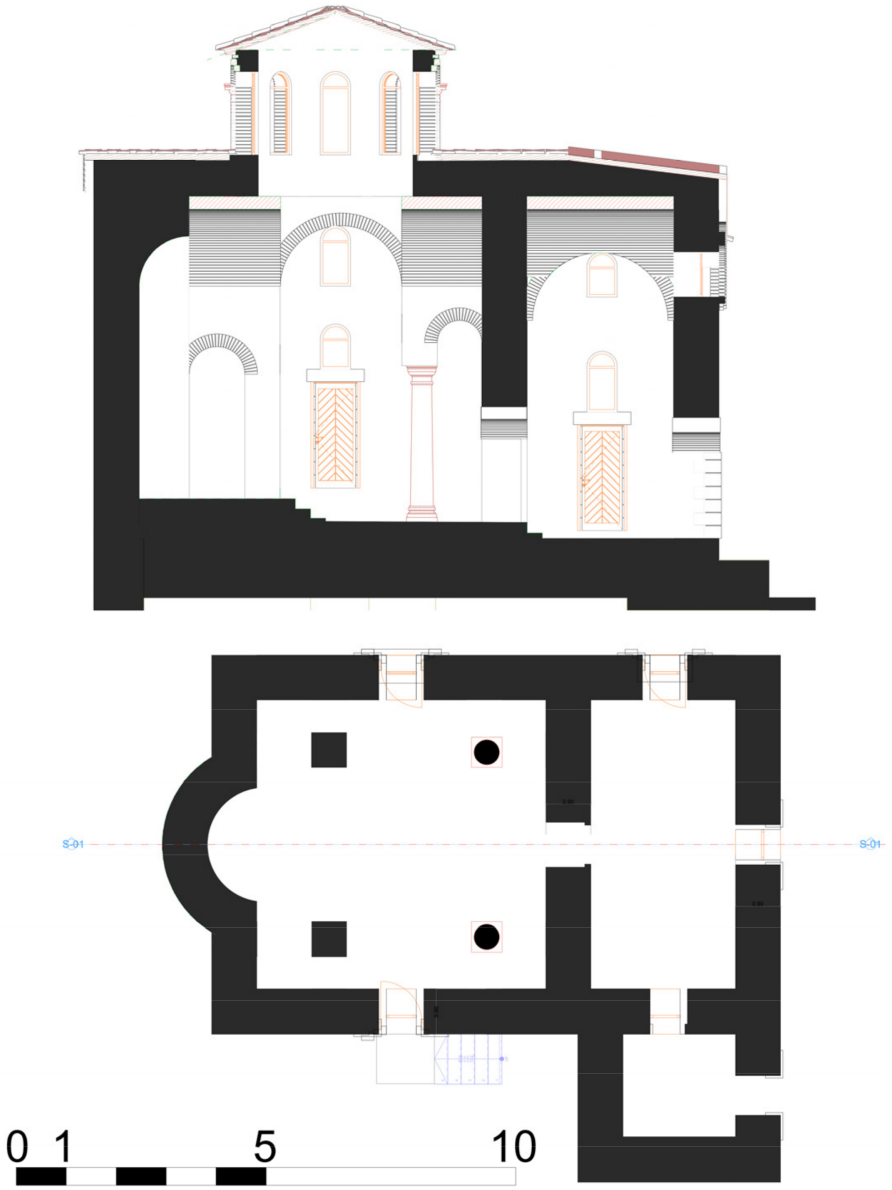

Figure 8. Plan layout and longitudinal section of the Holy Trinity's church of Berat. Provision courtesy of Arch. Arsim Murseli, UBT University.

Figure 9. Internal (**left**) and external (**right**) views of the Holy Trinity's church of Berat.

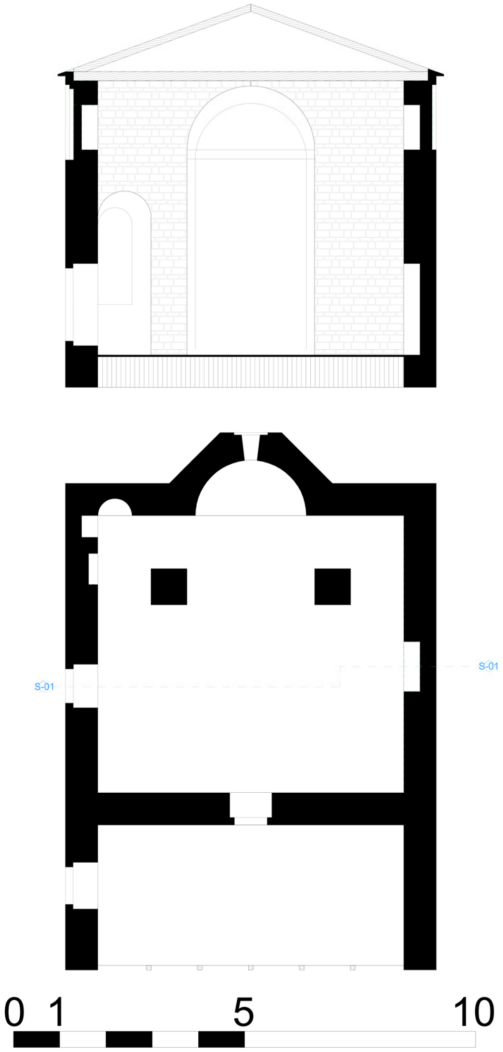

Figure 10. Plan layout and longitudinal section of the St Mary of Blachernae's church of Berat. Provision courtesy of Arch. Arsim Murseli, UBT University.

Figure 11. Internal (**left**) and external (**right**) views of St Mary of Blachernae's church of Berat.

Table 1. Architectural characteristics of the Albanian churches in Byzantine style.

Description	Assumpt.	St Parask.	St Nich.	Holy Trinity	Blachernae
Internal dimensions (m)	21 × 11.5	14 × 5.1	11 × 16.5	5.8 × 5.8	6.6 × 6
Maximum height (m)	9.5	6.4	13.5	10	5.9
Total volume (m^3)	1800	460	1750	300	234

The finish materials of all the churches are very similar: tiles on the floor and plaster (sometimes frescos) on the walls and roof.

3. Acoustic Surveys

Acoustic measurements were carried out inside the churches to analyze the main acoustic parameters according to ISO 3382 [13]. The following equipment was used:

- Balloon pops (Qualatex, Wichita, KS, USA);
- Omnidirectional microphone (Bruel & Kjaer 4165, Darmstadt, Germany).

The balloon pops are characterized by uncertainties of repeatability and directivity, although they are widely used in building acoustics tests [37]. The choice determined by the authors fell onto practical needs, to have the church unprovided of an electrical system. The balloon diameter was selected to be at least 0.5 m wide to abundantly cover the lower octaves of the spectrum [38]; however, the frequency bands which were to be assessed reflected the voice of the priests. The bandwidth used for the acoustic parameters ranged between 125 Hz and 4 kHz [39].

In each church, the sound source was placed in two locations: in the apse, corresponding to the position of the priests during sermons, and in the middle of the nave. The balloons were burst at a 1.4 m height. The microphone was moved into five positions across the naves, to be 1.4 m high. Figure 12 shows the equipment positions during the survey.

The acoustic measurements were undertaken without any audience [40]. The main acoustic parameters being assessed were the early decay time (EDT), reverberation time (T_{20}), clarity index (C_{50}), definition (D_{50}), and speech transmission index (STI).

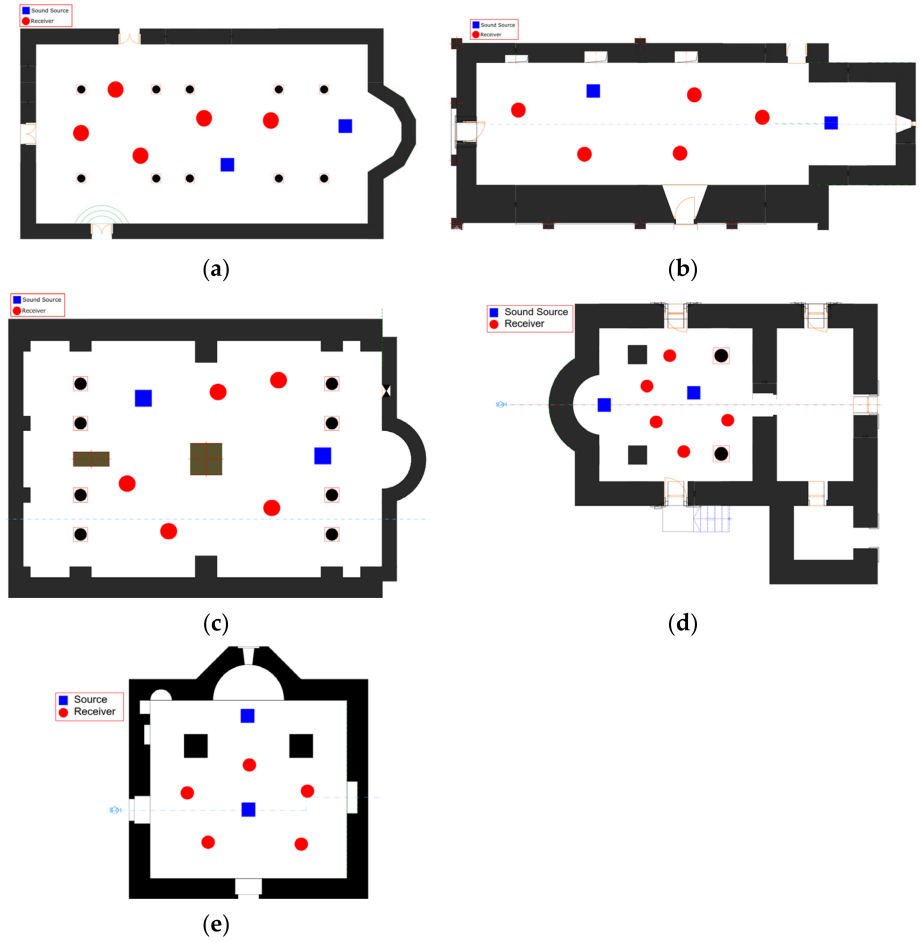

Figure 12. Location of the equipment during the acoustic measurement inside the five churches: St Mary Assumption's of Berat (**a**), St Paraskevi's of Cete (**b**), St Nicholas's of Mesopotamia (**c**), Holy Trinity's church of Berat (**d**), St Mary of Blachernae's of Berat (**e**).

4. Measured Results

The values obtained by analyzing the impulse responses (IRs) have been arithmetically averaged over all the measuring positions.

Figures 13–17 show the main acoustic parameters represented in different graphs where the spectrum bandwidth ranges between 125 Hz and 4 kHz.

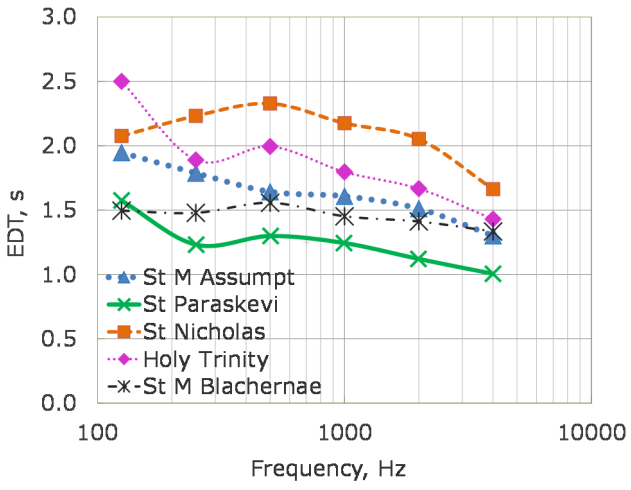

Figure 13. Measured results of early decay time (EDT).

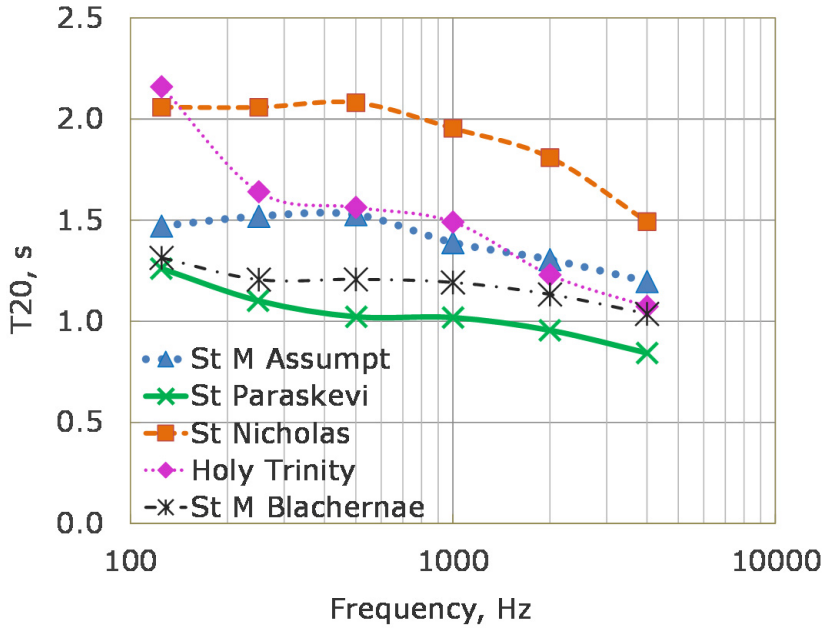

Figure 14. Measured values of reverberation time (T_{20}).

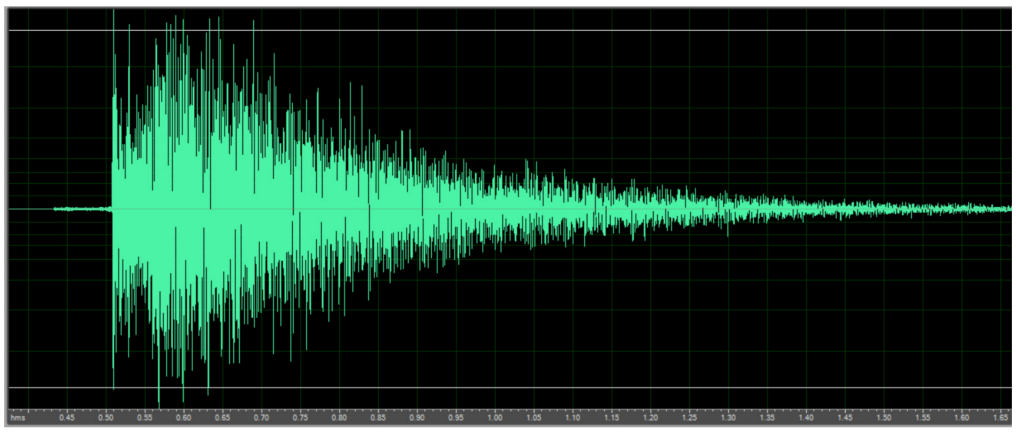

Figure 15. Impulse response measured inside St Nicholas's church.

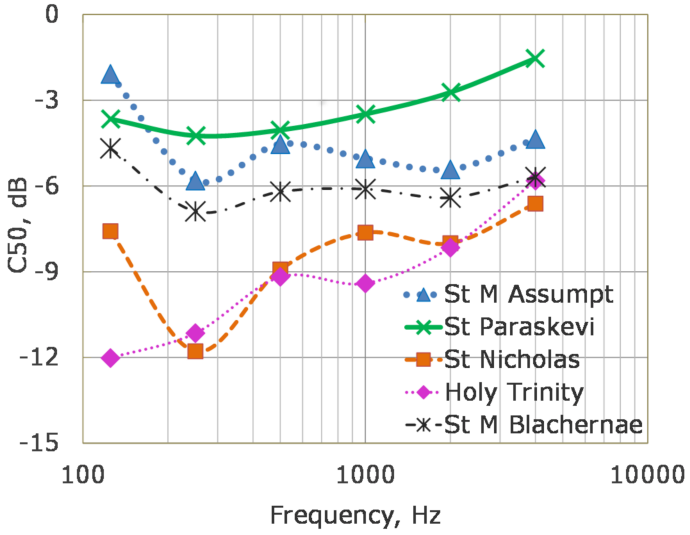

Figure 16. Measured results of clarity index (C_{50}).

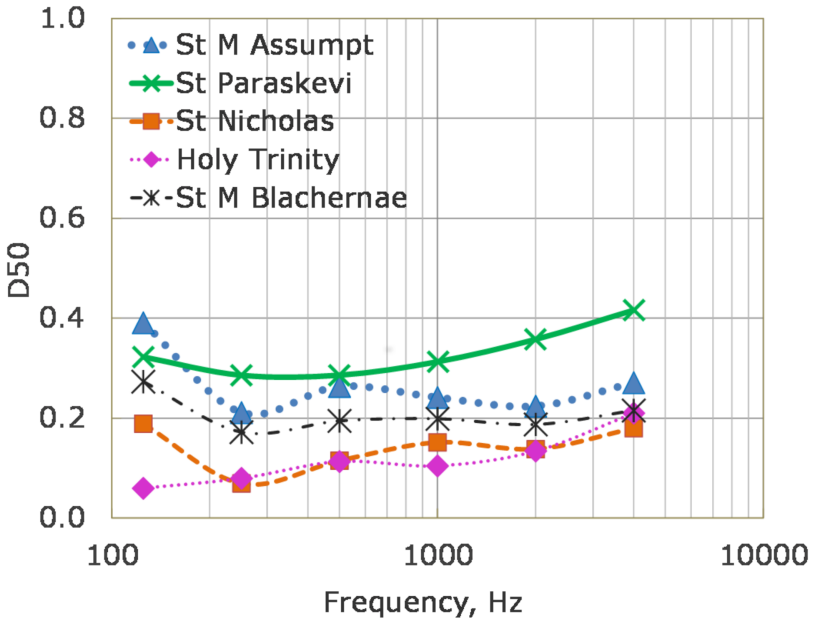

Figure 17. Measured results of definition (D_{50}).

Figure 13 shows the EDT values based on the measurements undertaken inside each church. The graph indicates that St Nicholas's church has the highest EDT values, fluctuating between 1.8 s and 2.4 s, corresponding to high and low frequencies, respectively. This outcome results in the optimal values outlined by Martellotta [41] for a good speech intelligibility. A similar volume shape, recalling the *basilica*, is represented by St Mary Assumption's, having an EDT trend line like that of St Nicholas's, but shifted below approximately 0.4 s at each octave [42]. Although St Mary Assumption's church has a volume size higher than St Nicholas's, the EDT results, comparable with the values found inside the St Mary Blachernae, were around 1.5 s [43]. This latest one has EDT values lower than Holy Trinity's church, although they have comparable room volumes; the only construction element that produces a difference of 0.2 s between the two rooms is the roof morphology, which is domed in the Holy Trinity's church. The EDT values measured inside St Paraskevi's were found to be the lowest, considering its room volume to be reasonably small and it is provided with a double slope roof.

Figure 14 shows that the trend lines of T_{20} are similar to the EDT curves, even if the T_{20} values shifted up to 0.2 s lower than the EDT values [44]. It should be noted how the measured values of T_{20} inside St Mary Assumption's church are very comparable to those found in the Holy Trinity's church. It should be remembered that other factors contribute to the reverberation results inside a room, such as the height and shape of the roof and the intensity of reflection of the finish materials [45]. In St Nicholas's church, the plaster on the walls has been restored whereas in other churches this action has not been fulfilled. Therefore, the sound energy concentration contributes to the increase in the level of reverberation depending on geometry and architectural composition [46].

Audition 3.0 was employed to analyze the measured impulse responses (IRs) obtained inside St Nicholas's church, as shown in Figure 15. A concentration of sound energy was found after 80–100 ms from the direct sound; this is determined by the reflecting surfaces at the boundaries of the room that contribute to the build-up of the noise [47,48].

The speech transmission index (STI) was analyzed based on orations and prayers being the main activity functions inside the churches. Because STI reflects the levels of distortion of the speech signal due to reverberation and background noise levels, in all the churches it has been found to be "fair", as defined by the intelligibility rating according to ISO 9921 [49].

The ambient noise levels (L_{Aeq}) were measured in each church to assess the speech transmission index values, as summarized in Table 2.

Table 2. Measured ambient noise levels of the Albanian churches.

A-Weighted Equivalent Sound Pressure Levels L_{Aeq} (dB)				
Assumpt.	**St Parask.**	**St Nich.**	**Holy Trinity**	**Blachernae**
38	41	40	42	39

Figure 16 shows the results related to C_{50}, found in all the churches to be below the optimal target for speech comprehension ($-2 < C_{50} < +2$ dB) [50]. This outcome reflects a fairly poor condition for the words' clarity. The worst C_{50} value was recorded in the Holy Spirit's church to be up to 15 dB below the lower-range limit, accentuated mainly at low frequencies [51].

St Nicholas's church indicates having similar results, while the measured values that more approximate the optimal target are related to St Paraskevi's church, closer to 0 dB at high frequencies. St Mary Assumption's and St Mary Blachernae's have similar clarity response, fluctuating around −6 dB. The outcome of C_{50}, found to have negative values in all the churches, is due to the reflections arriving at the receiver positions after 50 ms from the direct sound, as indicated in Figure 15. These late reflections are owed to the architectural elements, characterized by the curved surface of the vault and dome, where applicable.

In relation to the definition D_{50}, the measured results are summarized in Figure 17. The results related to all the churches show the D_{50} values to be fluctuating between 0.1 and 0.4 (10–40%). The best response is related to St Paraskevi's church, around 0.4 across all the frequency bands. St Nicholas's and Holy Trinity's churches have similar values in terms of definition, to be approximated to 0.1 at low frequencies and 0.2 at higher octaves, which is considered poor [52].

5. Conclusions

The Byzantine churches have always been studied from an architectural perspective, but none of the acoustic aspects have been analyzed. The authors' intention was to give some reference in relation to the level of speech understanding inside five selected churches, as prayers and orations are the main performed activities [53].

In all the churches, the reverberation time was found to be within or closer to the optimal values, except for the Holy Trinity's and the St Mary Blachernae's churches, where the reduced volume size determined the values that were measured.

The speech clarity index in all churches was found to be below the optimal range limits, accentuated widely in St Nicholas's and the Holy Trinity's churches. The measured values of C_{50} that were found to be closer to the optimal target are related to St Paraskevi's church. A similar outcome was found for the D_{50} parameter.

The authors are aware of the limitations that this study had fundamentally, especially regarding the utilization of the balloon pops as a sound source. Although the uncertainties in relation to directivity, repeatability and spectrum bandwidth are known, this measuring method is extensively used, particularly in places where the electrical system is not available, as in so many cultural heritage buildings [54,55].

Acoustic simulations of these Byzantine churches would predict the acoustic measures that could potentially be applied to improve the listening conditions inside the churches. In addition, the list of other Byzantine churches to be acoustically measured, located in other cities of Albania, will be implemented. This will also involve the employment of different equipment, such as an omnidirectional sound source to be fed by an Exponential Sound Sweep (ESS), in order to cover a broaden bandwidth.

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