

THE ACOUSTICS OF THE EARLY-CHRISTIAN MONUMENTS OF THESSALONIKI

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1. Introduction

This paper is the last of a series of four papers concerning the acoustics of historic monuments and churches of Thessaloniki. All monuments dealt with in these series have been built inside the very center of the old walled part of the town.

Although Thessaloniki has suffered many destructions, a number of fourteen buildings with some interest for the room acoustics, are to be found today witnessing her over two thousand year old history. Of these buildings five come from the early-Christian era, 4th to 7th century, and nine from the Byzantine era, 11th to 14th century.

The present paper reports on data accumulated on the first group of five early-Christian monuments, while data on the other group is at the moment already in print [4].

After the descriptions of the monuments and the measurement results, a discussion follows, comparing the main characteristics of both groups.

2. Descriptions

The early-Christian monuments described below are St. Demetrius, St. Sophia, Acheiropoietos, Hosios David and St. George. All of them except Hosios David have exceptionally large volumes and share many characteristics. St. Demetrius is an early-Christian basilica built during the first quarter of the 5th century. The building was destroyed by fire and rebuilt once during the 7th century. A little after 1917 a new fire destroyed the building as well as the largest part of the town and so today's form is the result of large scale reconstructions completed around 1950.

The basilica of St. Demetrius is a large rectangular building measuring $57 \times 33 \text{ m}^2$ with a height at the center axis of about 18 m. It is divided by four colonnades into five aisles. There is an upper storey above each of the four side aisles and the narthex. The nave and each aisle have separate tilted roofs.

The volume of the church is 22100 m^3 , while the total internal surface is 6500 m^2 . This gives a mean-free-path value of 13.60 m. The floor and a large percentage of the wall surfaces are covered with marble slabs. The rest of the walls is covered with mosaic and fresco paintings. The roof is made of reinforced concrete, imitating the old destroyed wooden construction, without an underceiling. The plans of the church are presented in Fig. 1.

St. Sophia is a scaled down imitation of the famous St. Sophia of Constantinople built during the 7th century. It has a transitional form between domed basilica and domed cruciform church. Also destroyed by fire in 1890, the building was reconstructed between 1907 and 1910.

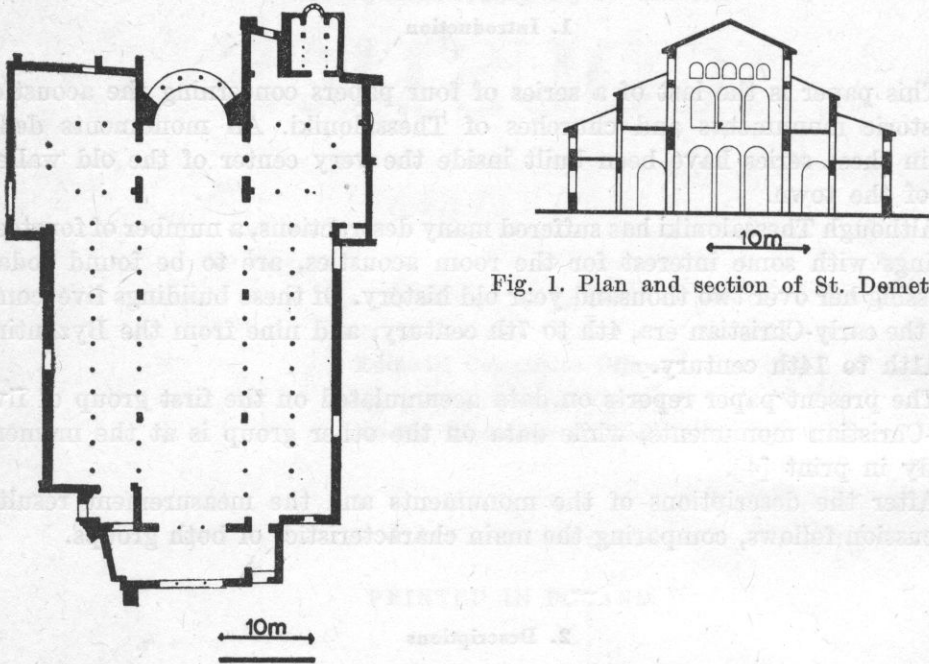


Fig. 1. Plan and section of St. Demetrius

The interior of the church is divided into three aisles by two rows of columns alternating with piers. The church of St. Sophia is square as in the domed cruciform type. In the center of the nave is a dome resting on four barrel vaults of which the western is wider.

The barrel vaults of the dome rest on thick piers. The aisles are roofed at a lower level by uninterrupted vaults and the narthex by smaller domes. Above the narthex and both aisles there are galleries.

The church has a volume of 15250 m^3 . A large percentage of the floor and wall surfaces is covered with marble, while the largest part of the roof and the rest of the walls are covered with mosaic and fresco paintings.

The plans of the church are presented in Fig. 2.

Acheiropoietos is another early-Christian basilica, built during the second quarter of the 5th century, which was never destroyed or altered. The building is large and rectangular with dimensions comparable to those of St. Demetrius. It is divided by two colonnades into three aisles. Above each of the two side aisles there is an upper-storey.

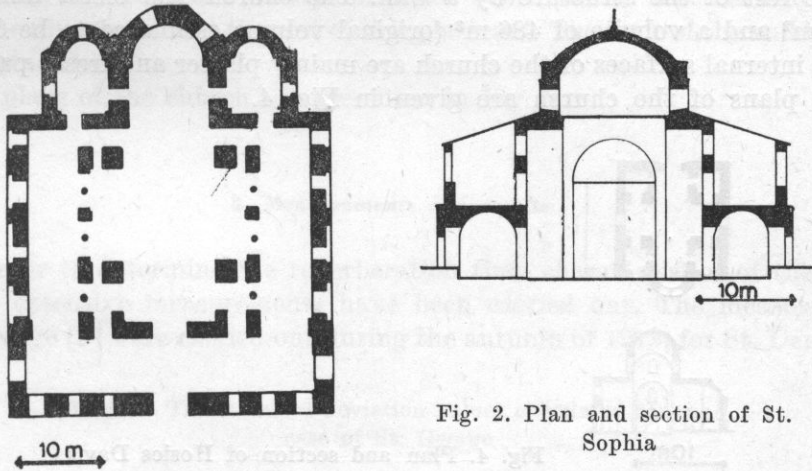


Fig. 2. Plan and section of St. Sophia

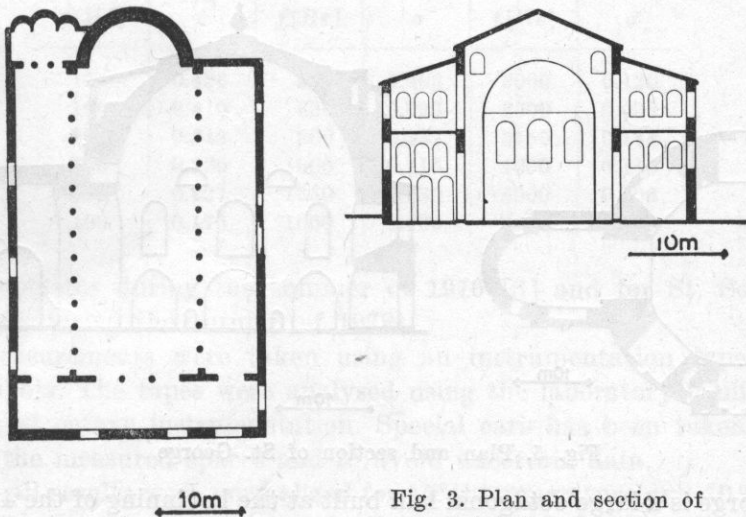


Fig. 3. Plan and section of Acheiropoietos

The volume of the monument is 19.250 m^3 and the total internal surface is 5900 m^2 , which gives a mean-free-path value of 1305 m . The floor area is

made of large marble blocks, and the wall surfaces are mainly of plaster. The roof of the church is a wooden tilted construction without an underceiling.

The plans of the church are presented in Fig. 3.

Hosios David is a small domed cruciform church, belonging to the old monastery of Latomou, built at the end of the 5th century. The original form of the church was partly changed during the Turkish age. The dome of the church was covered by a wooden underceiling which has existed until today. The entrance was transferred from the west to the south side, and the western part of the church, part of which has disappeared altogether, has been separated from the rest of the structure by a wall. The church has small dimensions $11 \times 8.5 \text{ m}^2$ and a volume of 486 m^3 (original volume estimated to be 650 m^3).

The internal surfaces of the church are mainly plaster and fresco paintings. The plans of the church are given in Fig. 4.

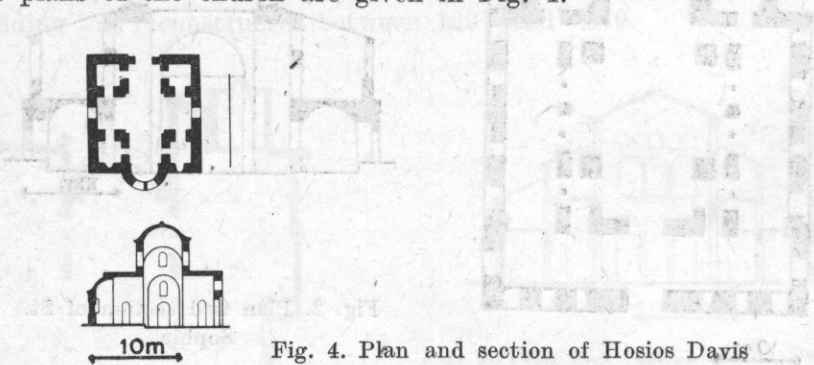


Fig. 4. Plan and section of Hosios David

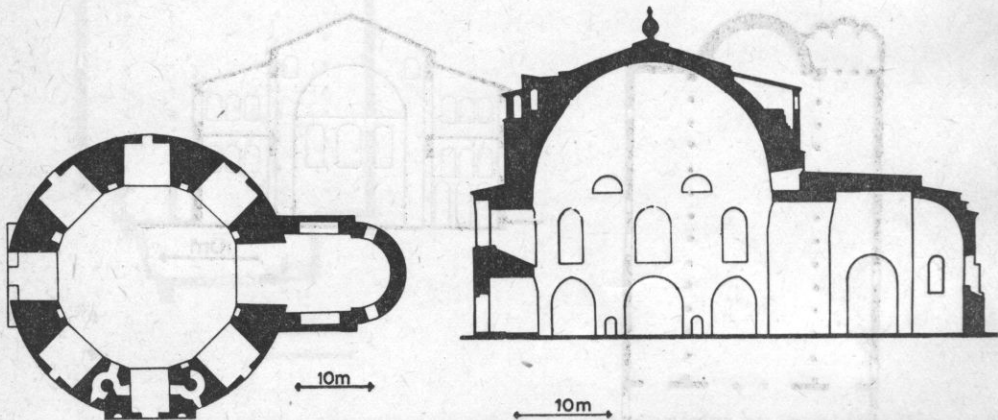


Fig. 5. Plan and section of St. George

St. George is a large octagonal hall built at the beginning of the 4th century and intended originally to be a Roman mausoleum. It has an octagonal form and large barrelvaulted recesses at the eight sides of the ground level. Above them there are eight similar but smaller recesses with windows. A little higher at the base of the dome there is a ring of even smaller recesses.

The central space has a diameter of about 24 m and a total height of about 26.50 m although the original floor level was more than 2 m lower than it is today. The eight recesses that surround the central space have an average opening of 6.20 m and a height of 6 m each. The hall has undergone two Byzantine transformations, the second one during the 10th century, which transformed it into a Byzantine church. The eastern recess was made a sanctuary with a width of 8 m, a height of 13.50 m and a depth of 20 m.

The hall's total volume today is 15340 m³ out of which 10710 m³ belongs to the central space. The largest part of the surfaces of the hall is made of glazed brick, interrupted by strips of small stone blocks. The surface of the dome is mostly mosaic and the rest of it is plastered. The floor of the hall is made of terracota tiles.

The plans of the church are presented in Fig. 5.

3. Measurements and results

In order to determine the reverberation time characteristics of these monuments, extensive measurements have been carried out. The measurements for St. George [2] were carried out during the autumn of 1973, for St. Demetrius

Table 1. The standard deviation values calculated for the case of St. George

f [Hz]	σ	f [Hz]	σ	f [Hz]	σ
125	0.426	500	0.203	2000	0.120
160	0.410	630	0.093	2500	0.098
200	0.343	800	0.137	3150	0.144
250	0.220	1000	0.115	4000	0.110
315	0.227	1250	0.180	5000	0.106
400	0.176	1600	0.166	6300	0.110

and Acheiropietos during the summer of 1976 [3] and for St. Sophia and Hosios David during the autumn of 1978.

The measurements were taken using an instrumentation tape recorder and pistol shots. The tapes were analysed using the laboratory facilities, with standard third octave instrumentation. Special care has been taken to cover thoroughly the measured spaces and to avoid uncertain data.

Finally all results were normalized for 15°C temperature and 70% relative humidity. The results are presented in Table 2. Table 1 gives the standard deviation values calculated for the case of St. George.

Examples of decay curves at various frequencies in two points are given in Fig. 6.

Table 2. Analytical measurement results of the five monuments

Church	Frequency [Hz]																	
	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300
St. Demetrius	6.50	7.00	6.90	7.20	6.00	5.90	5.90	5.70	5.30	4.90	4.50	4.00	3.40	2.80	2.30	1.85	1.50	1.10
St. Sophia	3.25	3.25	4.10	4.10	4.10	3.90	3.90	3.90	3.50	3.35	3.10	2.90	2.65	2.30	2.05	1.75	1.45	—
Acheiropoietos	5.10	4.80	4.40	3.90	3.80	3.70	3.70	3.70	3.50	3.10	2.80	2.60	2.30	2.00	1.75	1.50	1.25	—
Hosios David	0.82	0.73	0.64	0.66	0.65	0.64	0.63	0.65	0.62	0.59	0.56	0.58	0.54	0.53	—	—	—	—
St. George	5.30	5.15	5.05	5.00	4.90	4.90	4.90	4.95	4.75	4.60	4.40	4.25	4.10	4.00	3.80	3.35	2.70	2.20

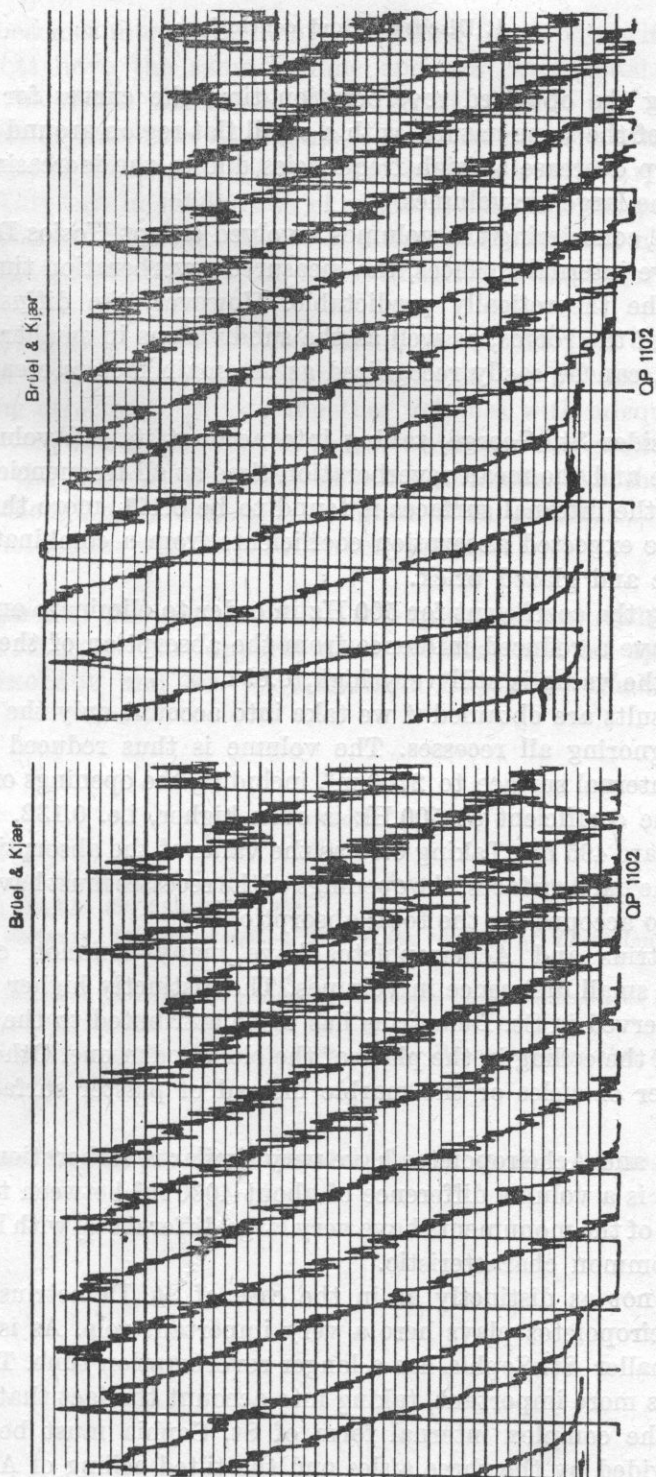


Fig. 6. Decay curves for St. George

4. Discussion and conclusions

Considering the obtained reverberation time the curves for all churches are essentially of the same nature, with a small flat region around mid-frequencies and a sharp decrease at high frequencies due to the increasing absorptive properties of the large air volumes.

Further on, considering the volumes involved except Hosios David and the totally reflective internal surfaces, the measured reverberation times are about one third of the theoretically predictable. However, the diffusion provided by the shapes of the rooms, as well as the subdivisions in smaller, acoustically coupled spaces, can be easily recognized as the main factors creating this discrepancy.

If we consider St. George, taking into account its full volume, its total internal surface and the mean reverberation time at all frequencies as 4.15 sec, the mean $\bar{\alpha}$ of the internal surfaces is found to be 0.111, more than two times higher than the expected absorption coefficients from a combination of stone, marble, mosaic and glazed brick.

Calculating the coefficient for 500 Hz in order to eliminate any air absorption, and to have a reduced influence from the absorption of the very limited glass surface, the value is still very high, 0.094.

Similar results are obtained if we take into account only the central space of the room ignoring all recesses. The volume is thus reduced to 10710 m³ and the total internal surface to 2700 m², including the openings of the recesses. In this case the coefficient at 500 Hz is even higher, i.e. 0.132. The openings of the recesses are 495 m². Taking 0.05 as the value of the absorption coefficient at 500 Hz for the hard surfaces, the openings of the recesses must have a coefficient equal to 0.50 to account for the total absorption.

St. Demetrius and Acheiropoietos have many common characteristics in form, and a small difference in volumes. The distinctly higher reverberation time value observed in St. Demetrius has to be attributed to the new concrete construction of the ceiling in the place of the old wooden one. Other differences, e.g. the number of aisles or the marble instead of plaster surfaces play only a minor role.

St. Sophia and Acheiropoietos have very similar reverberation time curves, although there is a volume difference of about 4000 m³ between them.

The forms of the monuments have very large differences, with large diffusion as the only common characteristic.

Although not as distinctly as in the case of St. Demetrius, the wooden ceiling of Acheiropoietos plays here a very important role. As is shown in the results the smaller St. Sophia has a longer reverberation time. The role of the ceiling becomes more important, taking into account the fact that the diffusion provided by the complex internal form of St. Sophia must be much larger than that provided by the three aisles and the tilted ceiling of Acheiropoietos.

This fact becomes more evident by comparing St. Sophia with St. George. Both monuments have the same volume and are constructed from similar materials with no noted difference. However, St. George has a one second longer reverberation time than St. Sophia, a fact that must be attributed to the very large volume of the central space of St. George, a situation not to be found in St. Sophia. This lack in subdivision of spaces is the only recognizable factor. It seems also probable that the absence of diffusing elements at higher frequencies in St. George is the cause of the noted linearity of the reverberation time curve.

In spite of the differences between them, these 1500-year old monuments all point to the fact, which is also supported by earlier publications [1], that rooms consisting of smaller coupled together volumes with adequate diffusing elements have very low reverberation times, which are not predictable in calculation using the known reverberation time formulae. Another interesting point is that although not acoustically designed all these rooms have reverberation time characteristics well suited for their purposes.

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