



Understanding the acoustics of Papal Basilicas in Rome by means of a coupled-volumes approach



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ABSTRACT

The paper investigates the acoustics of the four World-famous Papal Basilicas in Rome, namely Saint Peter's, St. John Lateran's, St. Paul's outside the Walls, and Saint Mary's Major. They are characterized by different dimensions, materials, and architectural features, as well as by a certain number of similarities. In addition, their complexity determines significant variation in their acoustics depending on the relative position of source and receivers. A detailed set of acoustic measurements was carried out in each church, using both spatial (B-format) and binaural microphones, and determining the standard ISO 3382 descriptors. The results are analyzed in relation to the architectural features, pointing out the differences observed in terms of listening experience. Finally, in order to explain some of the results found in energy-based parameters, the churches were analyzed as a system of acoustically coupled volumes. The latter explained most of the anomalies observed in the distribution of acoustic parameters, while showing at the same time that secondary spaces (aisles, chapels) play a different role depending on the amount of sound absorption located in the main nave.

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1. Introduction

Church acoustics have attracted significant attention in the last 20 years, resulting in a variety of contributions from different countries [1–14] and involving different aspects such as the modeling of sound field variations inside [8,15,16], the role of occupancy [6,18,19], the relationship with liturgy and music [20,21], the definition of rating schemes for optimal listening conditions [22,23], the use of innovative technologies to virtually reproduce buildings that have been destroyed or modified [24,25]. The need to correctly design the acoustics of new churches, and adapt the old ones, has prompted books on this topic [26,27]. However, despite the large amount of published research, the complexity and uniqueness of each building, resulting from the historical stratification of architectural styles, and addition/replacement of different elements or entire volumes, makes any generalization difficult. Consequently, any acoustic investigation of individual buildings may offer occasions to better understand some of the unique features and the related fundamental problems.

The present study is aimed at characterizing the acoustics of the four Papal Basilicas in Rome (formerly known as Patriarchal Basilicas), namely Saint Peter's (SPB), St. John Lateran's (SJL), St. Paul's outside the Walls (SPX), and Saint Mary's Major (SMM). All of them have been investigated in the past and are the subject of two of the earliest research papers in the field of church acoustics. In fact in 1953 Raes and Sacerdote [28] analyzed SJL and SPX, while twenty years later Shankland and Shankland [29] measured reverberation time in SPB and in the other three Papal Basilicas using a tape recorder, by ear

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and with a stopwatch. Despite the very rudimentary equipment, some of the key features of these spaces were identified. The most surprising being the mid-frequency reverberation time of 7.1 s measured in SPB, a value lower than those observed in other much smaller churches [5]. Double slope decays were observed in SJL when the source was moved inside the aisle. The origin of the unusual behavior observed in SPB has more recently been analyzed and explained [17], taking advantage of more sophisticated measurement techniques and interpreting the results within the framework of coupled-volume systems. Use of Bayesian analysis [30] and the representation of the space as a system of acoustically coupled volumes [31], successfully tested in St. Paul's Cathedral in London [32], have contributed to explain that reduced reverberation time mostly depends on increased absorption due to richly decorated surfaces. In the present paper, the same techniques have been applied to the whole set of Papal Basilicas, first describing their acoustic properties in terms of reverberation and other acoustic parameters, and then explaining the observed behavior as a function of the architectural features of the spaces, with particular reference to the effect of coupled volumes.

2. Methods

2.1. Measurement techniques

Measurements were carried out complying with ISO 3382-1 standard [33], together with a set of guidelines specifically defined for churches [7]. The measurements were carried out using omni-directional sound sources (a Look-Line D301 and a self-made dodecahedron made of twelve 120 mm loudspeakers), each one combined with an additional sub-woofer to cover low frequencies. Each sound source was fed by a different constant-envelope equalized sine sweep (40 s long) generated using

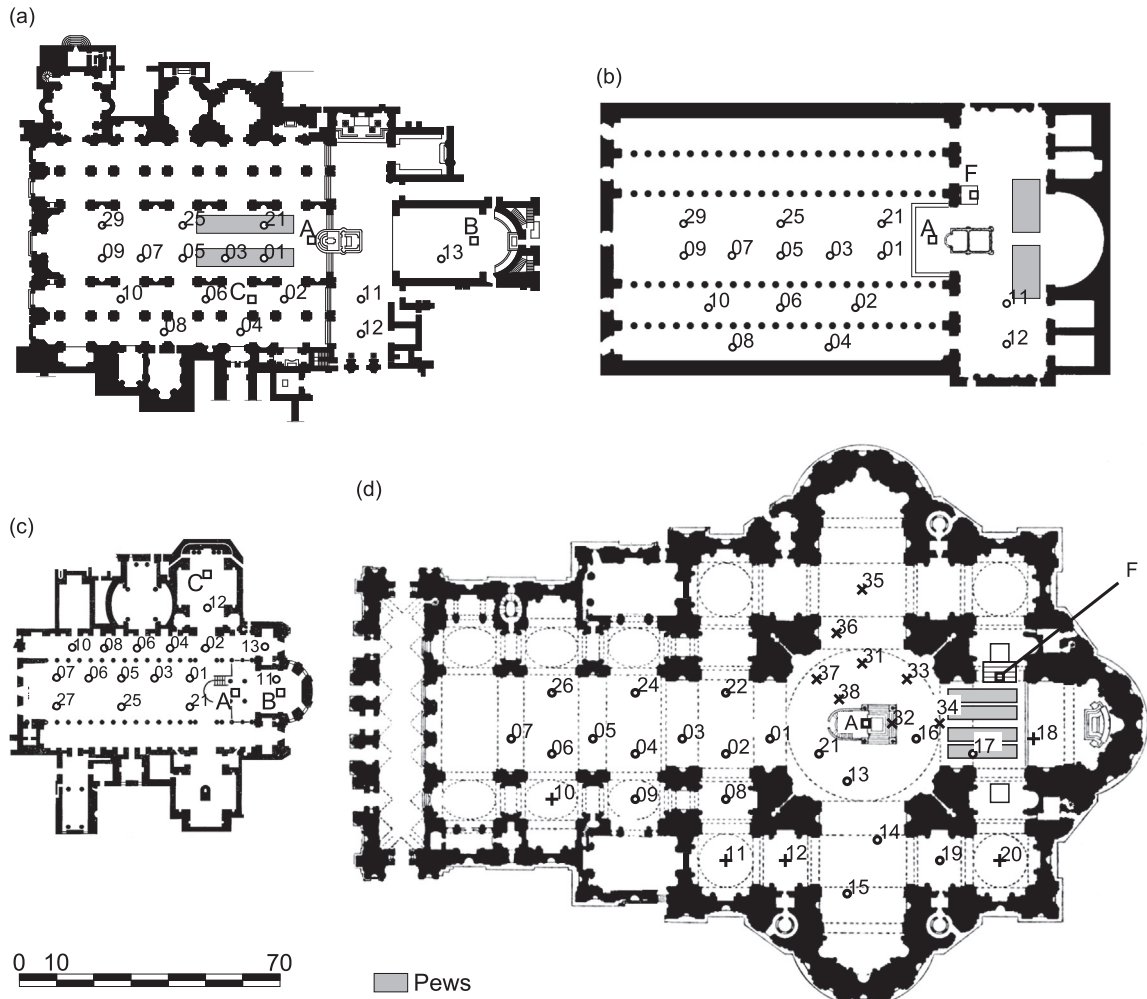


Fig. 1. Plan of the four basilicas with indication of the source and receiver positions. Capital letters correspond to sources, numbers to receivers: (a) SJL; (b) SPX; (c) SMM; (d) SPB.

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