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The Importance of Sound Strength (G) in Opera House Acoustics: Intimacy and the Role of Early Reflections

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Sound strength is shown to be a key acoustical factor in the success of opera house design with a major component being the early sound field as provided by the room design and geometry. The early sound field, along with the late energy and visual factors, are also hypothesized to be related to acoustical intimacy.

CONCERT HALL AND OPERA HOUSE ACOUSTICAL RELATIONSHIPS

It's difficult to quantify the relative importance of acoustical factors for opera houses, given the multidimensional characteristics of the opera performance and audience experience. The extra-acoustic visual aspects of the acting, costumes, scenic perspective, stage source position and so on can dictate room design which, for large occupancies, may detract from the architectural requirements essential to providing the necessary acoustical portion of the house's response. With a good understanding of the essential acoustical factors, and how they interrelate, an excellent acoustical outcome within the visual constraints is indeed possible. For large houses however, the traditional classical opera house design approach may not provide the desired results. The subject of this analysis is how the known concert hall parameters may apply to acoustical quality in opera house design.

Classical Theory and Concert Halls

The issue of normalizing the history, culture and mythology of established opera houses from judgment based purely on their acoustical response has never been squarely faced. The visual and physical relationship between performer and audience is the main differing element between the use of concert halls and opera houses. It is suggested here however that the purely acoustical factors must be sorted out for opera houses first, independent of visual, cultural or historical judgments or biases.

A half-century of concert hall research has provided us with the many acoustical attributes as well summarized by Beranek [1] and Barron [2]. Of the key subjective acoustical factors identified, acoustical Intimacy remains as yet illusive of definition and remains undefined in terms of its parameter correlates. The thesis developed in this paper will at the least suggest the factors to research, if such multidimensional analyses are possible at all, in defining "Intimacy."

For auditoria, starting with Sabine [3], sound needed to be "sufficiently loud," with speech or music to be "clear and distinct." Sabine derived statistical relationships for sound in rooms which essentially say that clarity and sound strength are inversely proportional. The generalized relationships are as follows, where the values for Clarity (C80) and Sound Strength (G) are approximated for greater distances in large rooms with volume (V) and room constant (A) (metric):

$$C_{80} \approx 10 \log \{e^{7A/V} - 1\} \text{ dB} \qquad (1)$$

$$G \approx 10 \log \{40^2\pi/A\} \text{ dB} \qquad (2)$$

This classical prediction says that when the room constant A (proportional to the number of seats) changes, one measure will decrease while the other increases, and vice versa. The room constant is the key factor in all classical predictions of G, where reverberation time (RT) is only a dependent variable, since "it's the level (of the reverberant field) that counts."[4] while this inverse relationship is somewhat true between concert halls, when the same averages between opera houses are compared, there is no meaningful correlation between C80 and G as shown in the study by Hidaka and Beranek [5]. While in apparent conflict, surely, both are important for the successful opera house.

Many [see 6] have noted that the statistical or classical mathematical approach to quantifying the acoustical event in an enclosure, while allowing for a simplification and approximation of what is an extremely complex event, can often provide results which are far from reality, including the equations given above. Beranek [7] has cleverly solved this problem for the calculation of RT by normalizing absorption coefficients to Sabine's simple equation. Such adaptations are not as easily done for the other parameters which are related to integrating the transient energy as a function of position within a space. Barron [8], however, has greatly improved the prediction of the behavior of G and C80 in large rooms with his "revised theory." Suggested ranges for acoustical parameters in concert halls are found in the literature [1, 2, 6, 9, 10].

Acoustical Factors in Opera Houses

That sound strength G is an important subjective factor in concert halls has been well established going back to work reported by Eysholdt & Gottlob [11], Schroeder, et al. [12], Cremer, et al.[13] among many others[10]. It is hypothesized here that for opera, it is a prime factor for a house's success, as it is certainly essential for singers to be able to fill the room with adequate loudness, without strain, also allowing for the ability to balance voice with the pit orchestra. That some of the larger opera houses, without admitting it, may use amplification to make up for sound strength deficiencies is a further testament to its importance. Similar arguments can be made for the importance of Clarity in opera houses and, in light of the visual aspects of opera, for the importance of acoustical Intimacy as well.

COMPONENTS OF "G" ARE IMPORTANT TO ALL OPERA HOUSE ACOUSTICAL FACTORS

In the study by Hidaka and Beranek [5], the major acoustical factors important to concert halls are found to be valid for opera houses as well, with C80 highly correlated with RT. Further, it has been demonstrated through room acoustical measurements [3,14] and computer modeling [15], that the early reflected sound in a hall up to around 80 msec. are a major factor in the value of G achieved in any space. As pointed out above, this is contrary to "classical" theory. Application of this concept in large hall design has been accomplished through the directed reflection sequence (DRS) design approach as discussed in the literature [16,2(Sec.4.1), 9, 6, 15] and of which the Christchurch Town Hall and Segerstrom Hall [1] are prime examples. Extensive measurement data from these halls have clearly demonstrated that G has a strong early energy component not at all predicted by classical or "revised" theories. Since sound strength G is difficult to achieve in large spaces, the early reflected energy issue is of singular importance in achieving the desired results through architectural design.

The early sound field, which is strongly linked to the architectural design and geometry of the room, is therefore found to be a component in the major acoustical factors of sound strength, clarity, spaciousness and Intimacy. The ability of listeners to judge differences in G due to changes in the early sound field has been reported to be at around 1.0 dB [17]. Kahle [18] has reported a similar degree of discrimination between different halls.

The Role of Early Reflections and "G" in Achieving Acoustical Intimacy

Subjective acoustical Intimacy is not easily defined and may well vary in the listening process between people. Likewise, its objective attributes are also elusive. Beranek [1, 5] has made a connection between Intimacy and his initial time delay gap (ITDG) taken at two seat locations, indicating a delay difference of around 10 msec. as defining the difference between excellent and not so acceptable ITDG values. Barron's [19] studies on the other hand have found no correlation between ITDG and Intimacy, but a correlation between loudness and Intimacy which therefore connects Intimacy to both the early and late sound fields. Toyota's [14] REC curves further connect Intimacy with strong early reflections in the first 80 msec. For further discussion on the links between G, visual perception and Intimacy, refer to Barron [2, 19(pg. S25)]. In summary, acoustical intimacy is surely multidimensional, with at least early sound field, G and visual components.

Sufficient values of G in large opera houses must be achieved through both reverberation efficiency (keeping A low) and importantly by providing significant multiple early reflections through architectural design and room geometry. For larger rooms, major reflectors may need to be added which are independent of the room's volumetric shell. General design opera house design approaches are well summarized by Hidaka, Beranek and Barron [1, 2, 5] with the general DRS design approach given in several published references including [2-Sec.4.1, 16, 9, 6, 15].

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