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DOMES AND ECHOES IN CLASSICAL OPERA HOUSES

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1. INTRODUCTION

In many classical opera houses built in 19th-century, the multiple galleries and the high ceiling are the basic elements of Italian and French-Italian style. Though a layout in the form of a horse shoe, semi-circle or ellipse could generate focalization near the stage side. But due to the strong absorption of the openings, the diffusive decorations and the overhead position of the focal point, the echo disturbance could go unnoticed. Conversely, some musicians 'want' to hear their sound returned from the hall. However, when the ceiling height exceeds 17~20m, the long delayed ceiling reflection may cause audible echo in audience area or on the stage. Much has been written about the floor plans of opera houses, but the literature contains few discussions about the impact of ceiling shapes in baroque opera houses.

With new projects as with the restoration of old opera houses, it is important to clarify the relationship between the ceiling shape, the height and the echo produced. The recent premilinary study for the restoration of the Opéra-Comique[1, 2](1840) in Paris —native theatre for the baroque lyrics of Berlioz, Offenbach, Bizet, Gounod, etc.— gave rise to a serious discussion about the concave dome causing the perceptible echo. This led to questions such as : Does the dome need to be covered by a suspended réflector or by an absorbing layer which would mask a Benjamin Constant painting dating back to 1889 ? Why is it that there have been no echo problems at the Opéra Garnier (1875) which also has a dome ? What is the situation in other 19th-century classical opera houses ? These questions must be answered for both the authorities and for the author's architecture students.

It is widely known that the perception of echo is influenced by three main factors :

(1) time delay after the arrival of the direct sound
(2) difference in level between the direct sound and the reflection[3]
(3) duration of the sound signal, short impulses (staccato tones, etc) leading to a higher perceptibility of echo than longer impulses

For instance, when a reflecting ceiling is flat and high, the long time delay may cause a certain perception of echo. This may be the case of Milan's La Scala where the flat ceiling is some 20m high and certains members of audience in the stalls can detect echoes[4]. If a ceiling is domelike and high (approximately 19m), the long delayed ceiling reflections will be reinforced by the focalization, and echo can be detected in certain place (e.g., in Covent Garden[5]). The worst scenario is the case of a domed ceiling of radius similar to the ceiling height (i.e. focal point near the audience). The focalized late reflections, such as those of the Opéra-Comique in Paris, constitute the perceptible echo in the audience area.

Is the concave dome the typical ceiling of 19th-century's opera houses ? Are there any structural reasons which require that opera house ceilings be dome-shaped ? What influence do the radius of the dome and the height of the ceiling have on the production of echo ? These are all valid issues and the answers to these questions may prove useful for the designing of new opera houses.

2. CEILING SHAPE IN DIFFERENT OPERA HOUSES

The shapes of ceiling in 18/19th-century opera houses[2, 6] in France and in other European countries can be classified into three main types, namely **concave dome, flat dome,** and **flat ceiling**. The following table is a synopsis of the aforesaid ceiling shape, with « C » representing Chandelier suspended under the ceiling :

Table 1. Ceiling shape in the 19th-century opera houses in Europe

Concave dome	Flat dome or flat cone	Flat ceiling
Opera of Nancy (1708/1919, 1500 seats, with C)	Teatro Communale of Bologne (1763/1935, 800 seats, with C)	Teatro Olimpico of Vicenza (1585, 1000 seats)
Grand Théâtre of Bordeaux (1780, 1200 seats, with C)	Théâtre Graslin of Nantes (1788/1814, 970 seats, with C)	Teatro Argentina of Roma (1732/1971)
Théâtre de l'Odéon of Paris (1782)	Gran Teatro La Fenice of Venice (1792/1837, 1500 seats, with C)	Teatro di San Carlo of Naples (1737/1946, 2400 seats)
Comédie-Française of Paris (1790, 892 seats, with C)	Teatro Reggio of Parme (1829, 1400 seats, with C)	Deutsche Staatsoper of Berlin (1744/1955, 1432 seats, with C)
Covent Garden of London (1809/1899, 2120 seats)	Teatro Municipale Valli of Reggio d'Emilie (1857, 1200 seats, with C)	Théâtre Municipal of Metz (1752, 750 seats, with C)
Staatsoper/Bayerishe of Munich (1818, 2100 seats, with C)	Opéra du Rhin of Strasbourg (1871/1888, 1229 seats, with C)	Royal Opera of Versailles (1770/1871, 800 seats, many C)
Opéra-Comique of Paris (1840/1898, 1400 seats)	Royal Theatre of Copenhagen (1874/1985, 1600 seats, with C)	Teatro alla Scala of Milan (1778/1946, 2289 seats, with C)
Théâtre Royal de la Monnaie Of Bruxelles (1856, 1818 seats)	Teatro dell'Opera of Roma (1880/1960, 2212 seats, with C)	Kungliga Teatern of Stockholm (1782/1898, 1200 seats)
Imperial theater of Compiègne (1870, 900 seats)	Opera of Budapest (1884, 1261 seats, with C)	Teatro National Sao Carlos of Lisbonna (1793, with C)
Theatre of Angers (1871, 1100 seats, with C)	Opéra of Nice (1885, 1200 seats, with C)	Theatre of Bolchoï of Moscova (1825/1856, 2150 seats, with C)
Opéra Garnier of Paris (1875, 1991 seats, with C)	Smetanovo Divadlo of Praha (1888, 1554 seats, with C)	Staatsoper of Dresde (1841/1985, 1103 seats, with C)
Opera of Monte-Carlo (1879, 600 seats, with C)	Teatro Massimo Bellini of Catane (1890, 2000 seats)	Teatro Communale of Modène (1841, with C)
Opera of Montpellier (1888, 1500 seats, with C)		Gran Teatro del Liceu of Barcelona (1847/1862, 3000 seats)
Theatre of Aix-en-Provence (1888, 600 seats, with C)		Opera of Rennes (1850, 750 seats)
Theatre of Fontainebleau (finished 1912, 516 seats)		Teatro Lirico Nacional La Zarzuela of Madrid (1856/1956, 1258 seats)
		Staatsoper of Wien (1869/1955, 2276 seats, with C)
		Festspielhaus of Bayreuth (1876, 1925 seats)

These different ceiling shapes can be analysed as follows :

2-1. The concave dome was not the dominant form in 19th-century opera houses

In the above list of 44 european classical opera houses, only 34% of the ceilings are concave domes, whereas flat domes and flat ceilings respectively account for 27% and 39%. The concave dome ceiling was clearly not a structural necessity. The Royal Opera House of Versailles[7] which was built in 1770, has an entirely wooden structure with a flat ceiling and not a dome ! Many 19th-century opera houses have a metallic truss which allows any kind of ceiling shape. In fact, concave domes were chosen for aesthetic purposes and frequently by the French-speaking architects (Victor Louis, Gabriel, Charles, Damesne), and are therefore not a symbol of the Galli-Bibiena family or the Italian style opera house.

2-2. Importance of the ratio of the dome radius to the ceiling height

The correlation between the concave dome and the echo varies according to the radius (r) and the ceiling height (h). **Figure 1.** illustrates the section of several opera houses where the radius (r) of the dome and the central ceiling height (h) are shown. When the radius is much smaller than the ceiling height, e.g., the Theatre of Fontainebleau (r=8,5m, h=14,2m), there is no echo problem. Nor is there any annoying echo when the radius is much greater than the central ceiling height, e.g., Grand Theatre of Bordeaux (r=22,4m, h=16,6m), Opéra Garnier (r=39,1m, h=21m). However, when the radius of the dome is close to the ceiling height, as in the Opéra-Comique (r=15,5m, h=17m), the focal points are located at the front of the 1st balcony and the rear part of the stalls level.

Figure 2. is a sectional drawing of the Opéra-Comique with the two different source positions related to their respective focal points. When the source n°1 is located in the « oversized » orchestra pit (extended in 1982, equal to 45% of the aera of the stalls), then the source is under the dome which provokes ~70ms delayed focalized reflections. When the source n°2 is located at the front stage, the focal point is moved to the 1st balcony with ~50ms delay time (in fact, the echo is perceptible for impulsive sound). So, the fact that the dome radius is close to the ceiling height causes problems at the Opéra-Comique.

2-3. Flat ceiling

In case of opera houses with a flat ceiling, there is also a danger of echo if the ceiling height exceeds some 19m and there are no efficient diffusing (decorative) elements. **Figure 3.** illustrates two opera houses with flat ceiling, one of which has more diffusive element (Vienna) as a result of which there is less danger of echo than in the other (La Scala). Nevertheless, flat high ceilings have less problem than concave domes with focalization.

It is necessary to point out that a flat ceiling in the longitudinal section may have a gently domed shape in the cross-section. Gently cylindrical ceilings cause fewer echo problems.

2-4. Chandelier

A chandelier suspended from the ceiling has only limited effect on focalizing echo. The small dimension of the crystal elements and the metallic structure do not have an efficient diffusive effect. Disk-shaped chandeliers may be better, but should be of sufficient dimension by comparison with the dome area and sound wave length of the lower frequencies.

3. POSSIBLE SOLUTIONS FOR THE DOMES

Generally, a domed ceiling is not a serious problem if the radius is much smaller or much bigger than the ceiling height, and many baroque opera houses do not have problem with echo. It is only with concave domes of critical parameters, such as those of the Opéra-Comique that the elimination of echo will be not so easy, especially in the historical monuments where the architectural originality must not be altered.

In order to reduce the disturbance of the focalized long delayed reflections produced by the dome, the main solutions are aimed at reducing the intensity of echo, as it is difficult to change the time delay. Four methods may be applied for this purpose :

3-1. Absorption on the concave surface

Without modifying the shape of the dome, it is possible to project a layer of mineral fibre supported by metallic mesh moulding the dome's shape. After manual smoothing, the original pattern can be imitated using mineral tincture instead of oil paints. If the architect can accept this imitation, the absorption coefficient can be > 0,5 and echo will be reduced by 3dB attenuation. This material had been used in France, Canada, etc., with an acceptable visual effect, especially when the domed ceiling is higher than 16 to 17m. However, many architects of historical monuments do not accept these imitations which they sometimes consider to be destructive solutions.

3-2. Scattering the echo

By suspending a big convex disk under the dome, the echo can be scattered in a wider frequency band. This kind of disk is often made of Makrolon or other transparent acrylic materials, and is aimed at keeping the original pattern as visible as possible. In practice, however, dust and optical reflections completely impair the transparency, leaving the suspended acoustic disk looking like some strange foreign body or « UFO » stranded in the middle of a baroque temple. This is why the actual architect of the Opéra-Comique will be removing the 9-meter disk (56% of the ceiling's surface) suspended in 1991. It has been suggested that lighting be projected from above the disk to make the original dome brighter, but all these ideas have been deemed mediocre solutions in the case of historical monuments.

The baroque chandelier will have limited scattering effect, unless it has been specially designed to contain several large optic transparent disks or rings, in which case it could be useful for scattering in the middle frequencies and reducing the intensity of focalized echo.

3-3. Inclusion of a short delayed reflection within the time gap

By adding well-targeted reflectors on the side walls, additional short delayed (30~40ms) reflections could be inserted between the direct sound and the echo, which will have the effect of lessening the perception of echo.

If these additional reflections are comprised of glazed panels covering the unoccupied gallery openings on the proscenium (like in the Grand Théâtre de Bordeaux[8]), the reflectors will be invisible to the audience. Moreover, if the musicians can be convinced, it is possible to create electronic delayed sound to segment the excessive time gap between direct sound and the echo. The digital artificial reflections can be achieved by means of commercially available systems such as SIAP, Carmen of CSTB, Philips, and so on. Excessive reinforcement must be avoided, as the sound level at focal point is already higher than elsewhere.

3-4. Displacement of the sound source position

Normally, the front stage and the orchestra pit are not movable. However, in case of the Opéra-Comique of Paris, the actual oversized orchestra pit could be reduced by some 28% of its area, and the entire orchestra can be pushed some 2m towards the stage. As a result, most impulsive sound sources (percussion, trumpet, piccolo, etc.) will be further from the dome. The focal point will thus be moved further away and the shorter delayed focalized reflections will no longer be a danger. The reduced pit area has a density of 1,4m² per musician, and the total area of the pit will be appropriate for the baroque operas.

4. CONCLUSION

The concave dome is not an indispensable ceiling shape in the 19th-century baroque opera houses. If the radius of a dome and the ceiling height are very different, the domes do not cause strong echo. As mentioned by M. Barron, 'the odd quirky echoes are audible' in Covent Garden, 'but they constitute only a minor irritant'. The other advantages of these famous opera houses could balance the defect of echo. However, the concave domed ceiling of Opéra-Comique is a particular case in point, and a careful remedy of the susceptible echo is just starting.

It is important to bear in mind that the historical decorations in the 19th-century opera houses are the heritage of the arts and civilisation, and that we must preserve them insofar as possible[9]. For the 21st-century, better « non-destructive » acoustic solutions must be found for these treasures from the past.

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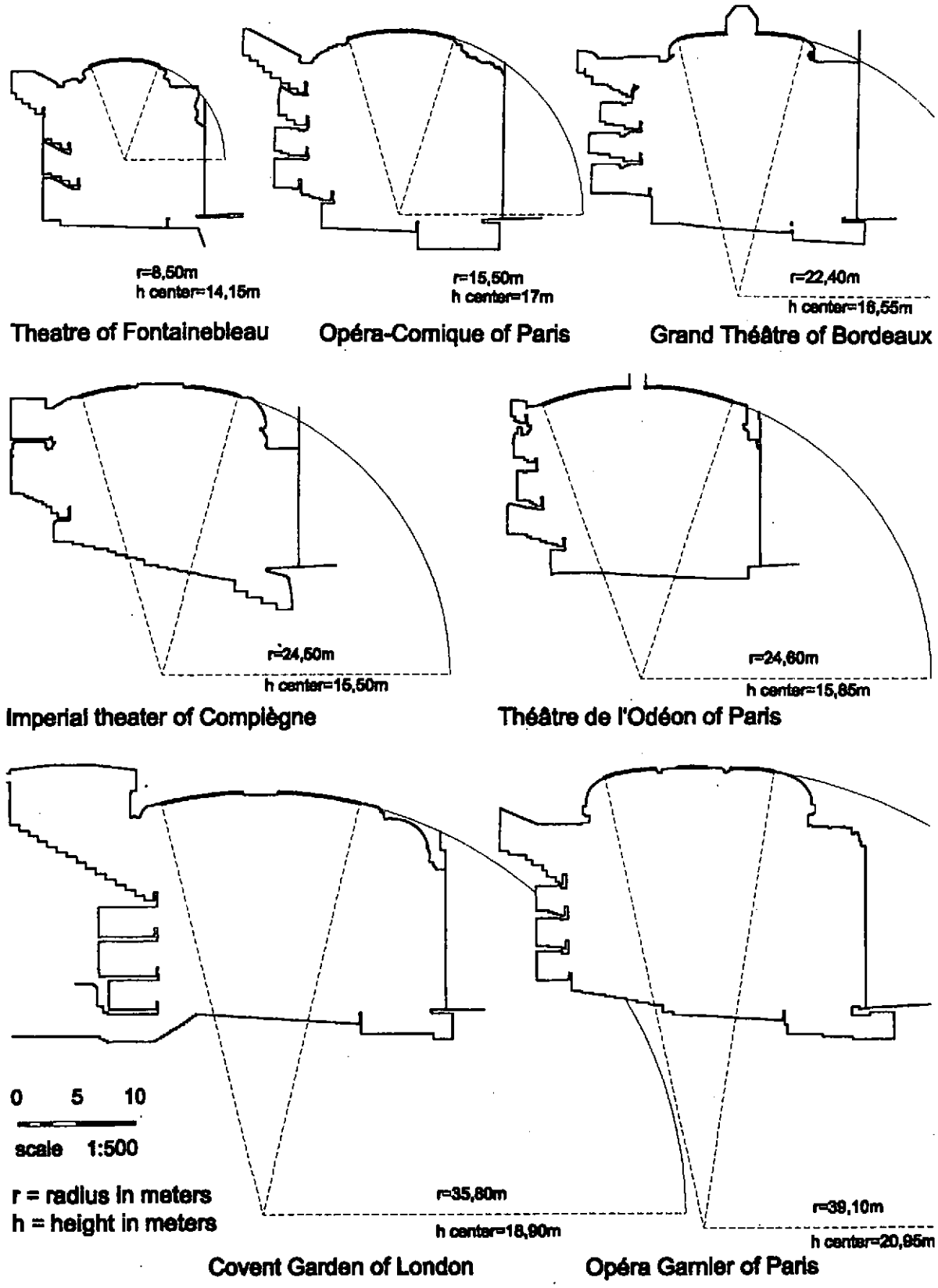

Figure 1. The analysis of the radius of dome and ceiling height in different opera houses.

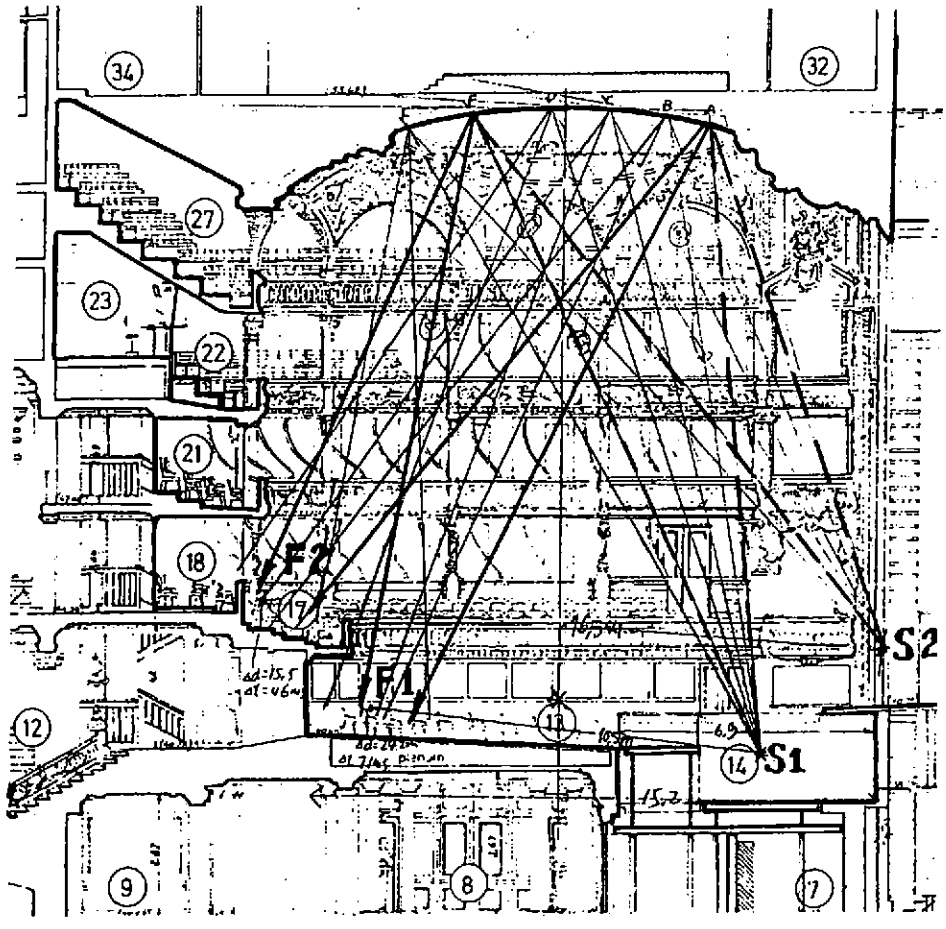

Figure 2. Opéra-Comique of Paris. Two positions of the sound source correspond to the two focal points. The radius of dome is 15,50m, ceiling height is 17m.

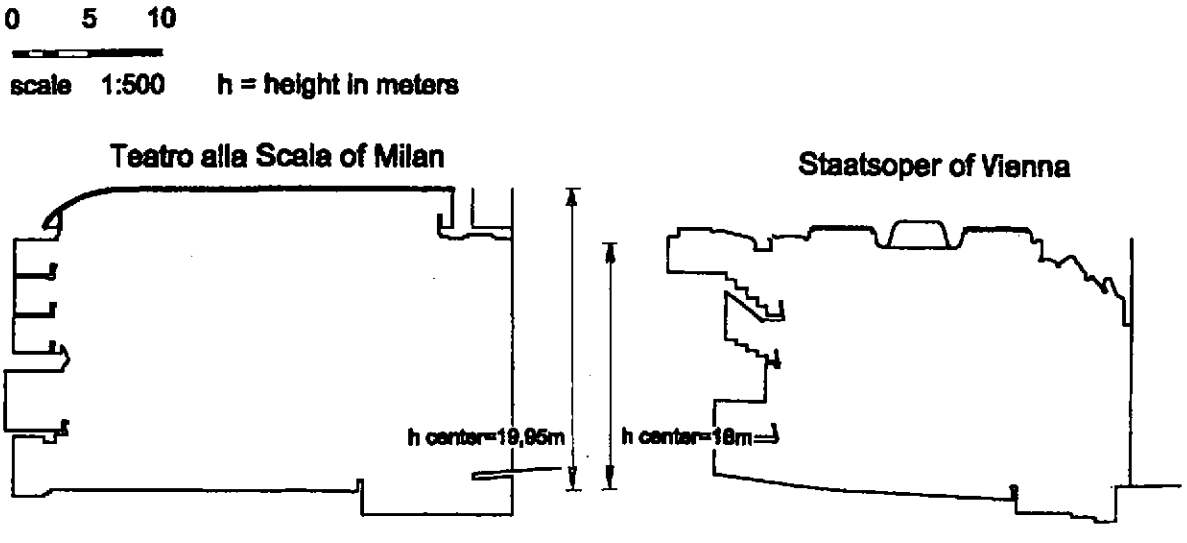

Figure 3. The small flat ceiling in La Scala (h=20m) is less 'echo free' than the diffused ceiling of the Staatsoper of Vienna.