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The Acoustical Design of the New National Opera House of Greece

Alban Bassuet

Arup Acoustics, New York, USA

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ABSTRACT

Scheduled to open in 2015 in the city of Athens the Stavros Niarchos Foundation Cultural Center will become the new home for the Greek National Opera and Ballet. This paper presents the acoustical design considerations for the future opera theatre. A retrospective of Greek influence in the history of the opera theatre design is presented with benchmarking and precedents considered for the project. Through presentations of the some of the design thoughts and approaches still in development, including the form, geometry, seating distribution, wall shaping, and materials in the opera theatre, the paper describes how the new design references and incorporates the profound influence of Greek Culture on development of the Opera House as we know it today.

PROJECT INTRODUCTION

Located at the Athens Faliron Delta, the Stavros Niarchos Foundation Cultural Centre (SNFCC) includes three national projects: the opera house to become the new home for the Greek National Opera and Ballet, the National Library, and the 200,000m^2 Stavros Niarchos Park. Renzo Piano Building Workhop is the project architect and Arup Acoustics is acoustic consultant.

The main opera theatre is a 1,400-seat state-of-the-art facility for productions by the Greek National Opera (GNO) and touring international productions. The facility also includes orchestral and choral rehearsal rooms, a 400-seat flexible performance space, and a new school of dance. The park will connect and complement the two cultural facilities and host various cultural and educational programs.

HISTORICAL BACKGROUND

The design of a new opera house in Greece poses an interesting challenge. Looking back in history, Greek antiquity was a primary influence in the birth of opera as an art form in Italy at the turn of the 16th century. The Greeks had also demonstrated a mature understanding of acoustics with famous amphitheatres, still in use today, which have profoundly influenced the science of venue design through the ages. After such a strong influence in the development of both the arts and sciences, Greece did not develop a tradition for opera until the early-mid 20th century. This raised a fundamental question at the beginning of the design process “What should be the design for a new opera house in Greece?” Before proposing an answer, let us explore the historical context.

In the 15th century, the spirit of the Renaissance permeated and reverberated across Europe. In Greece, it was stifled and suppressed by the Ottoman occupation.

In the context of opera, these developments include (amongst others) the use of linear perspective, which was becoming the ruling practice in pictorial and architectural arts and a standard practice for the painting of entertainment scenery backdrops (religious or otherwise). Early forms of opera were emerging in Italian palaces for court entertainment with *Dafne* as one of the first representative forms of fully sung performance. New theatres, perfect examples of the Renaissance spirit, were designed as enclosed miniature replicas of Greek amphitheatres, with scenery backdrops using multiple perspective vanishing points (Teatro Farnese, Olympico, Sabbionetta).

Ironically, many key aspects of opera development had already been experimented in ancient Greece (perspective scenery “skenographia”, sung entertainment, venue design, etc), and as the Renaissance turned to Greek antiquity in search for new ideas, the development of opera did not flourish in Greece as it did in the rest of Europe.

Opera as a musical form quickly spread across Europe with many purposely designed theatres. Different national design traditions emerged and led towards the end of the baroque era to the establishment of the modern opera theatre archetype (deep pit, vertical scenery system, horse-shoe form auditorium). Designers of opera houses have often looked back at Greek antiquity as a source of new ideas [1], as illustrated in the design of the Royal Theatre Drury Lane (1674), the Royal Opera of Versailles (1770), the Berlin Schauspielhaus (1819), or the Bayreuth Festpielhaus (1876).

As an answer to the question posed earlier, the author is proposing a design approach that takes into consideration the historical context described above. Greece has played a central role in the development of opera in other countries but it has no purpose built opera theatres. Therefore, the acoustical objective for the project is to provide, in a modern architectural context, a design inspired by precedents recognized as the culmination of acoustical design, returning to Greece the results of its substantial influence in several centuries of opera theatre development.

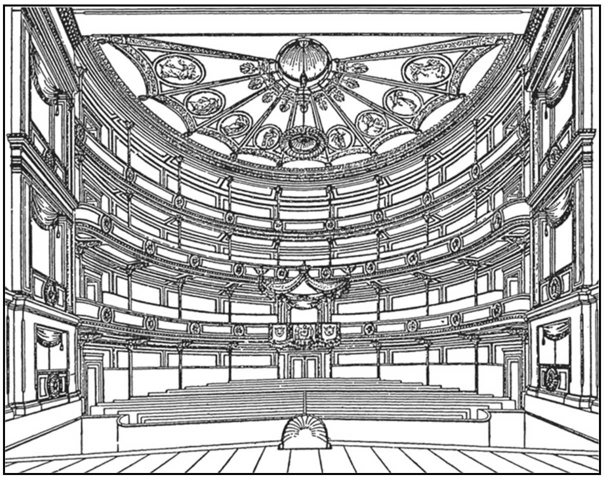
BENCHMARKS

Modern opera theatres have to accommodate a musical repertoire that ranges from early baroque and classical (e.g. Gluck, Rossini, Mozart), to romantic (e.g. Berlioz, Verdi, Weber), post-romantic (e.g. Wagner, Strauss), and contemporary operas (e.g. Schoenberg, Messiaen, Adams).

Post-romantic compositions (generally with a full symphonic orchestra in the pit) require the longest reverberance (with a reverberation time on the order of 1.6s). As shown from acoustical surveys conducted in many famous opera houses [2], the most acoustically successful opera houses that also achieve the reverberance needed for post-romantic compositions can be summarized as follow:

- Dresden Semperoper, Germany (1838 - 1879)
- Bayerische Staatsoper Munich, Germany (1825)
- Teatro Colon Buenos Aries, Argentina (1908)
- Prague Staatsoper, Zcech Republic (1888)
- Vienna Staatsoper, Austria (1860)

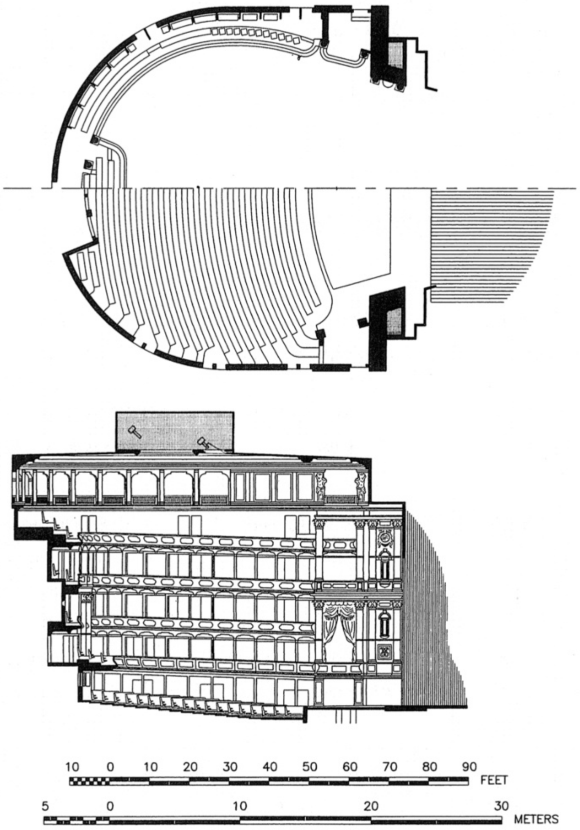
These venues share common architectural features. They have multiple tiers with no more than three rows per balcony (two in Dresden), with large wall surface areas exposed to sound. As a result sound is circulated in the balconies and scattered by the ornamentation, door recesses, columns, fixtures, etc, distributing reflections around the listener's head, and returning energy into the main central volume of the auditorium for reverberance. This geometrical arrangement results in an increased sensation of acoustical intimacy and envelopment in the balconies. These houses also have in common a large central volume in the middle of the auditorium surrounded by vertically aligned balcony fronts. Added together, these represent a large area of sound reflecting surface protecting sound from being absorbed by the audience and promoting the build-up of reverberation in the room.



Source: (Courtesy of the Märkisches Museum, Berlin)

Figure 1. Berlin Neues Schauspielhaus. Example of an architecture with shallow balconies and outer walls engaged into the acoustics of the auditorium

The shape and form of Dresden Semperoper (Figure 2) and Munich Staatsoper tend towards semi-circular. They are associated with a German tradition initiated by Carl Cothard Langhans and later used by Karl Friedrich Schinkel in the design of the Berlin Schauspielhaus (1817), (the opera theatre is unfortunately no longer standing today). Both architects were influenced by Greek amphitheatres in their designs to improve acoustics, sightlines, and the placement of the audience relative to the stage [1]. The Schauspielhaus was a perfect example of an architecture where the walls around the balconies are fully engaged in the auditorium acoustics, creating with the balconies a "uniform" acoustical volume (Figure 1).



Source: (Courtesy of Leo Beranek)

Figure 2. Dresden Semperoper Opera House

Teatro Colon and Vienna Staatsoper are closer to the Italian tradition featuring a more elongated horse-shoe shape auditorium. This shape allows for a more social experience where the audience on one side can see the audience on the other.

The popularization of opera and the desire to increase audience seating capacity in the latter 20th century has led to much larger opera theatres (over 2,500 seats). During this process some of the ideal acoustical qualities were lost, e.g. the ease of singing for performers, the perception of loudness of voices in the audience area as studied in [3], or deep balconies compromising acoustics.

In the New Greek Opera House it is our ambition to aim for the acoustical qualities of the older and smaller size opera houses discussed earlier.

INITIAL CONCEPT DESIGN

Inspired by the benchmark opera houses, an acoustic computer model was developed at the early stage of the project to encapsulate the acoustical concepts for the opera theatre. The model is represented in Figure 3. The main acoustical features are detailed below.

Shape and form

The balconies follow a circular profile at the back and continue into gently curved lines to connect with the proscenium arch. This creates a shape for the opera theatre between a semi-circular and horse-shoe form, which combines the social qualities of the horse-shoe with the best placement of the audience for views to the stage.

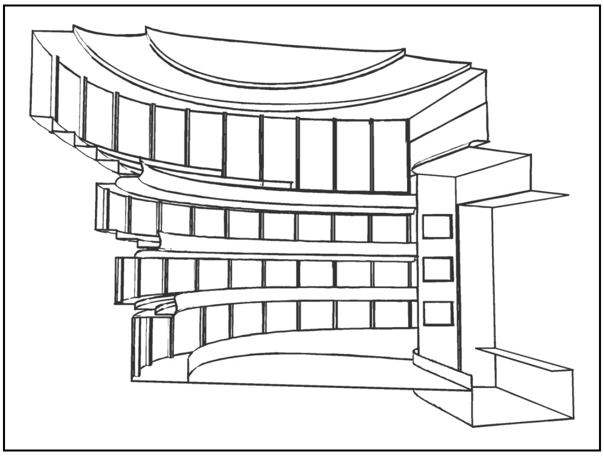


Figure 3. Computer model illustrating the acoustical concepts

The audience seating is composed of three balconies and a parterre around the orchestra level. Following the benchmark opera houses, the parterre, 1st and 2nd balcony have no more than three rows. The walls around the tiers are brought as close as possible to the audience. This is to engage the walls all around the balconies with sound like the Schauspielhaus example. As in Teatro Colon and the original design of Semperoper (before the 1841 re-construction), there is a parterre. Here it is used acoustically to shorten the timing of sidewall reflections to the seats on the orchestra level as well as to reduce the cue-ball reflection of sound from musical instruments in the pit located directly under the balcony. The balcony front is 24m away from the proscenium arch back line to maintain a good visibility of the singer's facial expressions, and the furthest seat in the audience area is at 34m away from the stage.

The opera theatre is dimensioned for a volume to achieve a mid-frequency reverberation time of 1.60s, needed for romantic and post-romantic operas. Deployable sound absorbing materials (banners, curtains) are located in the top volume of the opera theatre to reduce the reverberation time for earlier opera compositions. Common in concert hall designs, this technique has been successfully implemented in the opera houses of the Copenhagen and Olso designed by Arup Acoustics.

Proscenium zone

The design of the proscenium zone has seen several variations across history. It was originally used as a deep frame to set-up the perspective views to the scenery in the Renaissance and Baroque eras (typically 3m deep). Singers on stage would stay within the zone of the proscenium in order to not be out-of-scale from the perspective illusions created behind. The proscenium arch would amplify their voices projecting them well into the auditorium. At the end of the Baroque era, the perspective scenery started to be replaced with vertical scenery systems and the deep proscenium arch moved to the front of the stage to encapsulate the orchestra (with the exception of the English restoration theatres, which still utilized the proscenium arch for performer entrances).

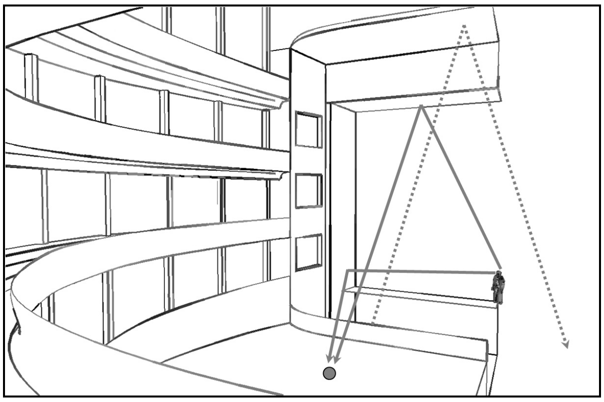


Figure 4. Role of the proscenium to project voices and serve as the orchestra reflector

Wagner with his Festspielhaus attempted to make the walls of the proscenium arch disappear to the eyes of the audience in order to create a more immersive effect into the action taking place on stage, achieving his artistic vision for "total artwork". Nowadays, a deep proscenium zone that would help project singer voices is often compromised by the placement and space needed for the fire curtain and modern theatrical lighting equipment.

In this design the proscenium is designed to create a 2.5m deep zone that helps project voices. A slight curvature was applied to the walls to improve the sound coverage. Mapping studies were conducted to optimize the curvature as illustrated in Figure 5. In front of the proscenium arch, the forestage acts as an overhead reflector for the orchestra in the pit improving cross-stage support and helping with orchestra ensemble support.

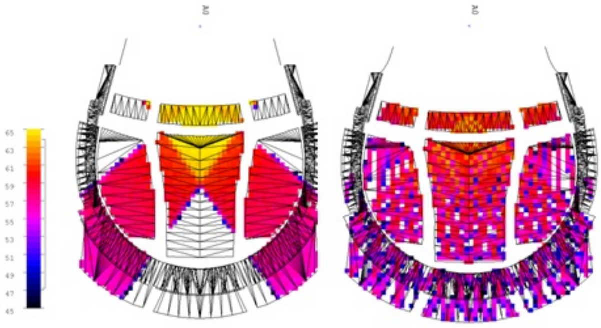


Figure 5. Mapping of 5-35ms reflected sound from the proscenium walls, (Catt-Acoustic). Left: flat walls, right: curved walls (striped coverage results from geometry faceting).

Wall shaping

The walls around the balcony follow a concave profile. Exposing them to engage sound reflections requires careful thought, as the fundamental form has a high risk of unwanted sound focussing. This approach (as demonstrated in the benchmarks) relies on optimized surface shaping and diffusion designed into or applied to the walls.

Figure 6 shows the approach developed for the shaping. It consists of series of convex modules that diffuse sound energy and eliminate undesirable focusing or image shifts. In addition, each wall module is separated by series of corners (or "kinks") facing sound emanating from the stage. The sizes of the wall modules and corners are modulated to avoid tonal effects. Three functions are achieved with this design approach: the convex shape scatters energy to avoid focusing, the specular energy is reflected to help the propagation of

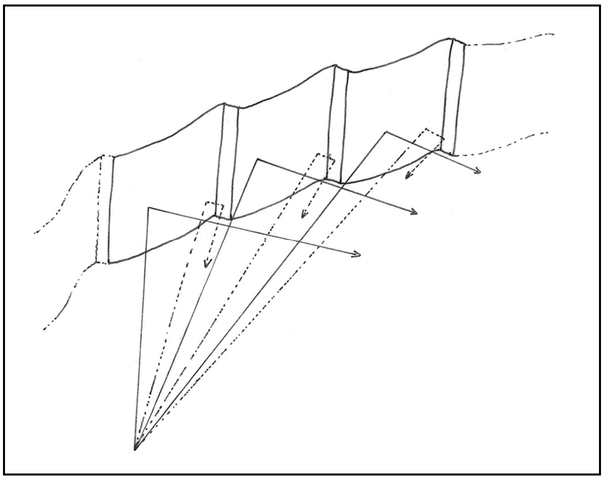


Figure 6. Wall modulation concept, perspective view

sound towards the rear of the room, and series of small "kinks" bounce energy back around the listener's heads.

The "kinks" are no more than 200mm deep to avoid creating image shifts. As shown in Figure 7, the "kinks" are separated by approximately two to three seats, locally serving sound to the seats in between. The function of these corners is to replace the role of pilasters, door recesses, columns, fixtures or ornamentation found in historic houses.

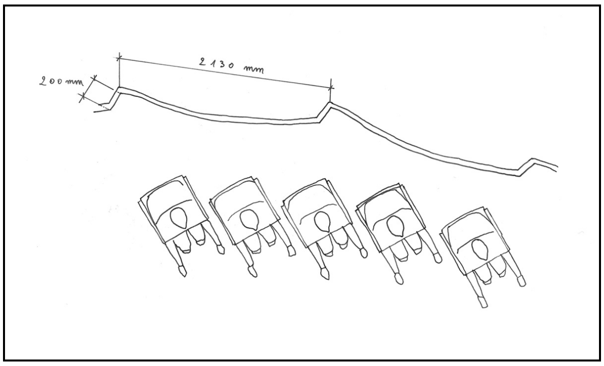


Figure 7. Wall modulation concept, plan view

The best example of this is in Semperoper where fully partitionned seating boxes of previous opera houses are replaced with columns along the walls and balcony undersides. This opens up the balconies to incoming sound and creates a series of angles and corners that are able to capture sound and reflect it around the audience's heads. These create an array of quick early reflections that enhance the sensation of acoustical intimacy and envelopment as measured in [2]. The wall shaping design also includes surface texture to prevent from an increase of mid and high frequency energy due to the multitude of reflections created by the number and size of the "kinks".

Along with improving acoustics, the decomposition of the walls into modules also helps to maintain a visual impression of "seating boxes" creating a more intimate opera experience.

Figure 8 illlustrates the comparison between the smooth and modulated opera house silhouette, (the direct sound is not shown for clarity). It reveals the un-desirable sound reflections such as focusing, or clusters of reflections across the room in the smooth profile, which are diffused in the modulated walls version. Looking closely, it is also interesting to notice the rippling effect of 1st order reflections occurring along the wall behind the audience, which gets progressively scattered as sound propagates from the front to the rear.

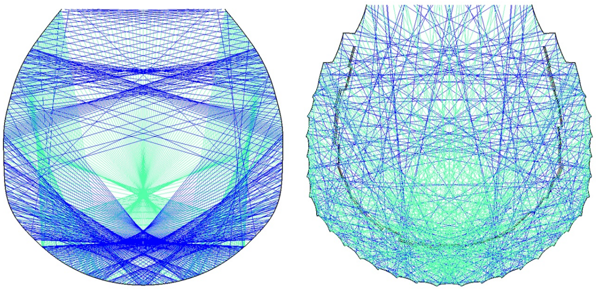


Figure 8. 1st order (green) and 2nd order (blue) ray tracing for a source on-axis, 3m behind the proscenium. Left: smooth horse-shoe shape, right: modulated profile, (Arup Acoustics ray tracing algorithm coded in Rhino3d-Grasshopper)

Under-balcony shaping

As mentioned above, Semperoper makes an interesting use of balcony underside shaping in conjunction with the walls for enhancing early reflections and sound diffusion. In fact, the shaping of reflecting surfaces in the proximity of the audience area is also reminiscent of certain acoustical features of Greek amphitheatres. As an example, in Epidaurus, a small curvature is carved inside each step of the seating. Over the entire seating area, the cumulative effect of all the steps helps to distribute sound behind the audience'heads and to return sound energy toward the stage.

Source: (Author, 2008)

Figure 9. Close-up view of a step in Epidaurus

Following this concept, the approach developed for the design was to shape the balcony undersides with a series of small corners facing the incident sound. This creates early sound reflections and diffusion around the listener'heads to increase, in conjunction with the walls, the impression of acoustical intimacy and envelopment. An illustrative example of such shaping is given in Figure 10.

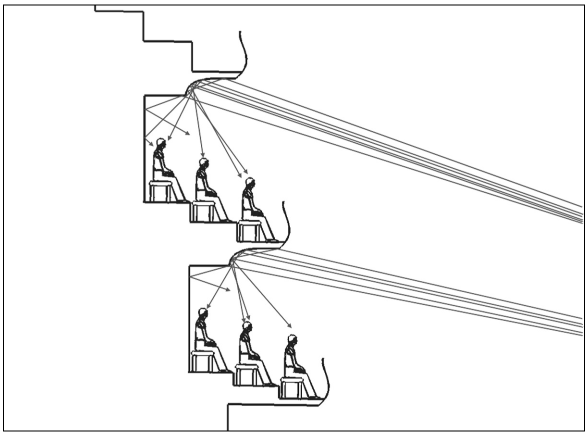


Figure 10. Concept for the balcony underside shaping (Arup Acoustics ray tracing algorithm in Rhino3d-Grasshopper)

The underbalcony shaping also includes regular transverse ribs and surface texture applied to the curve profile to prevent from image shifting or an increase of mid and high frequency energy. A representative example of such shaping is also well illustrated in the design of the underbalcony at Schwetzingen Rokokotheater, already studied in [3].

Balcony fronts

The balcony fronts serve several acoustical functions. In the front they are aimed downwards to help project voices towards the seats at the back of the opera theatre. At the rear, the balcony front faces are aimed upwards to deflect sound towards the ceiling and help increase reverberance (and also avoids undesirable reflections from the house sound system when in use). The transition zone between the downward and upward balcony tilting is chosen differently on each of the balcony levels, resulting in different sweeping balcony profiles on each tier of the opera theatre.

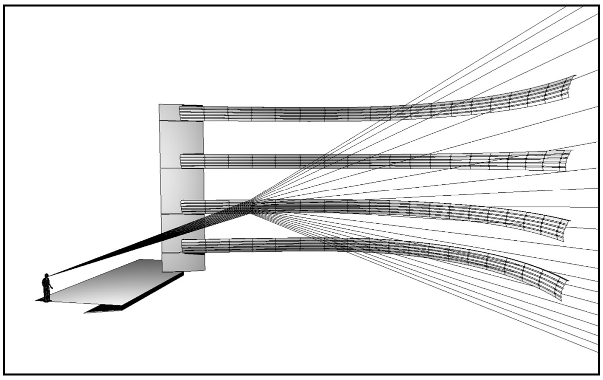


Figure 11. Downwards aiming of the balcony front profile at the front, projecting sound towards seats at the back

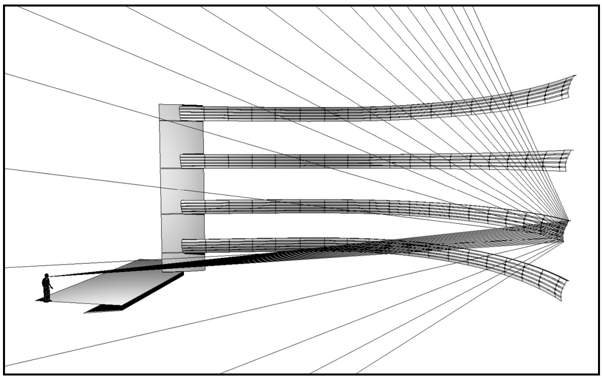


Figure 12. Upwards aiming of the balcony front profile at the rear, deflecting sound towards the ceiling

Orchestra pit

Separating the stage from the audience area, the design of the pit is crucial to the balance of sound between the singers and the orchestra. Here the pit design includes 4 lifts. Each lift can be adjusted individually in height to accommodate different orchestra sizes and layouts: Lift 1 and 2 for early operas, lift1, 2 and 3 for normal orchestra (up to 80), lift1, 2, 3, and 4 for extra large orchestras (110 musicians, e.g. Wagner, Strauss).

In more modern opera houses there is a tendency towards placing the pit further into the auditorium area as musicians generally dislike playing under the stage overhang. This improves comfort for musicians and the "timbre" of musical instruments in the auditorium. There are several knock-on effects on the acoustics. The orchestra is much louder in the auditorium and that can compromise the balance with the voices from the stage. It forces the first row of seats to be placed further away from the stage distancing the audience from the drama on stage. Also the orchestra occupies half of the field of view to the stage for the audience on the balconies. This result is far from Wagner's dream of completely hiding the orchestra outside of the field of vision, so the audience could be fully immersed into the drama, which also has problematic issues of loudness and musician comfort.

Considering this carefully, this design improves upon the relationship by utilizing the space that separates the stage lift systems from the orchestra pit as an extension of the pit under the stage. The goal is to control the extent to which any orchestra layout and size project into the opera theatre utilizing the space extension under the stage and configuring the pit lifts. To reduce the exposure to high sound levels, the zone under the overhang includes a sound absorbing ceiling and adjustable acoustic panels on the walls. The first lift can be lowered to reduce the musician's exposure to the build-up of sound under the stage overhang.

Finally, the individual control of the pit elevators also gives the possibility for conductors to stagger the lifts such as in the Festpielhaus, if needed, for Wagner productions.

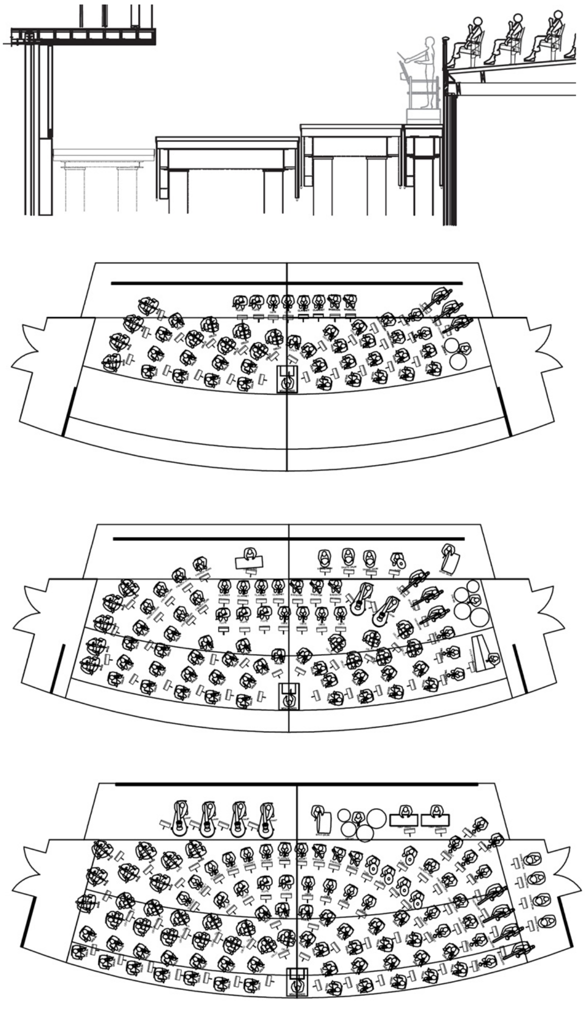


Figure 13. Orchestra pit design and representative orchestra layouts. On top, from left to right: lift1, lift2, lift3, lift4. Orchestra sizes, from top to bottom: 52 (Mozart), 80 (normal), 107 (Strauss).

DESIGN TARGETS

The acoustical design targets for the opera theatre are summarized in Table 2. Ranges are derived from measured values in the benchmark opera houses compared with measurements conducted in the current facilities used by GNO (Olympia Theatre) and with measurements in recently completed Arup Acoustics opera house projects.

The design is aiming for a mid-frequency reverberation time of 1.60s. The acoustical objective of the room design is to bring sound reflecting surfaces closer to the audience in the balconies and to couple the balconies with the main auditorium acoustics. Acoustical intimacy, envelopment and liveness will be improved as a result. These are reflected in the design targets for EDT and IACC.

The Olympia Theatre, currently used by the GNO seats 1000. It is a smaller venue, without orchestra pit. Reverberation Time is 1.0s, acceptable for early or baroque operas, but could be judged as not reverberant enough for romantic or post-romantic repertoire (reverberation in Festpielhaus and Semperoper are above 1.50s).

As expected, loudness values for the orchestra G_{pit} exceed stage loudness G_{stage}. The difference between G_{stage} and G_{pit} represented by G_{diff} is an indicator of the balance between voices and orchestra. G_{diff} values in Olympia fall within ranges typically measured in baroque opera houses as shown in [3]. In such spaces, the balance between voice and orchestra is naturally achieved assuming period instruments, smaller orchestra, and no pit. However, with modern instruments and larger orchestras, voices can be overpowered by the orchestra. The design target for G_{diff} for a modern opera house is generally above 0.0dB to ensure that loudness measured from the stage is higher than loudness measured from the orchestra pit to help with the voice and orchestra balance. The proscenium and the forestage are specifically designed to aim towards this target.

Table 1. Measured acoustic parameters in the benchmarks (Colon, Dresden) compared to the current GNO opera house. (*) unoccupied measurement, (**) centre-stage

	Dresden Semp.	*Teatro Colon*	*Olympia Theatre (current facility)*
RT	1.61s	1.60s	1.00s
EDT/RT	123%*	120%*	93% ±8.2
G_{stage}	2.5dB	2.4dB	2.5dB ±1.2
G_{pit}	-	1.9dB	4.1dB ±2.0
G_{diff}	-	-	-1.6dB
$D50_{stage}$	-	-	59% ±7.3
$C80_{pit}$	-	-2.6dB	3.4dB ±1.4
$1\text{-}IACC_{early}$	0.72	0.65	≥ 0.60 ±0.075
$ST1_{early}$	-	-16.0dB	-15.0dB**

Source: (Arup Acoustics, 2008, L. Beranek [2], 1996)

The need for more reverberation is also illustrated by the clarity targets for voice and orchestra (D50 and C80) closer to the benchmark spaces. An average D50 value around 50% generally indicates a good balance between room response and voice clarity in modern opera houses. Under 45%, voice clarity becomes too low and above 60% the presence of the room response relative to the source becomes too weak.

Compared to older spaces, values for support (ST1) have had a tendency to decrease in modern opera houses. The return of energy to the stage in modern opera houses is reduced due to many factors. These generally include wider proscenium, thinner proscenium walls, deep balconies where the walls are covered by the audience, and bigger stage houses that have large amounts of scenery and draperies. The aim in the new design is for the walls around the balconies and the deep proscenium zone to also participate in returning more sound energy back to the stage improving singer support.

Table 2. Target ranges of the acoustical parameters, for the future GNO opera house, averaged across the audience. (*) balconies only, (**) stalls only, (***) centre-stage

	GNO
RT	1.55 – 1.65s
EDT/RT	≥ 85%
G_{stage}	G ≥ 1.0dB
G_{pit}	-2.0 ≤ G ≤ 2.0dB
G_{diff}	-0.5 ≤ G ≤ 1.5dB
$D50_{stage}$	≥ 45%
$C80_{pit}^{*}$	-2.0 ≤ C80 ≤ 2.0dB
$C80_{pit}^{**}$	-4.0 ≤ C80 ≤ 0.0dB
$1\text{-}IACC_{early}$	≥ 0.60
$ST1_{early}^{***}$	≥ -18.0dB

ARCHITECTURE DEVELOPMENT

The acoustical concept was presented to the architect in the initial stages of the project as a 3D model encapsulating the acoustical functions of each key architectural element of the opera theatre. It set the opera house basic shape, form and dimensions, distribution of balconies, and conceptual shaping for the proscenium zone, walls and balcony fronts. As part of a collaborative process, the initial concept has now been adapted to the architectural vision for the project.

Using the wall and balcony front modulation that give the impression of dividing the balconies into series of boxes as a reminiscent effect of historical opera houses, we have developed with the architect an approach that sees the composition of these elements made into a series of facets. Each wall module is made up of nine elements approximating the original curved wall shaping. The balconies are broken into blocks continuing the division of the wall into modules along the silhouette of each tier. The front face of each block is composed of two vertical panels. In the front of the room, the taller panel is aimed downwards whereas in the rear it is aimed upwards as in the original design. The shaping of the underside of the balconies is achieved by series of structural ribs connecting the modules of the walls with the modules of the balconies.

The architect has also chosen to visually expose the ceiling. The connection between the proscenium zone and the ceiling is often more difficult to resolve in modern designs than older opera houses because of increasing technical and acoustical requirements (longer orchestra reflector covering deeper orchestra pit, lighting equipment, etc). Here the space above the orchestra reflector is closed from the main volume of the auditorium to encapsulate the house sound system, a lighting bridge and the technical grid.

CONCLUSION

As highlighted in this study, Greek culture has played a major role in the evolution of opera as an art form and in the development of opera theatre architecture and acoustics. As a fair return for its contribution to the art form, the approach considered for the New Greek Opera House has been to identify across history the most successful opera house precedents and to use in the design their key architectural features participating to their acoustical success. These include a deep proscenium arch to project voices such as in the baroque opera houses, series of shallow balcony tiers with walls engaged into the acoustics of the main central volume as in the most acoustically renowned opera houses, semi-circular shaped auditorium at the rear like the 19th century German opera houses, and shaping on walls and under-balconies to scatter sound. The aim of the acoustical design is not just to achieve the reverberation target but also some special acoustical qualities like intimacy and envelopment that are essential to the great opera houses and to the most engaging opera performances.

One half of this study is founded in the past by learning from the success of the great opera houses. The second half is the current development of the acoustical concepts into a modern architectural language. An inspired design is being progressed with a fresh and original vision preserving some of the essence of the opera house and which, at the time of writing, promises to new experiences of opera performances.

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