The New National Opera House for Greece: Reflections from an Acoustical Design Practitioner

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At the heart of the new Stravros Niarchos Foundation Cultural Center (SNFCC) is the New Greek National Opera House. The creation of this space poses a number of fascinating design questions, tied to the long and complex history of the relation between nation and opera.

Greek antiquity was a primary influence to the birth of opera in Italy at the turn of the 16th century. Several ancient amphitheatres, still in use today, demonstrate a sophisticated understanding of acoustics and they have had a profound impact on the art and science of venue design through the ages. Despite all this, Greece did not develop a tradition for opera until the mid-20th century. For the international team tasked with the design of a new national opera house, it was clear that the historical context required careful considerations.

Since 2008, I have led the room acoustical design on this project, collaborating with architect Renzo Piano Building Workshop and with my acoustic consulting colleagues at Arup. Financed by the Stavros Niarchos Foundation, the project aims to create a state-of-the-art facility with all required rehearsing and staging facilities for contemporary international opera productions, scheduled to be completed in 2015. The project also includes a National Library of Greece, an outdoor agora connecting the library with the opera house, and a 170,000m^2 park surrounding the complex. The architect's design situates the buildings at the apex of the park's topography, which is conceived as a gradually rising manmade hill. Poetic circulation paths leading visitors through the park to the buildings provide striking views of both the Aegean Sea to the south and the Acropolis to the north.

The project is symbolically important in many ways. As one of the biggest construction projects in recent Greek history, it will help the local economy by providing jobs and infusing capital into a challenging economic climate. In some respects, the opera house also represents a sense of unification of the Greek culture. The Center has been designed to serve as a social and cultural hub that will attract many kinds of people, and will also be the first major national opera house since Greek's independence in 1821.

DESIGN | HISTORY

In the 15th century, the spirit of the Renaissance reverberated across Europe. Early forms of opera were emerging in Italian palaces for court entertainment. Opera quickly spread across Europe, leading to the emergence of distinctive national opera house design traditions. Toward the end of the baroque era, the modern opera theatre archetype (deep orchestra pit, vertical scenery system, horseshoe form auditorium) became widely accepted as the standard typology.

During this period, the strong influence of ancient Greece was evident throughout the opera world. Partly because many key aspects of operatic performance had already been experimented within ancient Greece (perspective scenery (*skenographia*), sung entertainment, venue design, etc), but also because Greeks had successfully rationalized the design of performance spaces, Designers of opera houses have often looked back at the nation's history as a source of new ideas. Renaissance-era theatres such as Teatro Farnese, Olympico and Sabbionetta, for example, were designed to resemble enclosed miniature replicas of Greek ampitheatres, with scenery backdrops employing multiple perspective vanishing points. Later venues such as the Theatre Royal Drury Lane (1674), the Royal Opera of Versailles (1770), the Berlin Schauspielhaus (1819), and the Bayreuth Festpielhaus (1876) also reveal a strong Greek influence.

In Greece, however, these developments did not take root. During this critical initial period of opera's development, Renaissance culture was stifled and suppressed by the Ottomans, who occupied the nation from the 15th to the 19th century. While its antique traditions were inspiring opera-lovers throughout the continent, Greece did not develop an opera tradition of its own.

After analyzing the historical background and precedents, a design direction started to emerge. In order to pay tribute to Greece's substantial influence on opera's development and attempt, in some small way, to compensate for history, we decided to incorporate into our design attributes both from Greek Antiquity and from the most successful opera houses in history.

As a starting point, we visited several ancient amphitheatres in Greece and measured their acoustic signature. Good audibility of speech and visibility of the performers are some of their well known features, due in part to a carefully shaped audience rake providing uninterrupted line of sight to the stage, and a circular audience layout shaped around the natural directionality of the human voice. Amphitheatre such as Epidaurus also exhibits noticeable musical qualities. Its rake, not as steep as its Greco-Roman precedents, creates longer travel distances for sound waves to reflect off the audience steps, resulting in an effect of sound reverberation. The carving of every step also allows sound to circulate across each row, creating the acoustical effect of envelopment and intimacy, which are attributes of some of the later great spaces for music and opera. The steep rake of the outdoors amphitheatres gradually evolved into the enclosed performance spaces of modern opera houses. The softer rake and multiple balconies shaped the natural acoustics of the space, and the sound reflections from the walls, normally occluded by a steeper audience rake, became part of the musical effect. A balance was found specifically for opera, where a moderate audience floor rake provided both with the clarity needed for the recitatives and with the reverberance needed for the orchestra and the singing.

Figure 1 Detail of the carving of the steps in Epidaurus Amphitheatre.

We also reviewed hundreds of opera houses, studying acoustical surveys and commentaries and descriptions that musicians, directors, audience members[1, 2], and critics, have written over the years. Interesting trends emerged. Baroque opera houses such as Versailles or Markgraflishes were particularly appreciated for their tonal beauty and facilitating the singing voice because of their size and volume dimensioned in scale with the power of human voice. However, they became too loud with modern instruments, new styles of singing and not reverberant enough for later compositions (because of their smaller dimensions). 19th century opera houses provided instead the reverberation and volume needed for larger orchestras, the Romantic repertoire, and the increasingly more symphonic orchestra sound. Many early mid-20th century venues are today viewed as somewhat bloated acoustically, their designs having been driven more by the desire to popularize the art form and increase revenue rather than focus on audience experience. To address this criticism, 21st-century opera spaces such as the Glyndebourne, Oslo and Copenhagen Opera Houses provide optimized views to the stage, improved acoustics in all seats, and lower seat counts.

As a result of this review we decided that two opera houses renowned for their superior acoustics would be the benchmarks for the design: the Semperoper (1841) in Dresden, Germany, and the Teatro Colon (1908), in Buenos Aires, Argentina. Despite their geographical separation, the spaces exhibit interesting architectural similarities typical of classical Italian opera houses, including curvilinear shapes and multiple seating tiers with a small number of rows per balcony. The vertical alignment of the balcony fronts creates the effect of walls that delineate a central volume acting as a drum for sound reverberation.

As we looked more closely at the balcony geometry of both venues, we realized that both improve upon the Italian model in a similar manner. They have fewer and therefore less compressed balconies, lower box partitions that allow a better circulation of sound across the balconies, and a gradual step back between each of the balcony fronts. Acoustically, the open balcony throats results in the freer circulation of sound waves which are then circulated along the curved walls like and scattered by the columns, door recesses, ornaments, and various fixtures, that articulate the walls surface. After successive reflections, sound is then returned to the main central acoustical volume to contribute to the effect of reverberation.

These two opera houses are often praised for their rare combination of reverberation, intimacy, tonal quality (warmth of sound and embellishment of the musical instrument's *timber*), and envelopment. Our studies led us to understand that the subtle arrangements of the balconies around the main central volume, combined with the wall articulations, are responsible for these qualities. When sound is scattered inside the balconies, quick sound reflections are created around the listeners' heads, amplifying the effects of intimacy, envelopment and *timbre* of the musical instruments, effects that are directly related to quantifiable acoustical phenomena studied with experiments[3, 4]. These acoustical attributes are often compromised by the deep balconies of modern opera houses, or by the full height box partitions of earlier Italian opera houses, where the walls of the balconies are occluded by the body of the audience.

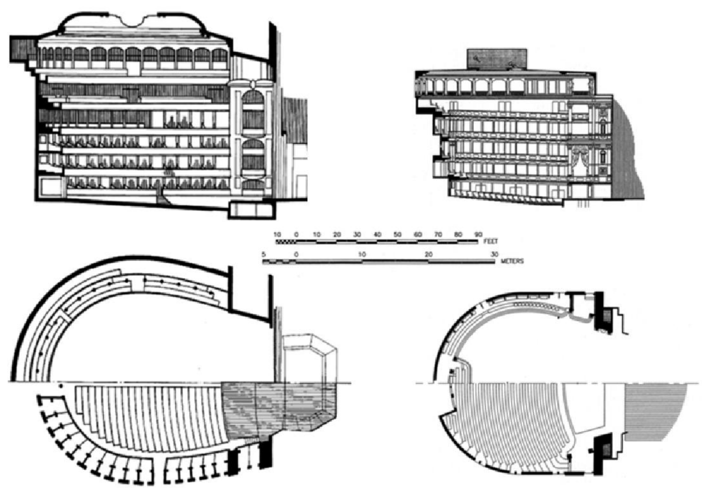

Figure 2 Plan and section[5] of Teatro Colon (left) and Dresden Semperoper (right) opera houses.

Comparisons of the shape of Semperoper and Teatro Colon also reveal subtle but interesting differences that can be traced back to specific national traditions. Teatro Colon, with its horse-shoe shape is in the direct tradition of the Italian opera house. Its elongated shape creates a high number of seats looking directly across the auditorium, emphasizing the social experience of opera. This shape can also be traced back the Baroque era. During this period, it was common to emphasize the royal box at the rear, like in Versailles, where it is located at the visual and acoustical focal point of the auditorium; perspective sceneries were also best experienced for seats closer to the central axis; these often resulted in elliptically shaped opera houses.

Semperoper was built in a semicircular shape. Circular auditoria have been in favor in Germany since the 1817 construction of the Berlin Schauspielhaus. This opera house, unfortunately no longer standing, was designed by Carl Cothard Langhans and later renovated by Karl Friedrich Schinkel. As documented by Radice[6], both architects studied Greek amphitheaters as part of their effort to establish a new style of opera houses in Germany which would provide better views and acoustics to a larger percentage of the audience members (the horseshoe shape, on the other hand, tends to produce stronger disparities in audience experience in different seats). The success of the Schauspielhaus led to the building of a series of circular opera houses in Germany, including those at Karlsruhe, Munich, Hamburg and Mainz, and, later, the Dresden Semperoper. Once again, milestones of architecture and acoustics were inspired directly by Greek antiquity.

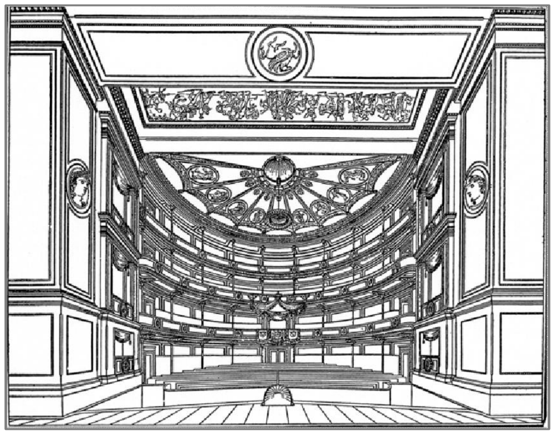

Figure 3 Berlin Neues Schauspielhaus[7]*.*

At this point, the architectural and acoustical aims for the new venue were clear. The space would have a deep proscenium opening to help project voices, similarly to Baroque theaters. It would have a low angled audience rake to balance clarity and reverberation. Its shape would be a combination of horseshoe and semicircle, melding/integrating the social qualities of the former with the optimized audience views of the latter. Its volume would be sized in such a way to provide the reverberation of Semperoper and Teatro Colon. Walls around the balconies would be visible and well exposed to the sound from the main central volume. Articulations on the walls would be arranged in various scales to scatter and circulate sound in the balconies. The theatre would have a parterre on the orchestra level in order to create a closer wall around the audience and thus strengthen and shorten the sound reflections from the sides, as in the original Semperoper. It would contain 1,400 seats in order not to exceed more than 3 rows per balconies and therefore foster both the effect of acoustic intimacy and a good visibility of the singer's facial expressions everywhere in the auditorium, as well as to absorb the loudness of large orchestra forces.

ARCHITECTURAL DEVELOPMENTS

All of the considerations discussed above were drawn and assembled into a three-dimensional computer model to serve as the basis for the collaborative development of the architectural design. We also accompanied the model with sketches showing conceptual shaping for the walls, the ceiling of each balcony and the balcony fronts. As for the articulation of the walls, the challenge consisted in replicating the function of the historical precedents while modernizing the style. In order to emulate the effect of the columns and recesses of earlier precedents such as Semperoper and other highly ornate theatres, shaping for the walls was conceptualized as repeating modules with a convex section, scattering and orientating sound towards the rear, and a series of corners redirecting sound energy around the listeners' ears. Each Module has a slightly different configuration and is specifically sized to serve small groups of seats acoustically. The shape of the balconies was abstracted as a curved profile varying from downward at the front to upward at the rear in order to redirect sound energy in the desired directions. Articulations of the underside surface of the balcony were also created as a way to augment the sound-scattering effect of the walls on the ceiling. The same pattern as the carving of the steps of Epidaurus, was applied to the ceiling of each balcony to catch sound and send it back to the audience underneath.

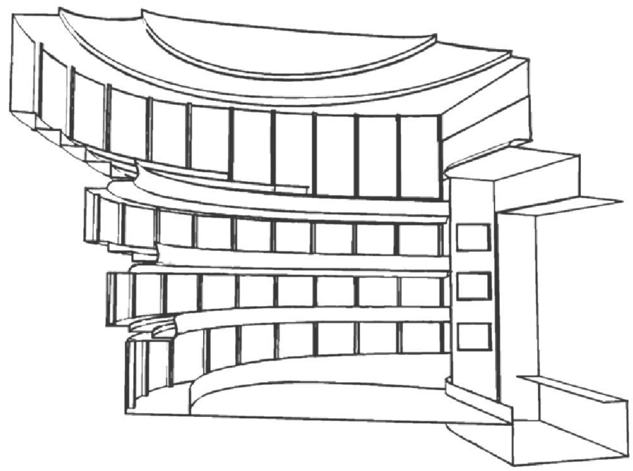

Figure 4 Three-dimensional model encapsulating the acoustical concepts.

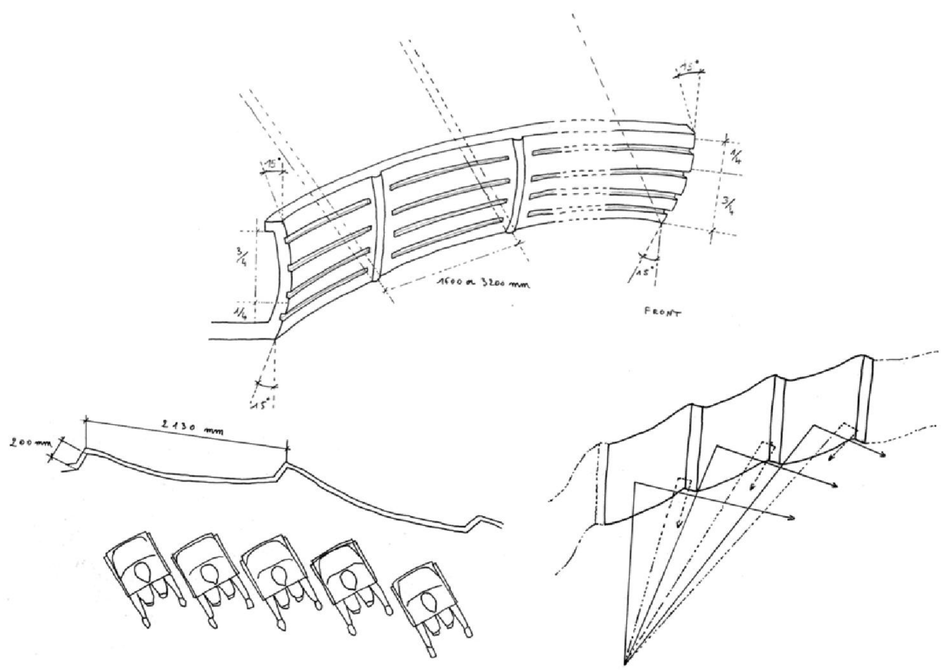

Figure 5 Acoustic sketches showing conceptual shaping for the walls and balcony fronts.

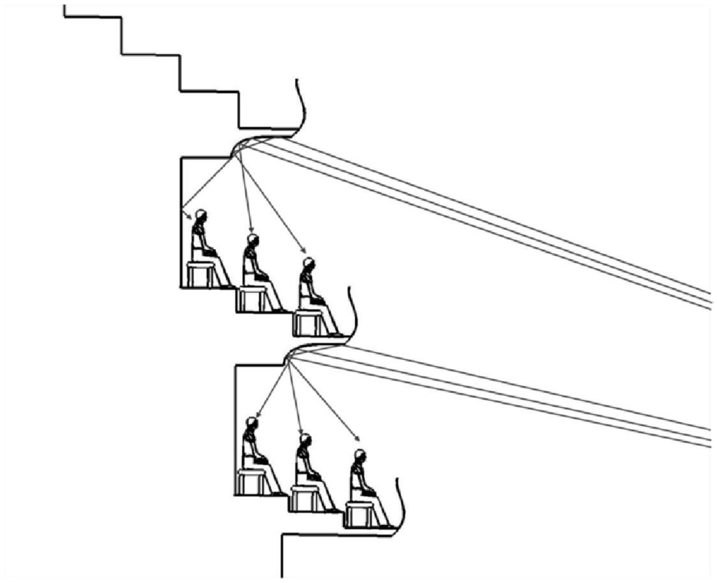

Figure 6 Acoustic sketches showing conceptual shaping for the balcony undersides.

Modern science also played a major role in setting the acoustical goals and developing the design. The science of acoustics has advanced dramatically in recent years. Today, we are able to demystify the sonic principles underlying the most renowned performance spaces. A process known as Auralization[8], allowing designers to listen to buildings before they are built was used to model and compare the acoustics of existing spaces and various design option iterations for purposes of optimization.

The process of Auralization uses music recorded in anechoic conditions[9] (without the presence of any rooms) which is processed electronically[10] by the acoustic signatures of a future or existing space. In the case of a real space, the acoustic signatures are measured by recording the response of a room to a known acoustical test signal (such as sweeping frequency sine wave[11]) played through a loudspeaker and recorded with microphones at various positions in the hall. In the case of a future space, acoustic signatures are calculated using acoustic computer simulations. With higher computer power and computer modeling programs calibrated on a number of built projects, the auralization process has now reached a high level of accuracy. It allows not only predicting acoustical effects and engaging pro-actively with architects to create new shapes, but it also allows deepening our understanding of some of the most prestigious acoustical spaces and decoding their architectural and acoustical features during the course of history and music evolution[12, 13].

The next phase of the design work consisted of working with the architect to interpret the model and sketches in a modern design language. From an architect's point of view, opera houses have a very codified design, typically including an arch for the proscenium, a horseshoe shape and symmetrical auditorium, warm colors (often in the red tones), chandelier(s), a visually expressed ceiling, seating boxes, and heavy ornamentation, all of which is often caricatured with the French term *bonbonniere* (a candy box roughly translating as "highly ornate and precious intimate apartment"). The auditoria alone constitutes but a small portion of an opera house, which in reality is an elaborate machine for theatre, filled with technology and moving parts that limit spatial positioning, and whose seamless integration impose a number of architectural challenges.

For the new opera house, Renzo Piano wanted to achieve qualities of clarity, visibility, openness, light, togetherness, and comfort. The architectural team researched different materials, colors and articulations for the interior walls to emulate different architectural narratives and responses to the building's external envelop, landscape and surroundings. An early iteration used roughly cut marble for the interior walls identical to that being used for exterior; together with the vertically aligned balconies, this would have conveyed the impression of a marble quarry. This idea was ultimately abandoned as marble is a cold material both architecturally (and warmth was considered essential) and acoustically because sound reflections from marble are harsh to the ear. Somewhat ironically, many earlier opera house walls were made of papier-mâché with a *trompe l'oeil* marble effect, often as a reference to Greek drama. It is in fact possible that fake marble may have been better than the real thing in this context, as papier-mâché does not have the same visual glare and coldness as stone, and is less harsh acoustically.

Instead, the design evolved towards more fluid geometries and a modern and elegant interpretation of the *bonbonniere,* with warm materials and colors contrasting with the exterior's rectilinear forms of glass and stone materials. The seats are red and the floors are in wood. The ceiling visually unifies the space, its continuous and seamless surface also serving as a projection space for different sky effects, avoiding the highly technical "black" ceiling of the some modern houses. The ceiling connects to the stage, opening with curving organic shapes resembling a seashell - Figure 8. The continuous lines of the sweeping balconies lead into blocks continuing the articulations of the walls to give the impression of seating boxes. Balcony undersides become structural ribs. The typical crystal chandelier is replaced by a giant floating mobile made of paper, offering an ever-changing spectacle of light. The deep, bright proscenium zone serves as a dignified picture frame. A darker frame in front of the proscenium opening reads as the zone for technology, contrasting with the brighter interior colors. Fillets of gold color along the walls and the balcony fronts continue the silhouette of the auditorium visually embracing the space of the audience and encouraging glances around the room.

The opera house also incorporates all the latest technology to accommodate touring intentional productions. Today, this means the possibility to accommodate different musical-theatrical repertoires, ranging from early operas to more contemporary works (e.g. Schoenberg, Messiaen, Adams, Saariaho). This necessitates a massive floor rotating table, wagon systems to move sceneries, stage lifts, and large backstage spaces used to store and move entire sets of scenery to and from the main stage. The auditorium therefore is six times smaller than all backstage areas added together.

An alternating repertoire also implies sensitive adjustments of the acoustics to match different musical styles. The building is designed with a room volume to accommodate the longest reverberation, needed for post-romantic operas. Sound absorbing curtains are concealed behind the walls of the auditorium and deployed to reduce reverberation to match the desired repertoire. (We previously employed this technique in the Copenhagen and Oslo opera houses.)

Orchestra size will also vary substantially depending on the repertoire, from as few as 20 musicians for baroque performances to more than 100 for post-romantic operas. The modern orchestra pit has gradually moved into the audience area to reduce the extent of the stage covering the orchestra in the pit. This creates more pleasant conditions for the musicians, improves acoustics in the pit, and offers the audience the spectacle of the orchestra in action, but also has the effect of creating a vast space separating the audience from the action on stage, and of upsetting the balance between singers' voices and the orchestra. This is far from Wagner's dream of a completely hidden orchestra, which on one hand, avoids the spatio-temporal disruption of the drama on stage, but on the other hand creates problematic issues with loudness and musicians' comfort. By suppressing the visual presence of the auditorium architecture, dimming the lights and hiding the orchestra, Wagner achieved the immersive and projected qualities of our modern movie theaters.

Our design for the pit took inspiration from both of these models. The pit can be moved into the audience area or under the stage through the use of four lifts and moveable walls. Adjustable acoustic finishes along the walls and the ceiling of the pit provide a local control of the musician's exposure to the orchestra sound.

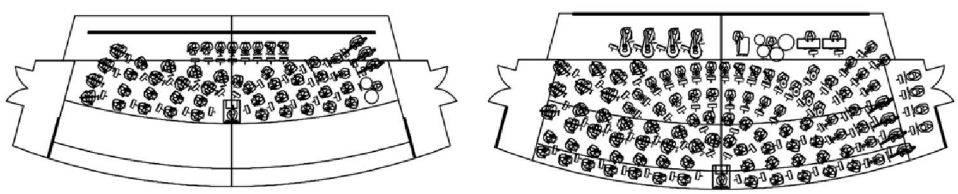

Figure 7 Orchestra pit in different configurations: left, 52 musicians (Mozart), right 107 musicians (Strauss).

With the desire of reaching broader audiences always as a primary concern, the stage of a modern opera house also needs to accommodate different genres such as musicals, symphonic music (performed by the orchestra and the choir on the main stage), and, on rare occasions, large multi-mode performances with amplified sound and projections.

In addition, large-scale video projections can be shown on the building façades to engage with visitors to the opera complex's social gathering spaces (the Agora) and park. State-of-the-art broadcasting technology can distribute performances around the world. Shows can also be relayed to screens in the second, smaller performance hall, which shares the same lobby as the opera house. Designed as a flexible space where stage and audience can be reconfigured for more experimental performances, it will also house a children's theater, which is very popular in Athens, and serve as an intimate space for smaller operas with fewer sets, such as baroque productions.

OUTCOME

After a four-year period of intense design studies and drawing production, construction is scheduled to start in spring 2012 and the first performances are scheduled to begin in 2016.

When finished, the new cultural complex will be one of the most technologically advanced and the largest construction projects in recent Greek history. With the park, the water canal, a green roof and a photovoltaic canopy covering the building, the Center is also an example of sustainability. It incorporates elements essential to the national ecology and Greek culture –sea, sun, stone and earth.

Although the opera house will be a resolutely modern building, its design creates strong, humanistic connections to history. The design incorporates many celebrated qualities of the world's most renowned opera houses decoded by the team through the arts and sciences of acoustics. The new opera house, long overdue, will be much more than a performance space: a destination in its own right, reconnecting the Greek people to the deep roots of their culture.

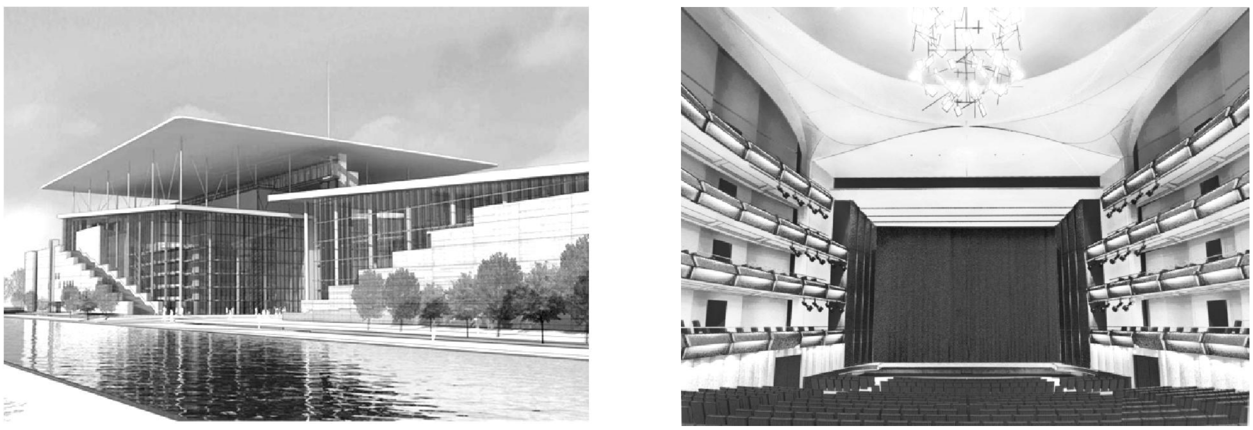

Figure 8 Rendering[14] of building's exterior and of the interior of the opera house.

ACKNOWLEDGMENT

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Notes

1. Leo L. Beranek, *Concert Halls and Opera Houses: Music*, *Acoustics*, *and Architecture*, (Second Edition, Springer-Verlag New York, LLC, 1996).
2. Alban Bassuet, "Acoustics of a selection of famous 18th century opera houses: Versailles, Markgräfliches, Drottningholm, Schwetzingen", ASA, SFA, Acoustics'08 conference, Paris 2008. http://webistem.com/acoustics2008/acoustics2008/cd1/data/articles/003503.pdf
3. Yoichi Ando, *Architectural Acoustics-Blending Sound Sources, Sound Fields, and Listeners*, AIP Press/Springer-Verlag, New York, 1998.
4. Jens Blauert, Spatial *hearing: the psychophysics of human sound localization*, MIT Press 1997.
5. Courtesy Leo L. Beranek.
6. Mark A. Radice, *Opera in Context*, (Amadeus Press, 1998).
7. Courtesy of the Märkisches Museum, Berlin.
8. Underlying principle of the ArupSoundLab, allowing to listen to subjective impressions of sound of three dimensional architectural spaces.
9. Anechoic chambers are usually lined with tall sound absorbing wedges on the walls, the ceiling and the floor, to create a totally

acoustically dry environment. An acoustically transparent wire mesh stretched above the floor wedges is often used as a walking surface. Because music recorded in anechoic conditions is devoid of any room reflections, it can be used as inputs to create room auralizations, as described below.

10. Mathematical process known as convolution. Assumes the acoustical response of a room to always respond equally to the same input, such as a non variant linear filter in signal processing theory. According to the same theory, the acoustic signature of a hall can be represented by the response of the room to a single impulse which contains all humanly perceivable frequencies (impulse called Dirac delta function, named after the Mathematician Paul Dirac). Auzalization is then created by the convolution of the music recorded in anechoic music with the acoustic signature of the hall. Historically, acoustic signatures of rooms were recorded using gun shots or large balloons.
11. Equivalent signals to Dirac delta functions, but more efficient as, in practice, Dirac delta functions are too short to engage in motion the inertia of loudspeaker's membrane.
12. Readers interested in recent discoveries concerning the relationship between architecture and music across history and its relevance into today's performance space design can refer to the research conducted by the ConstellationCenter project, which aims for the design and construction of five new music venues in Cambridge Massachusetts. www.constellationcenter.org
13. Alban Bassuet, "New Acoustical Parameters and Visualization Techniques to Analyze the Spatial Distribution of Sound in Music Spaces", Proceedings of the International Symposium on Room Acoustics, ISRA 2010, 29-31 August 2010, Melbourne, Australia. http://www.acoustics.asn.au/conference_proceedings/ICA2010/cdrom-ISRA2010/Papers/O3b.pdf
14. Courtesy of Renzo Piano Building workshop