PRESENTING OPERA IN THE 21ST CENTURY, AN APPROACH COMBINING MULTIPLE INDOOR/OUTDOOR VENUES, HISTORICALLY INSPIRED AUDITORIUM DESIGN, VARIABLE ACOUSTICS AND IMMERSIVE TECHNOLOGY - THE STAVROS NIARCHOS FOUNDATION CULTURAL CENTER

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1 INTRODUCTION

Opened in 2017, the new Stavros Niarchos Foundation Cultural Center (SNFCC) is one of the most important cultural projects recently realized in Europe. It is a vast and ambitious development that propels Greece into the 21st Century and upgrades its current infrastructure for sharing knowledge, culture and presenting the performing arts. Its success is in many ways a symbol of the revitalization of the country after its period of crisis, playing a major role in the economic, cultural and sociological development of Athens and of the country.

Designed by Renzo Piano Building Workshop Architects, the project features a building set within a new 200,000m^2 park which contains the National Library and National Opera House. The Opera House is the new home for the Greek National Opera and Ballet with a 1,400-seat opera theater, a 480-seat Alternative Stage, and a full suite of opera, chorus, orchestra, musician and dance's rehearsal and practice rooms.

The site is in Kallithea, located on the periphery of Athens, bordering the Aegean Sea, set to revitalize the area and create a new destination in the capital. The project is conceived with public engagement as its core. Much like an opera setting, the building is sited around a central area or Agora, used for the SNFCC outdoor music festival. The park is built as an artificial hill that covers most of the new building and supporting infrastructure, creating a welcoming and informal environment. Public access is available throughout most of the building, including its rooftop, creating open-ness and accessibility.

With those goals, the design team set out at the beginning of the project to offer a range of performing arts' platforms to engage with a wide spectrum of public demographics. Events include opera and music performances in the Opera House, Alternative Stage and in the Agora, but also impromptu events and large-scale outdoor concerts in the park, performances on the rooftop, Library and lobbies, or in the larger rehearsal rooms equipped for performances. SNFCC also organizes regular family and kid's friendly events such as dance classes, puppet theater or children's opera. Since its opening, the center has received countless public reviews demonstrating the success of the entire project. The project was also awarded the 2017 RIBA Architectural Award.

In this article, we detail how the acoustic team conceived the performance spaces and how they complement each other for various events and usages. The article also summarizes the results of acoustical tests conducted in the finished spaces and how they compare to known benchmarks.

Fig. 1: Exterior of the Stavros Niarchos Foundation Cultural Center. Park at the foreground, the Aegean Sea in the background[6]

Fig. 2: Interior of the Opera House[6]

Fig. 3: Interior of the Alternative Stage[6]

Fig. 4: Orchestra Rehearsal Room[6]

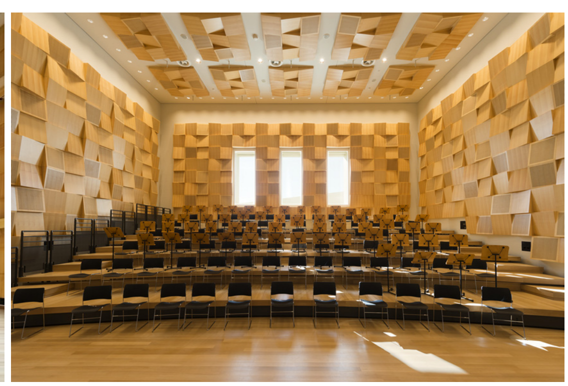


Fig. 5: Chorus Rehearsal Room[6]

Fig. 6: Outdoor concerts in the park

Fig. 7: Outdoor concert at the Agora

2 ROOM DESIGN

2.1 The Opera Theater

In 2008, the authors presented[1] the basis for the design of the SNFCC Opera House. Summarizing the approach, while Greece has had a profound influence on the development of theater and lyrical arts with its ancient theaters and dramatic arts, opera really started to flourish in Greece from the 19th century. Some theaters had been built on the Western part of the country and islands in earlier times due to the Italian's influence, but the SNFCC Opera House is the first purpose-built modern venue dedicated to the lyrical arts in Greece.

Because of this historical context, the design team decided to create a design for the opera house's natural acoustics that would take features from different periods of opera history to create a design that functions well for all the classical opera repertoire, and to incorporate variable acoustics and a distributed sound system for more modern productions. The benchmarks used for the design were the Dresden Semperoper Opera House and the Buenos Aries Teatro Colon, and the more recently completed Oslo and Copenhagen Opera Houses where the Arup teams had previously implemented variable acoustics. From those benchmarks the team extracted the following features:

- 1,400 seats, medium-size audience capacity to create a volume at the appropriate scale of the human singing voice
- A volume per seat sized to achieve a reverberation of 1.7 seconds, adjustable down to 1.3 seconds with variable acoustics, depending on the opera composition's style - Fig. 8-1
- A deep proscenium arch to project voices and help with the exchange of sound between the stage and the orchestra pit, similar than baroque theaters[2], Fig. 8-2
- An orchestra reflector to help with musician's support in the pit and voice projection, Fig. 8-3
- Multiple shallow balconies, with no more than 3 rows per tier as in Semperoper and Teatro Colon - to allow sound to reflect on the outer walls of the auditorium and participate to the perception of reverberance, intimacy and envelopment with quick early reflections surrounding the audience on the balconies, Fig. 8-4
- Shaped wall surfaces to help with the distribution of sound inside the balconies imitating the acoustical effect of ornamentation on the walls of historical opera houses, Fig. 8-5
- Shaped balcony fronts which reflect sound towards the audience at the front of the room and deflect sound towards the ceiling at the rear to prevent from echoes, particularly when sound systems are used, Fig. 8-6
- A 4-lift orchestra pit, to adjust the size of the pit to the size orchestra and control the loudness difference between the orchestra and the singers, Fig. 17
- Variable acoustical panels in the pit to control the orchestra's loudness in the pit, the timbre and loudness of the orchestra in the auditorium, and the loudness difference between the orchestra and the singers, Fig. 18

- Heavy wall construction to preserve low frequency energy and create a warm acoustics, or be used for dramatic low frequency effects, Fig. 13 and 14

Fig. 8: Primary design features of the Opera House[6]

During early stages of design, the architects were interested in the concept of bringing the balconies closer to the stage at higher elevation in the auditorium. While instinctively a good idea, computer modelling analyses and auralization studies demonstrated that moving the balcony along a 20° vertical inclination towards the stage would result in a reduction of approximately 10% to 15% of perceived reverberation (i.e. 1.45 seconds instead of 1.7 seconds), due to the upper balconies cutting out the reverberation coming from the ceiling. It would have also led to steeper seating rakes for sightlines and less audience to audience interaction. The balconies were therefore kept vertically aligned, Fig. 9.

The walls of the auditorium are constructed in medium density fiberboard (MDF). The surface mass ranges from 100 kg/m^2 at the bottom of the room to 70kg/m^2 at higher elevation. The walls were constructed by the Greek company Epexyl to the highest standard of the industry. Shaping was created with CNC router machines onto single elements that then served as a template for all other panels fabricated using a combination of the CNC router and a vacuum press. The contractor developed a modular construction technique allowing smaller elements shaped in the factory to be easily carried inside the Opera House and assembled in-situ. For high precision assembly, the concrete shell of the Opera House was laser scanned so the machining of the wall panel would include the small variations in the concrete structure construction. The final veneer finish layer was applied with a portable press brought into the space. The wall panels were also stiffened at the rear with MDF ribs running approximately every 50 cm, Fig. 15. The soffits of the balconies and the ceiling are plaster. Surface texture was applied on those surfaces to soften the acoustic reflections at high frequencies.

The acoustical development of the opera house was conducted using 3D acoustic computer modelling (Catt-Acoustics), auralizations in the Arup SoundLab with the architects and a 1:50 physical scale model throughout the entire design process.

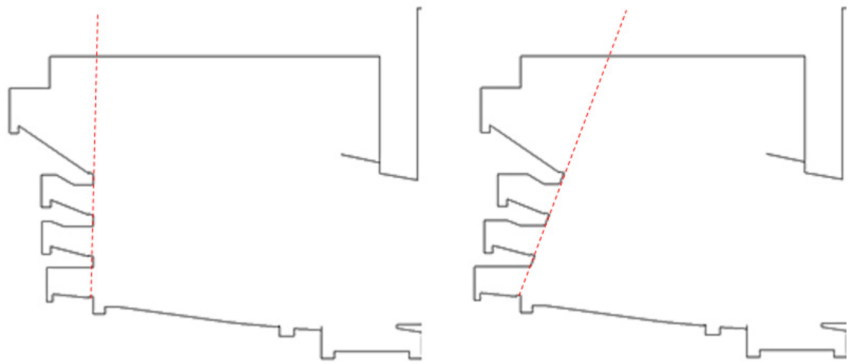


Fig. 9: Study comparing vertically aligned balconies, versus 20° forward leaning balconies. Computer modelling analyses show a 10% to 15% reduction in RT and EDT with leaning forward balconies

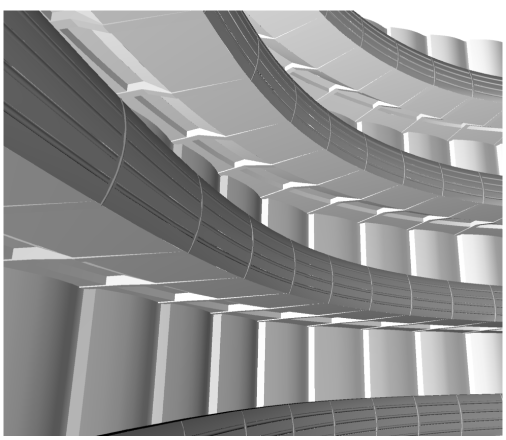


Fig. 10: Acoustic shaping

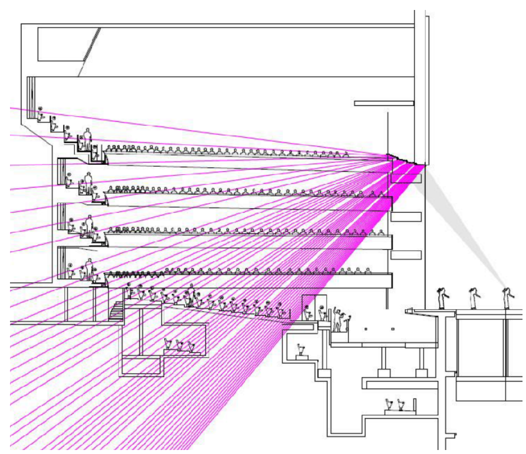


Fig. 11: Shaping of the proscenium arch ceiling

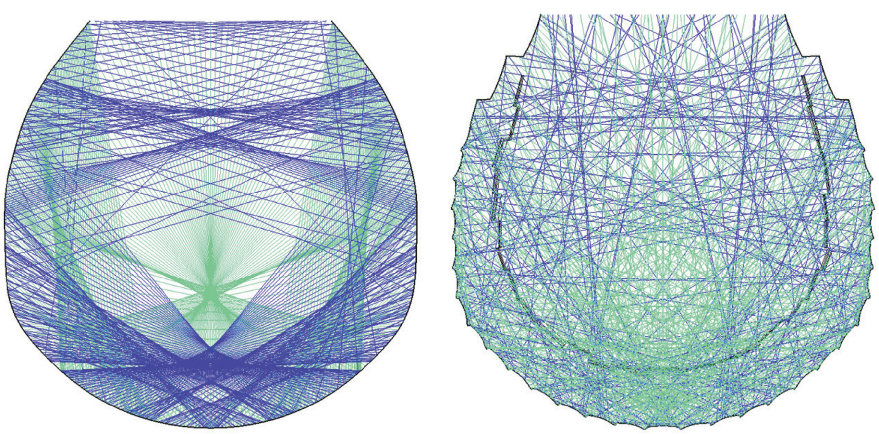


Fig. 12: Comparison of flat envelop versus the wall shaping applied to the Opera House

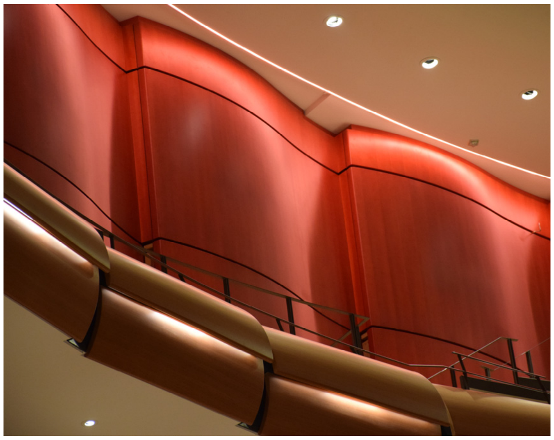


Fig. 13: Final wall panels

Fig. 14: MDF panel during construction

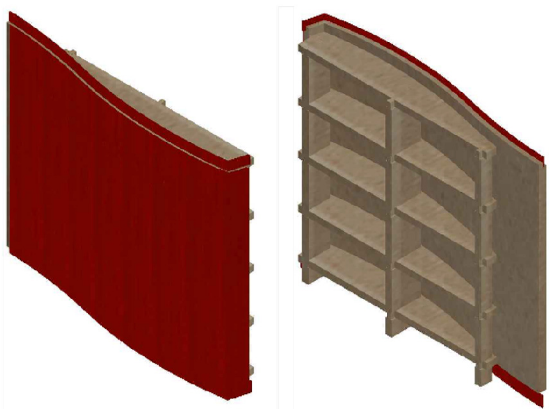


Fig. 15: Wall construction detail

Fig. 16: View of the acoustical curtains and orchestra shell[6]

Fig. 17: The 4 lifts of the orchestra pit[6]

Fig. 18: 1-Removable absorbing ceiling panels, 2-Moveable absorbing/reflecting wall panels on rails, 3-Openable pit rail panels[6]

2.2 The Alternative Stage

The 480-seat Alternative Stage is a versatile, flexible hall used for smaller, baroque or contemporary opera productions, chamber music, small orchestra works, multi-media installations and performances, banquets, children's opera or amplified music events. Performers can be arranged anywhere in the room, and series of catwalks can be configured to light different areas of the space. It is conceived as a classic rectangular enclosure with ideal dimensions for music. Instead of a typical black-box, the hall is expressed as a warm wooden enclosure with curved solid MDF panels covering the walls and the underside of catwalks to provide sound diffusion and avoid flutter echoes. NivoFlex platforms are used to create a depression in the floor to make an orchestra pit or extend the seating under the floor and create a stage edge. Manually operated, double layers acoustical curtains are used along the walls and across the ceiling to reduce reverberation time. The Alternative Stage offers a dynamic program of new music and is very popular with younger audiences. Its seating arrangement is regularly re-configured ranging from *traverse*, *front-end stage* to *flat-floor ambulatory* / *inter-active* / *immersive* layouts.

Fig. 19: Acoustical and proscenium curtains[6]

Fig. 20: Orchestra pit using scissor lifts[6]

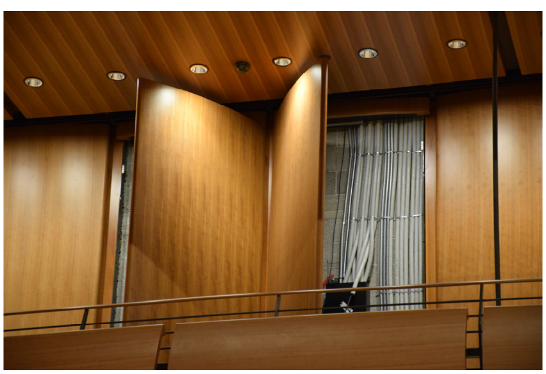


Fig. 21: Hinging of the acoustic panels to offer network/audio/video connectivity

Fig. 22: MDF ribs used to stiffen all the wood panels in the Alternative Stage and Opera House

2.3 The Orchestra and Choir Rehearsal Rooms

Located on the upper floors of the building, above the Alternative Stage, both rehearsal rooms are built as box-in-box constructions. They are sized respectively for full symphonic orchestra and 90-singer choir with enough height to contain loudness of the orchestra and the choir. The team designed wall panels using a single wall panel geometry that is rotated in various directions for sound diffusion. Faces of select panels are perforated for sound absorption in the chorus rehearsal room to control loudness and reverberation. Double layer acoustic curtains are used in both rooms to adjust reverberation and offer different acoustical conditions ranging from critical listening/rehearsing conditions or chamber music to performance conditions emulating the acoustics of the Opera House. Seating in the Chorus Room is retractable and both rooms offer AV wiring and theatrical rigging so they can be used for recordings and performances.

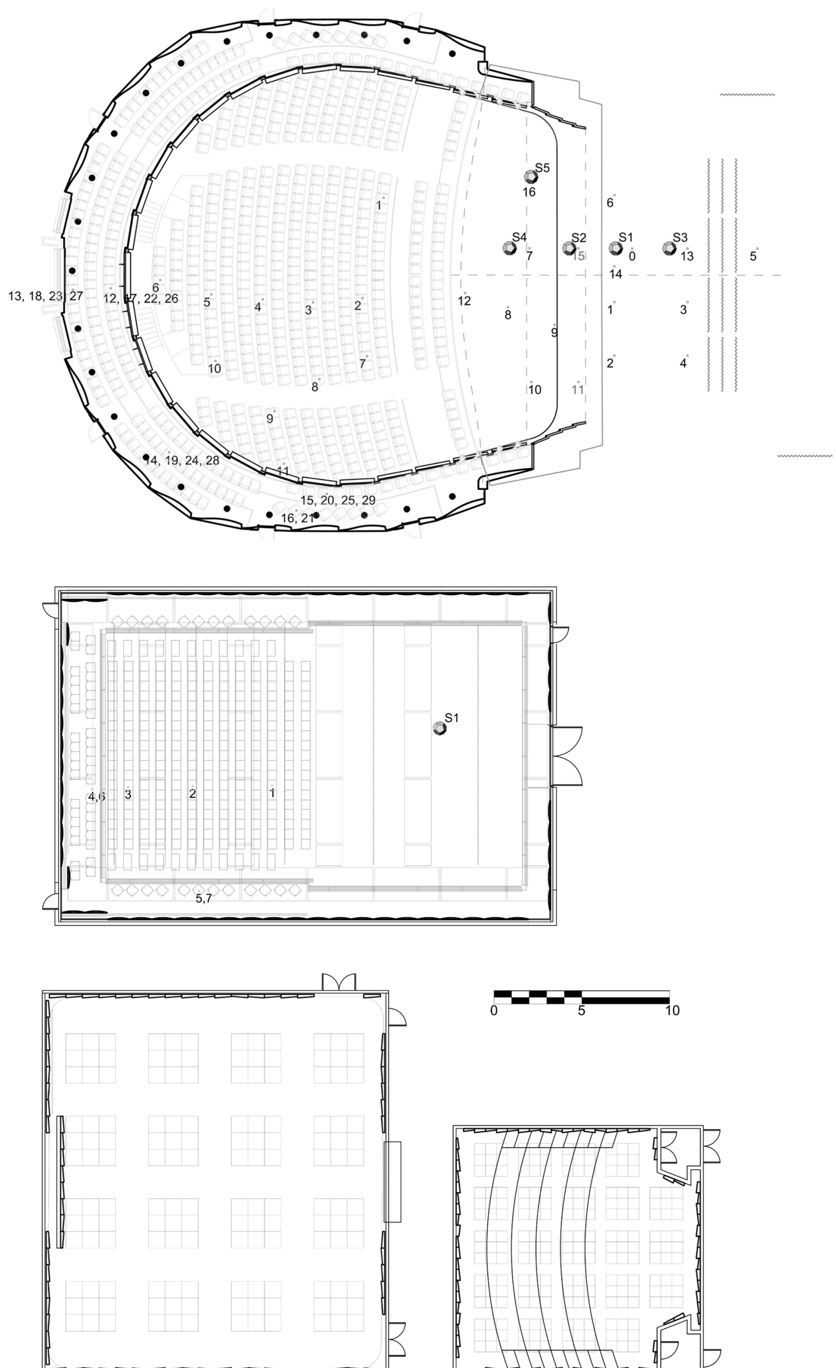


Fig. 27: Floor plans and measurement positions

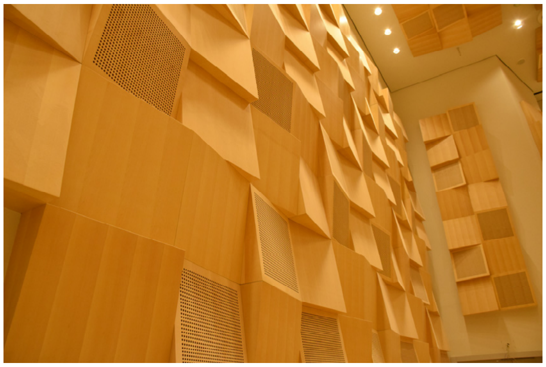


Fig. 23: Diffusion pattern of the wall panels

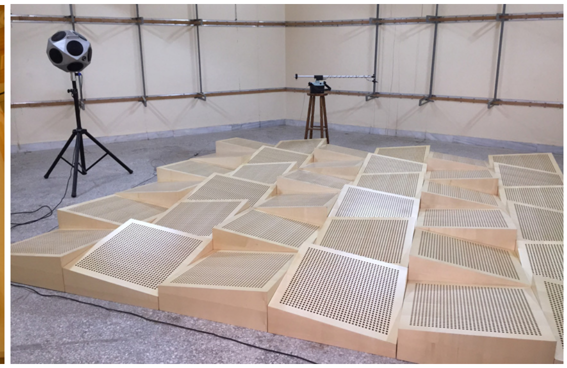


Fig. 24: Testing of the sound absorbing panels

Fig. 25: Acoustic curtains in the Orch. Room[6]

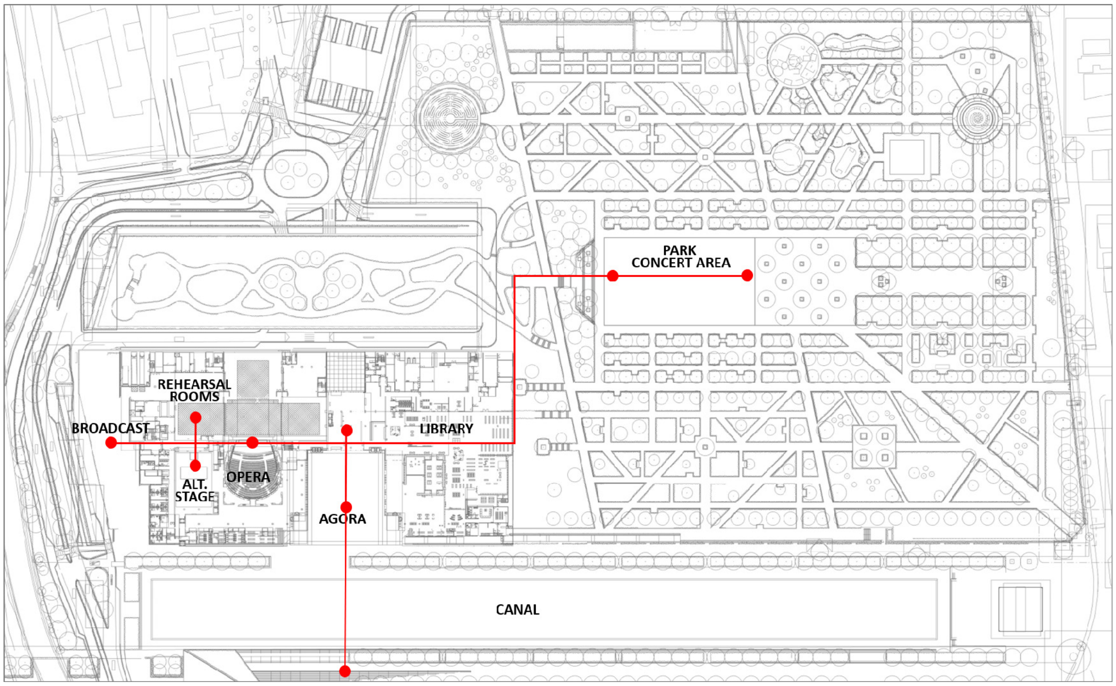
Fig. 26: Acoustic curtains in the Chorus Room[6]

2.4 Audio-Visual System

The deployment of technology throughout the facility is an integral part of the project for the support of modern productions and to provide a durable infrastructure for future programming. The AV system network is not only envisioned to support modern productions using electronics but also to provide a broad system of connectivity allowing equipment or performers to connect, in real-time, anywhere to anywhere else in the entire facility, and to use the entire facility as a potential stage for performances[3], (e.g. real-time broadcasting inside the Opera House of singers located in the park, or multiple inter-connected events alongside TV broadcast).

Performance sound, video and communication (PSVC) technologies are built over a large fiber distribution network that covers all the performance and rehearsal spaces and other informal spaces in the buildings (e.g. Lobby), but also the Agora, the Canal and the park, over a 50-acre area. PSVC connectivity includes dedicated analog and digital connections for microphones (single and multi), loudspeakers, video, cameras, broadcast, lighting, intercom, show relay and paging, in addition to network (Cat-6) and fiber connections. All signals are routed throughout the facility with 8 equipment rooms where any signal form any space can be converted to fiber and routed anywhere in the entire facility and be accessed via mobile AV stations equipped with fiber converters.

The sound system of the Opera House is composed of a main left-right-center system integrated inside the proscenium frame behind motorized panels, augmented with a distributed surround system on each balcony for immersive effects, with individually addressable loudspeaker zones, Fig. 27. Both in the Opera House and Alternative Stage, PSVC boxes are regularly distributed in the auditorium, with accesses in the floor, and behind hinged acoustical panels in the Alternative Stage. Content can be played, recorded and broadcasted throughout the facility via the venues' control rooms, mobile sound cockpits and facility's recording studio.



3 ACOUSTICAL ANALYSIS

3.1 Measurement Descriptions

Acoustical measurements were conducted using SoundDevices 788 and 744 digital recorders, Neuman KU-100 Binaural Head, Soundfield ST450 and ST350 Ambisonic microphones. The sound source was a Bruel&Kjaer Dodecahedron and horn-loaded subwoofer. Tests signals were 30 seconds 20Hz to 20,000Hz sine sweeps. Placements of the receiver and source positions are indicated in Fig. 27. Measurements in the presence of an audience were conducted at 3 positions in the Opera House with a 1,100-person audience (79% occupied). All other measurements were conducted in un-occupied conditions with various deployments of the acoustical curtains. Variable sound absorption in the pit included 30% of the stage underside covered with sound absorbing panels, and where 2 of the 11 acoustic panels behind the orchestra were turned towards their absorbing side. Four panels of the orchestra pit rail were opened. Drapes in the flytower were arranged to emulate the presence of scenery, and included 3 full width sets of drapes, 8m behind the front edge of the stage, hung a few meters above the singers' head, and 2 sets of drapes parallel to the side stages.

3.2 Results in The Opera House

3.2.1 Auditorium

Octave band reverberation times for the 29 positions measured in the Opera House are indicated in Fig. 28 and 29. Mid-frequency values average over all the positions to 2.0 seconds without an audience, down to 1.8 seconds with a full audience and orchestra. The occupied reverberation is slightly higher than initially targeted (1.6 to 1.7 seconds) to provide additional headroom for post-romantic opera (e.g. Wagner, Weber, Strauss) and account for additional scenery's acoustic absorption. Shorter reverberation can be achieved by gradually deploying the acoustical curtains. Reverberation can be lowered to 1.65 seconds in the empty hall which allows the orchestra to simulate the presence of an audience during rehearsals. The reverberation reaches 1.30 seconds with the presence of an audience with all the curtains deployed for other performances using amplification or technology, or baroque operas.

A rise below 125Hz is noticeable and shows the effect of the heavy wall and ceiling construction successfully retaining the low frequencies in the auditorium, creating a warm acoustics and support for the double basses. This effect is also visible on the Bass Index parameter (G_{125}-G_{mid}) in Table 1 which fits within typical concert hall ranges[4], for orchestra sound.

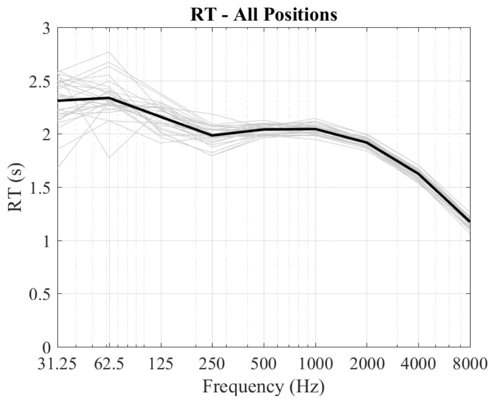


Fig. 28: Unoccupied RT

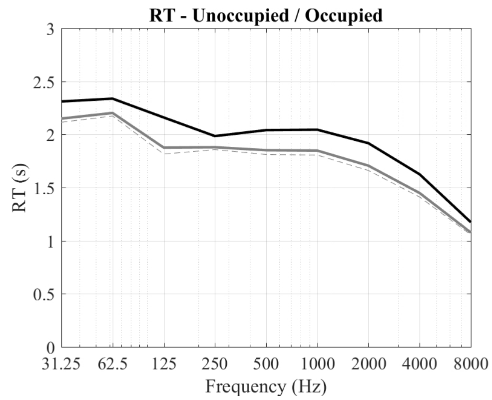


Fig. 29: Average RT unoccupied, occupied with 1,100 seats, and extrapolation for 1,400 seats

The ratio of perceived reverberation (EDT15/RT) across all the positions remains above 90% under occupied conditions, which indicate that most audience members can appreciate the full extent of the reverberation of the room. This shows the benefit of shallow balconies with the walls around the audience contributing to mixing reverberant sound energy in the auditorium instead of creating sound traps as it can happen with venues with deep balconies.

Voice clarity is above 45%, which is good for balancing the understanding of spoken words of recitatives with singing voices of arias. D50 does not to exceed 65% which is preferable for natural acoustic opera and music events.

The loudness difference (G_{diff}) between a source on stage and a source in the pit is an important measurement in opera houses to express how singers might sound in comparison to the orchestra, as there is a tendency in more modern opera house for orchestra to overpower voices of singers. Over all the positions, the results indicate a loudness of about 2.4dB for the singers and 2.0 for the orchestra. Firstly, those values show that the room is not too quiet; secondly that singers and the orchestra are in balance; thirdly that the room naturally amplifies singers a little bit more than the orchestra. This shows that the proscenium arch, reflector and wall shaping are helping with the projection of singer's voices to rise above the orchestra sound. Lower orchestra loudness can also be achieved by deploying more of the sound absorbing panels in the orchestra pit, closing some the orchestra pit rail panels, or reducing the size of the pit.

Averaged values of orchestra clarity (C80) for a source in the orchestra pit fall within the desired range for symphonic orchestra. Higher clarity values are measured from the stage showing the natural amplification of the early sound from the Hall for singers or musicians on stage.

Averaged values of interaural cross correlation 1-IACC are above 0.64 expressing high values of spaciousness over all the positions in the auditorium. Once again, those results indicate the positive effect of the shaping and engagement of the wall and balcony surfaces distributing sound around the listeners' head.

Auditorium Receivers	Stage $_{S1}$	*Semper. & Colon*	Pit $_{S4}$	*Semper. & Colon*	Stage and Pit Receivers	Stage $_{S1}$	Pit $_{S4}$
$RT_{unoccupied}$	2.00s						
$RT_{occupied}$	1.80s	*1.61s*					
$RT_{unoccupied\ Ac.\ Curtains}$	1.65s						
$RT_{occupied\ Ac.\ Curtains}$	1.30s						
$EDT15/RT_{unoccupied}$	95% ±5%	*120-123%*	94%		*EDT15*	1.78s	1.37s
$EDT15/RT_{occupied}$	90%				*EDT15/RT*	96%	79.8%
$G_{mid\_unoccupied}$	2.4dB	*2.4-2.5dB*	2.0dB		$G_{pit\ to\ stage@3m}$		5.5dB
$G^{*}_{mid\_occupied}$	2.2dB		1.8dB		$G_{pit\ to\ stage@7.5m}$		0.5dB
$G_{diff\_occupied}$	0.4dB				$G_{stage\ to\ pit}$	3.2dB	
$BI_{unoccupied}$	-0.6dB		-1.1dB		G_{early}		6.9dB
$D50_{unoccupied}$	47.5% ±3.2%				G_{late}		0.2dB
$D50^{*}_{occupied}$	49.4% ±3.2%				$ST1_{early}$		-13.5
$C80_{unoccupied}$	1.6dB ±1.3dB		-0.7dB ±1.9dB	*-2.6dB*	$ST1_{late}$		-18.5
$C80^{*}_{occupied}$	1.8dB ±1.0dB				*ST1*		-12.4
$1\text{-}IACC_{early}$	0.64 ±0.06	*0.65 – 0.72*					
$1\text{-}IACC_{late}$	0.84 ±0.06						

Table 1: Summary of acoustical parameters in the Opera House averaged over all the measurement's positions, * average over 3 measurement positions (receivers #5, #17, #27)

Fig. 30 shows measurement positions located along the center axis of the Opera House. The orchestra is louder at the front, which can be controlled by closing some of the panels of the orchestra pit rail. Higher values of G_{diff} and voice clarity (D50) are obtained on the balconies. Positions 4 sees a loudness increase for voices compared to the orchestra due in one part by the attenuation by diffraction of the direct sound from the pit and by the convergence of reflections from the lateral walls and proscenium for a source on stage. Values of apparent source width/early spaciousness (ASW), are good throughout the auditorium. Maximums are achieved on the parterre and 1st balcony where the shaping on the balcony soffit and walls are most effective.

Plots of 3D impulse responses in Fig. 31 show that positions at the front of balconies receive larger contributions from the proscenium arch, reflector and ceiling, while positions inside the balconies receive a greater contribution from the soffit and walls. With the walls and soffits close to the audience on the balconies, an array of early reflections reaches the audience within the first 15ms (red) of sound arrival, blending with the direct sound to enhance intimacy, clarity and envelopment, which could be clearly heard in the Auditorium during the tests. This effect is also clearly visible for the positions on the side of the balconies (Fig. 32) where the curved wall shaping distribute sound reflections throughout. On the ground floor, early reflections are mostly coming from the proscenium and lower walls, while on the top balcony, positions receive a greater contribution from the ceiling, at shorter time's arrivals, contributing to greater intimacy and clarity despite the distance to the stage. The Low-High and Front-Rear parameters indicate a mostly frontal distribution of lateral sound, more suited for drama spaces for a focus towards the stage. For seats on the parterre, lateral sound is evenly distributed from the front and the rear of the listeners' head, as those are directly across the singers on the stage and benefit from a greater engagement of the side and rear walls. Positions on the top balcony receive a greater lateral energy from the ceiling.

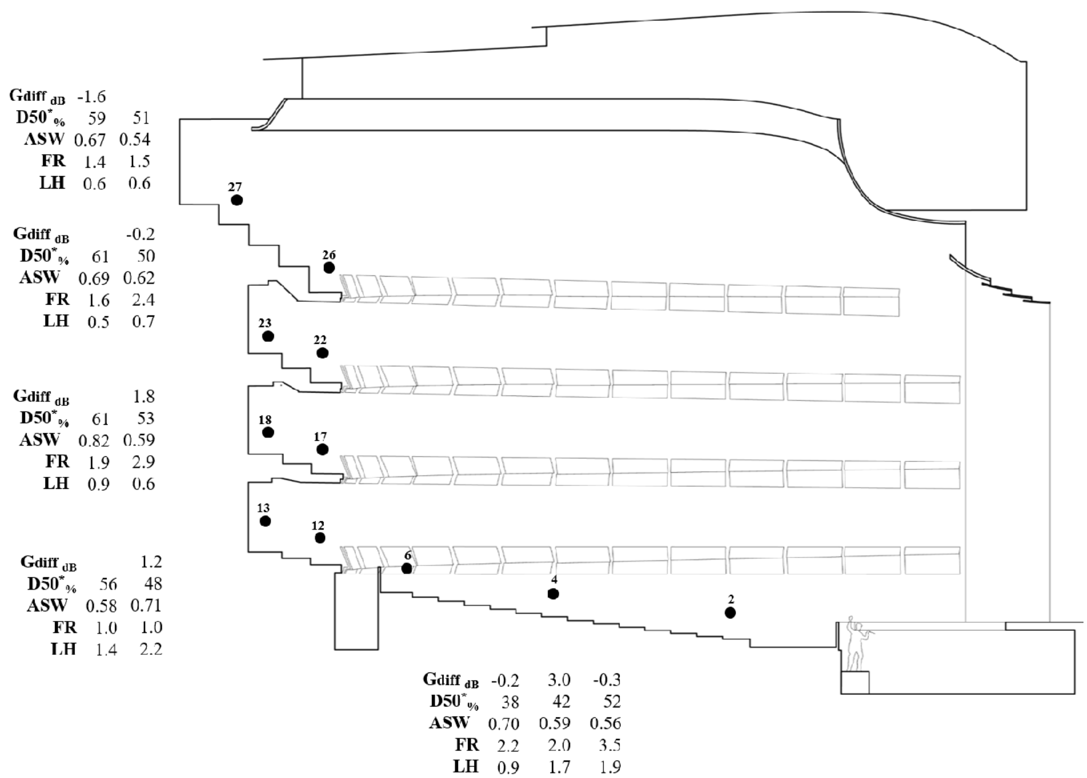


Fig. 30: Variation of parameters along the center axis of the Opera House

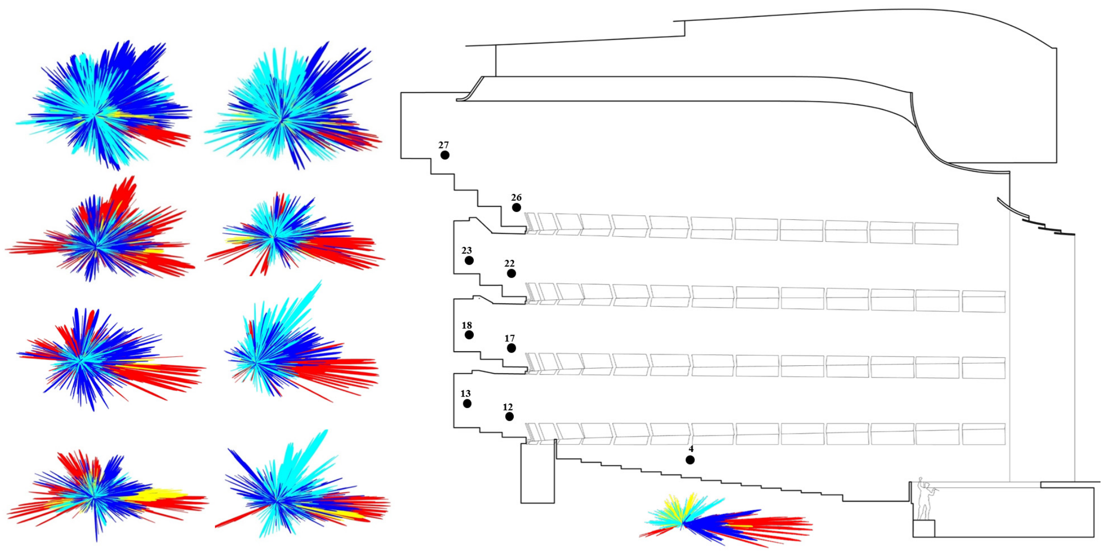


Fig. 31: Normalized 3D Impulse response representations along the median plane

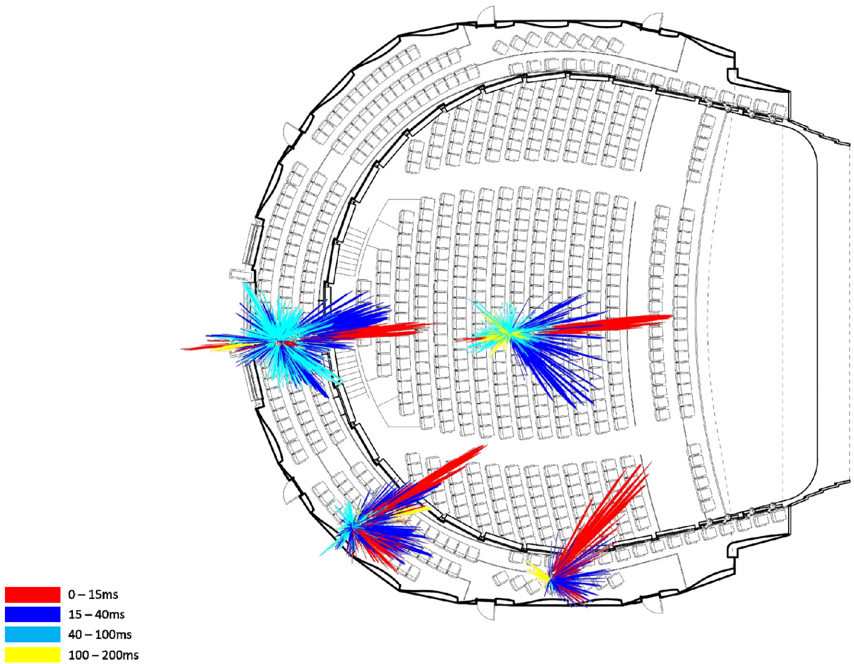


Fig. 32: Plan view representations of normalized 3D Impulse responses

3.2.2 Performer Conditions

The stages of modern opera house, typically surrounded by sides stages, sceneries and a tall flytower are usually not very supportive for singers. Due to the quantity of flying scenery machinery and tight spacing of the flying system, there are very few opportunities to make acoustical improvements. The usual techniques are to close the side stages from the main stage during performances with tall sliding doors (10 meters tall at SNFCC), so that sound from the singers does not escape into the side and rear stages. Another technique is to provide guidance for set designer to create sets that will help with the projection singers' voice and avoid too much sound escaping into the flytower. It is also possible to imagine hanging reflectors over the stage, but those will be in the way of flying sceneries.

At SNFCC the stage is extended further into the auditorium and surrounded by a deep proscenium arch, which participate to singer's self-support, cross-stage support between singers, better ensemble playing with the orchestra in the pit, and a better voice projection in the auditorium. The walls of the auditorium are also shaped with regularly occurring recesses which bounce an array of small reflections back to the stage. This is clearly perceptible towards the front of the stage, which singers noticed during the tests. The feedback from the auditorium's acoustics seems to provide singers with good support and to help them develop beautiful tones. Values of liveness (EDT) and ratios of reverberation (EDT/RT) indicate a live environment for singing, even with the deployment of drapes in the flytower.

The results also include measurements of loudness from a source on stage inside the orchestra pit. Values including positions under the stage overhang average around 3dB, which highlight the roles of the proscenium arch for stage-pit ensemble support and the front wall of the pit reflecting singer's voice to the orchestra. Similar values are obtained with a source in the pit and measurements conducted on stage, with 5.5dB of orchestra loudness at singing positions 3m behind the stage edge, decreasing to 0.5dB 8 meters further inside the stage house (averaging around 3dB).

Early loudness (G_{early}) is good in the pit, showing good self and sections' support. It can be lowered by deploying more of the acoustical panels. Late Loudness (G_{late}), indicative of the room's feedback at the performers is comparable to other symphonic halls[5]. ST1 early and late also fall within typical ranges for symphonic halls, demonstrating that the orchestra pit tends to function like the stage of a concert hall.

It is interesting to compare the results with the design benchmarks of Dresden and Teatro Colon. The reverberation is slightly higher, but it can be reduced with the deployment of the curtains or allow for a more symphonic sound for works by composers such as R. Strauss, R. Wagner or modern Greek composer D. Mitropoulos. The loudness both from the pit and the stage are very similar. Spaciousness are also very comparable. Clarity from the pit is higher in the new Opera House, which would benefit the orchestra sound (maybe too low in the old spaces). Overall, the new Opera House compares well with the Semperoper and Teatro Colon opera houses.

3.3 Results in The Alternative Stage and Larger Rehearsal Rooms

3.3.1 The Alternative Stage

Measurements of reverberation times average around 1.7 seconds in the empty room without the deployment of the acoustical curtains. Values of reverberation can be lowered to 1.0 second without an audience when all the curtains are deployed.

The overall impression in the hall is a diffuse and immersive acoustics that works well for classical music, but which also works well for amplified music with the help of the wall shaping diffusion which softens the bounce from sound systems during amplified music events.

The room provides great lateral reflections from the lower walls and from the underside of the upper balconies creating a well-balanced sense of envelopment (LH = 1), as the plots of 3D impulse responses indicate in Fig. 33. The plan view of the 3D plots also shows how the wall shaping in the hall distributes and spreads lateral reflections.

Values for the clarity, reverberation and loudness parameters are within the desired ranges for natural amplified music when the curtains are retracted. The deployment of the acoustical curtains allows to reduce loudness by 3dB and to increase voice clarity (D50) up to 70%. A good room for amplified music is also characterized by a high clarity (C80) at low frequencies to avoid boomy-ness and control spectral masking. C80 values averaged over 31Hz, 63Hz and 125Hz rise from 1dB without curtains, which is adequate for natural acoustics orchestral music, to 3.5dB, which is preferred for amplified music.

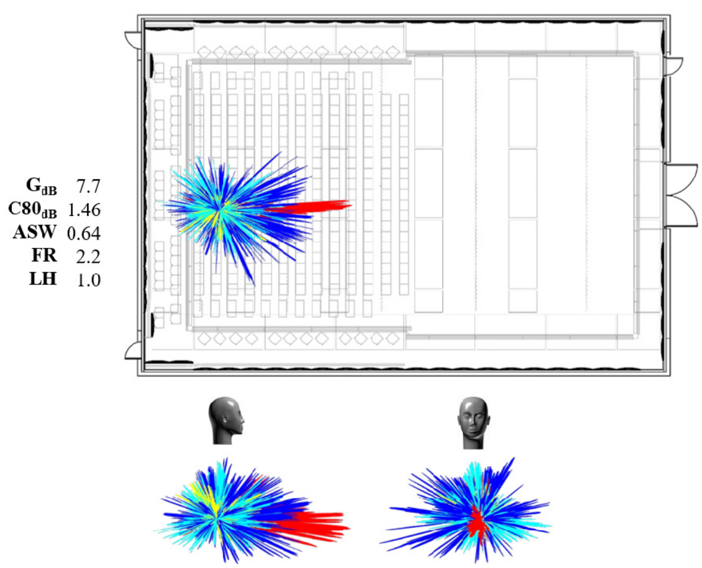


Fig. 33: 3D impulse response at rec.3, parameters including Front-Rear and Low-High indexes

Auditorium Receivers	Alt. Stage	Orch. R.R.	Chorus R.R.
$RT_{unoccupied}$	1.68s	2.2s	1.45s
$RT_{occupied}$	1.36s		
$RT_{unoccupied\ Ac.\ Curtains}$	1.00s	0.90s	1.15s
$EDT15/RT_{unoccupied}$	98% ±2%		
$G_{unoccupied}$	8.7dB ±0.6dB		
$G^{*}_{unoccupied\ Ac.\ Curtains}$	5.8dB		
$BI_{unoccupied}$	-0.8dB		
$D50_{unoccupied}$	41.5% ±3.8%		
$D50^{*}_{unoccupied\ Ac.\ Curtains}$	70.0%		
$C80_{unoccupied}$	1.0dB ±0.4dB		
$C80^{*}_{unoccupied\ Ac.\ Curtains}$	6.5dB		
$C80_{unoccupied\ 31\text{-}63\text{-}125}$	0.9dB ±1.9dB		
$C80^{*}_{unoccupied\ 31\text{-}63\text{-}125\ Ac.\ Curtains}$	3.5dB		
$1\text{-}IACC_{early}$	0.66 ±0.13		
$1\text{-}IACC_{late}$	0.87 ±0.04		

Table 2: Summary of acoustical parameters in the Alternative Stage averaged over all the measurement's positions, * measurement at one position (receiver #2)

3.3.2 The Orchestra and Chorus Rehearsal Rooms

The primary function of those rooms is to offer adequate conditions for rehearsals. The challenge for those spaces is to control the build-up of sound levels while preserving reverberation, when needed by the musicians. The volumes were sized to contain the sound levels of both the orchestra and the full choir, and tests with the orchestra have revealed excellent rehearsing conditions for the performers. The deployment of the curtains in the orchestra rehearsal room allows to reduce the reverberation from 2.2 seconds down to 0.9 seconds (empty room), while the acoustic curtain at the front of the chorus room helps to soften the bounce from the front wall facing the singers and control loudness.

The wall shaping in both rooms create a very diffuse acoustics, which are not only good for concert or rehearsals, but also very beneficial for recordings.

4 CONCLUSION

The Stavros Niarchos Foundation Cultural Center opened in 2017. Books are filling the new library, and the Greek National Opera and Ballet have moved into their new spaces. The official music seasons have also started, including the Foundation's music festival, outdoor events and concerts in the park and other parts of the building. The center has been very successful to attract audiences of all demographics. The alliance of places for knowledge, performing arts and nature into vast indoor or outdoor areas of pristine architectures attracts up to 40,000 visitors per week. The accessibility, quality and diversity of content are resulting in widely successful public engagement.

Music programs are making full use of the scale and acoustic complementarity of the spaces, and modern and classic operas are performed simultaneously in the Opera House and Alternative Stage. Measurements in the spaces illustrate that the acoustics of the Opera House fits within some of the best venues in the world, such as the Dresden and Teatro Colon opera houses. The measurements also show the range of acoustics that the spaces offer which allows presenters to set-up natural or amplified music events in all the performance and rehearsal spaces. Both the Opera House and the Alternative Stage provides great reverberance, clarity, intimacy and envelopment for operas and orchestral music, but also shorter reverberation times, higher clarity and immersive technology for modern productions. All the spaces including areas of the park are also digitally connected for broad/simul/podcasting or recording.

In a time when opera and the performing arts are in search for new means of public engagement, the SNFCC offers new hope with its multiplicity of indoor and outdoor environments, accessibility and diverse programming. The Stavros Niarchos Foundation Culture Center positions itself as a new benchmark for promoting knowledge, arts and culture, and for the creation of future opera house facilities.

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