McGraw Hill CONSTRUCTION Continuing Education

Virtual but Vivid

A sonic rendering technique known as auralization helps acousticians make the sound of even unrealized spaces audible.

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Acoustics have the ability to influence our appreciation of a space, perhaps as much or even more than other physical properties, including shape, the amount or type of illumination, and the colors and textures of finishes. But since sound is not at all visual, and is arguably the least tangible attribute of an architectural environment, understanding what makes a room acoustically successful can be challenging for the nonengineer. Even for technologically savvy architects and acoustically acute clients, data describing absorption, reflection, or diffraction is often inadequate for communicating what a proposed space will sound like.

However, an acoustical rendering technique known as “auralization,” enabled by faster computer processors and the increasing sophistication of software for analysis and simulation, has been gradually gaining ground over the past decade, allowing project teams and owners to experience the sound of an unbuilt room. Even though these sonic renderings are often created long before the first wall is erected, proponents insist that well-devised auralizations are more than rough approximations. “The process has scientific rigor behind it,” says Ben Markham, a senior acoustical consultant at Cambridge, Massachusetts–based Acentech.

Continuing Education

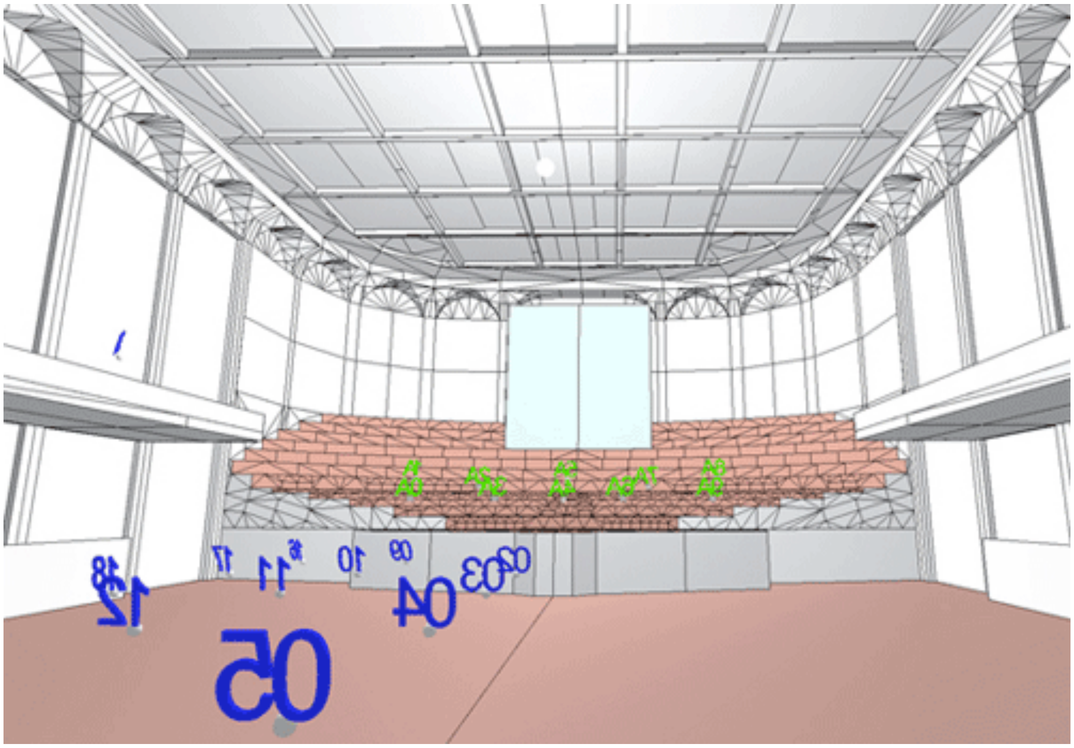
Use the following learning objectives to focus your study while reading this month’s Continuing Education article.

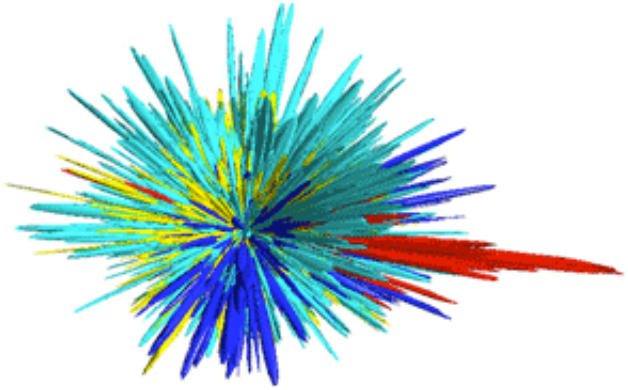
Learning Objectives - After reading this article, you will be able to:

1. Understand key acoustical concepts.
2. Explain the simulation process known as auralization.
3. Describe the acoustical design challenges presented by several recently completed projects.
4. Discuss how auralization helped inform decision making for these projects.

The process of auralization (a neologism that combines “aural” and “visualization”) begins with a so-called “impulse response” — an acoustical signature unique to a particular room, sound source, and listener location. In an existing space this signature can be captured: Acousticians emit a brief, sharp signal from an omnidirectional loudspeaker and record it with a specialized microphone placed at the listener’s location, documenting the original impulse and subsequent reflections from all angles and surfaces. Engineers can analyze this signature to better understand the correlation between perceived acoustical qualities and architectural characteristics.

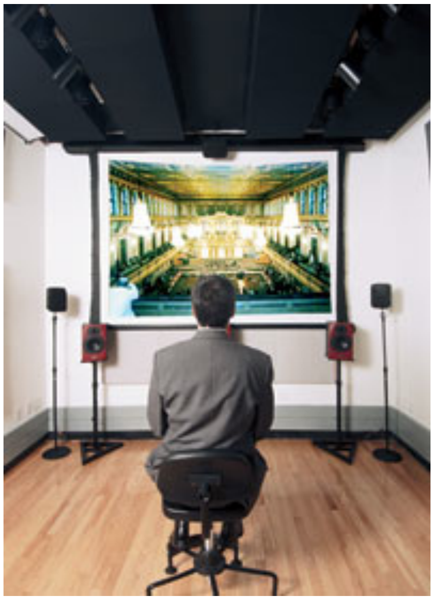
Photo: © Miriam Rossignoli





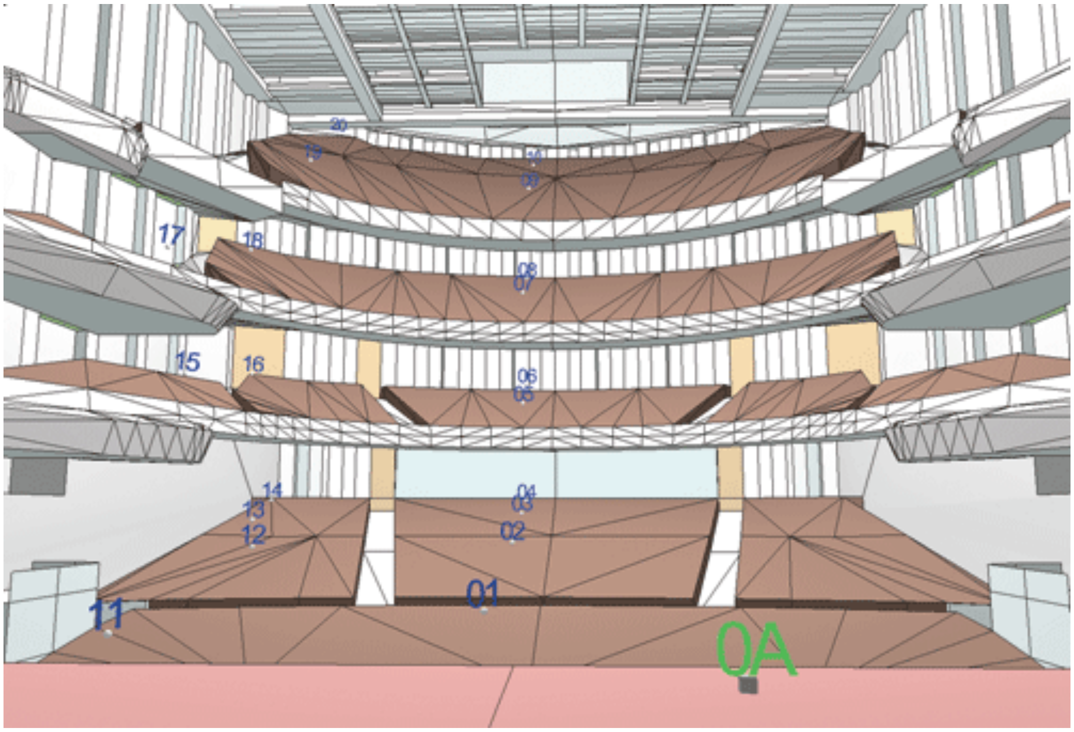
The study of the acoustic signatures of spaces with highly regarded sound, like the late 19th-century Concertgebouw in Amsterdam, can help engineers understand what makes a space acoustically successful. Arup deploys a proprietary visualization technique that maps these signatures in three dimensions, describing how quickly reflections arrive from different directions.

For spaces that aren't yet built, engineers must create an impulse within a virtual acoustical model based on the architect's 2-D or 3-D digital files. Acousticians then estimate the response to the signal at locations throughout the room. Finally, they combine, or "convolve," this signature with music, speech, or other sound typically recorded in an anechoic, or reflection-free, environment. The computer adds the reflections and time delays to simulate the acoustical qualities specific to the proposed space.



Auralization and specialized listening environments, like the one in Arup's New York City office, allow for side-by-side comparisons of rooms that have sought-after acoustics with spaces that exist only as digital models. Here, an Arup acoustician compares Vienna's Musikvereinssaal (1870) with an unbuilt concert hall.

Photos: Andreas Pessenlehner/EPA/Corbis (top); Arup (left)



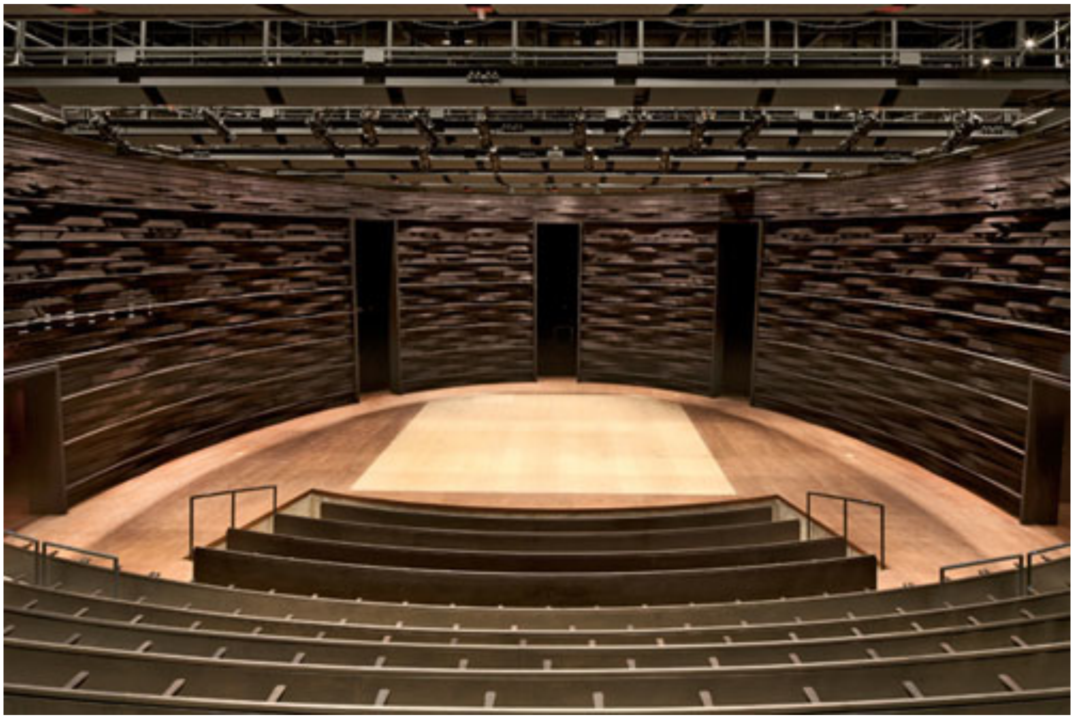
With the audible output of this process, acousticians can then virtually adjust geometry or finishes and listen to how this will alter the sound. Or they can compare the sound of the still-unbuilt room to an existing one with sought-after acoustics. "We can easily move from space to space, and scenario to scenario," says Raj Patel, an acoustician and principal based in the New York City offices of Arup.

Acousticians can present auralizations via headphones. But a few acoustics practices, including Arup and Acentech, have purpose-built rooms in their offices where they can review these sonic renderings and present them to a group. The goal is to allow project decision makers to experience the sound of a proposed space collectively in an immersive setting. Such controlled environments typically include audio processing systems with multiple speakers working together to simulate the directional and three-dimensional qualities of sound.

The specialized rooms in acousticians' offices usually have a projection system for displaying architectural and acoustic visualizations. And in order to avoid coloring the listening experience, these spaces are designed to be acoustically neutral: They are relatively nonreverberant, with attention to isolation from mechanical noise and other disruptive sounds, but in general they are not anechoic. Even though an echo-free room would provide a more faithful rendition of the virtual space, it would be physically unpleasant, says Patel: “You would hear your own blood flow.”

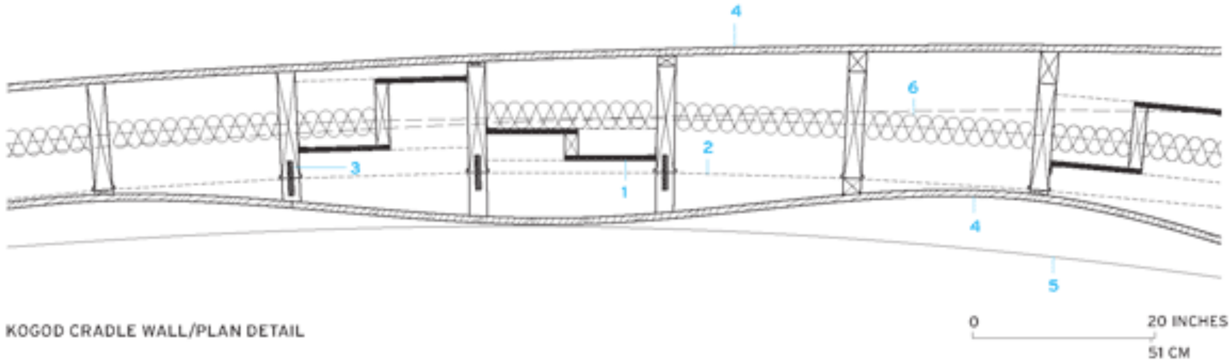
Focusing form

Regardless of whether auralizations are presented via headphones or in a tailored listening room, the technique can help project teams and owners weigh various acoustic options. It can also be used as a means of demonstrating the sound of a nearly final design to confirm that the properties of a proposed space will meet client expectations. The process was deployed in this way for the Arlene and Robert Kogod Cradle, a 200-seat experimental theater in Washington, D.C. The performance space is one of three sheltered by the swoopy roof of the Arena Stage at the Mead Center for American Theater, just revamped and expanded by Vancouver, Canada–based Bing Thom Architects.



The Kogod Cradle, a theater at Washington, D.C.’s Arena Stage, has an acoustically challenging elliptical shape.

Photo © Nic Lehoux

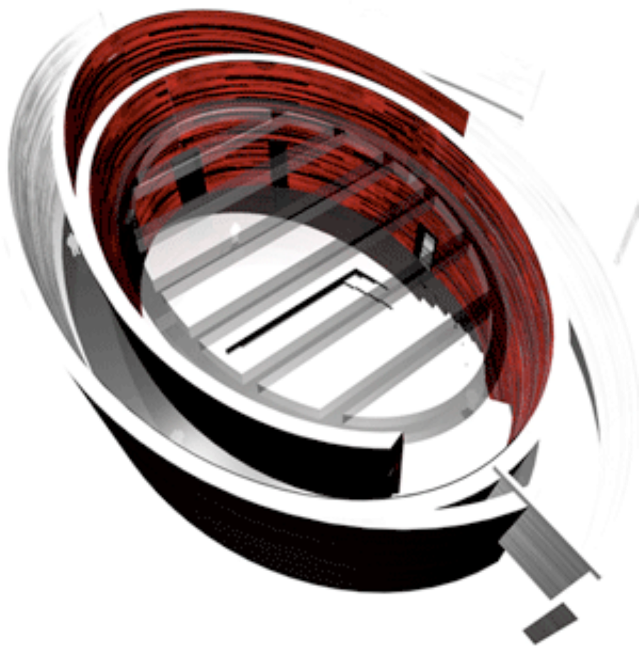


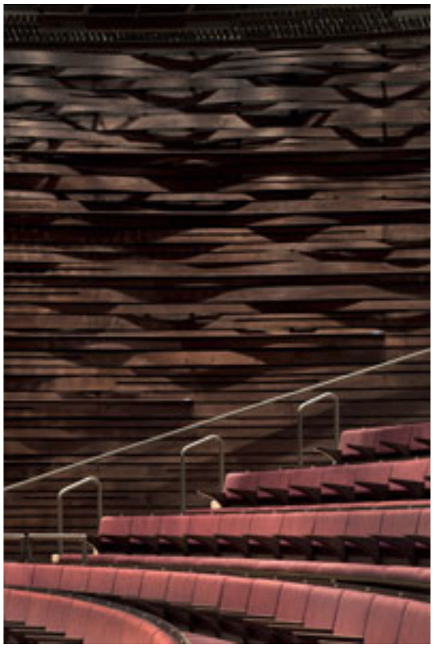
1 Acoustic reflectors
2 Black nylon screen
2 Concealed fastener
3 5/16" poplar slat system
4 3⁄4" poplar shelves
5 Acoustic insulation

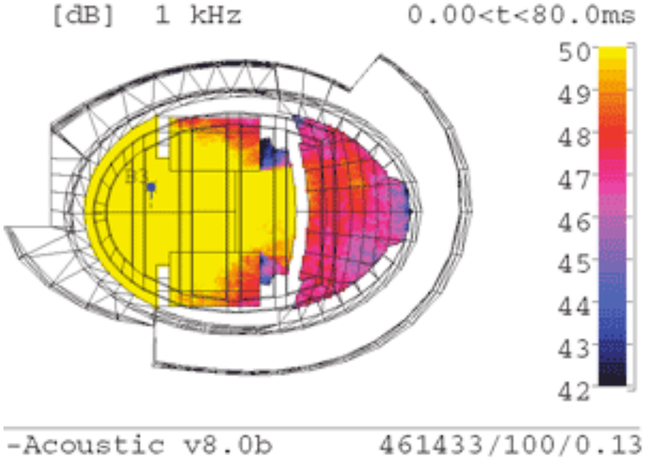
Right: The spiraling path between the theater's concrete structure and its inner skin serves as a sound-and-light lock.

Below: Auralization helped demonstrate that the inner walls' poplar slats, bent to combine convex and concave radii, would effectively distribute sound.

Photo © Nic Lehoux







Above: Acousticians closely examined how sound would be distributed over the Kogod's seating area, contributing to speech clarity.

The Kogod, the only completely new Arena venue, presented a particularly sticky acoustical challenge: It has an elliptical plan, emblematic of artistic director Molly Smith's desire to nurture new playwrights. Without the right acoustical solution, this shape would focus sound instead of distributing it over the entire seating area, explains Richard Talaske, president of the eponymous Oak Park, Illinois–based firm that served as the project's acoustical consultant.

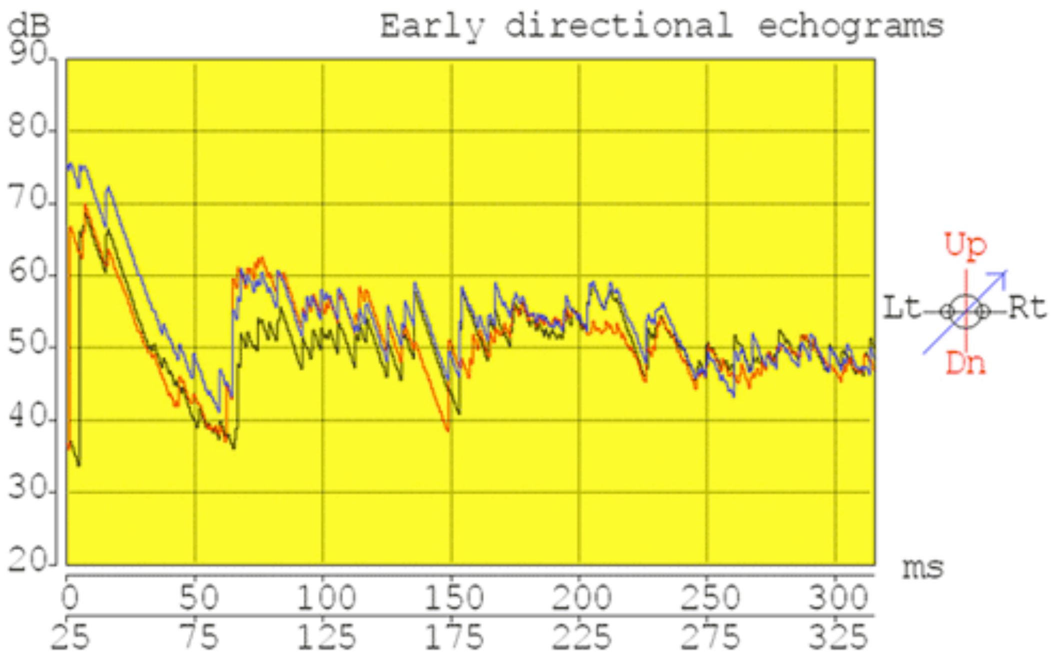
In order to neutralize the focusing effect, the design team developed an inner wood skin that peels away from the theater's poured-in-place concrete structure. The resulting spiraling path leads theatergoers from the lobby and serves as a sound-and-light lock. The two walls in combination help diffuse low-pitch sound, while the inner wood-sheathed wall, made of horizontal dark-stained poplar slats, 5⁄16 inches thick, helps distribute high-pitch sound. The slats, which vary in height from three to six inches, were field bent and secured to underlying studs to give each a wavy shape, combining concave and convex radii.

Although the interior wall surface seems randomly composed, it is the product of a process that included computer modeling combined with testing of a 1:10 scale model built by the acousticians and of a mock-up of an approximately 30-foot-square section of wall constructed by the architects. To identify the sound-diffusive properties of the design, Talaske projected signals from speakers at the walls from several angles and then documented the reflections. With data garnered from these tests, acousticians calibrated the computer model and performed analyses that included an examination of the reflections' timing, strength, and distribution to ensure that speech would be intelligible in all parts of the seating area.

Once the scheme was acoustically optimized, Talaske and his team created an auralization by convolving the space's impulse response with speech they recorded in an anechoic environment. After presenting the simulation to the architects and client, the only adjustment deemed necessary was the addition of plywood-and-gypsum panels to the bottom of catwalks to provide more reflection from the ceiling and improve the localization of sound.

Calm and clear

At Boston's Museum of Fine Arts (MFA), the acoustical issue was not an unorthodox shape but a large volume enclosed by highly sound-reflective finishes. Here, acousticians from Acentech began working with the London-based Foster + Partners in 2003, soon after the concept for the 121,000-square-foot Art of the Americas Wing solidified. Both museum trustees and the architects were concerned that the 63-foot-tall, 12,000-square-foot enclosed courtyard conceived as the addition's centerpiece would be acoustically unsuitable for the varied programming envisioned to take place there. The monumental space — enclosed by glass, stone, and brick — would need to serve as the setting for social functions and special events such as receptions or banquets, and to provide acoustics conducive to listening to a string quartet, a swing band, or a lecture. During normal museum operating hours, designers hoped the courtyard would be calm and contemplative, even though it would house a café.



As part of their analyses, MFA acousticians studied the reflection patterns generated in the courtyard for particular sound sources and listeners.

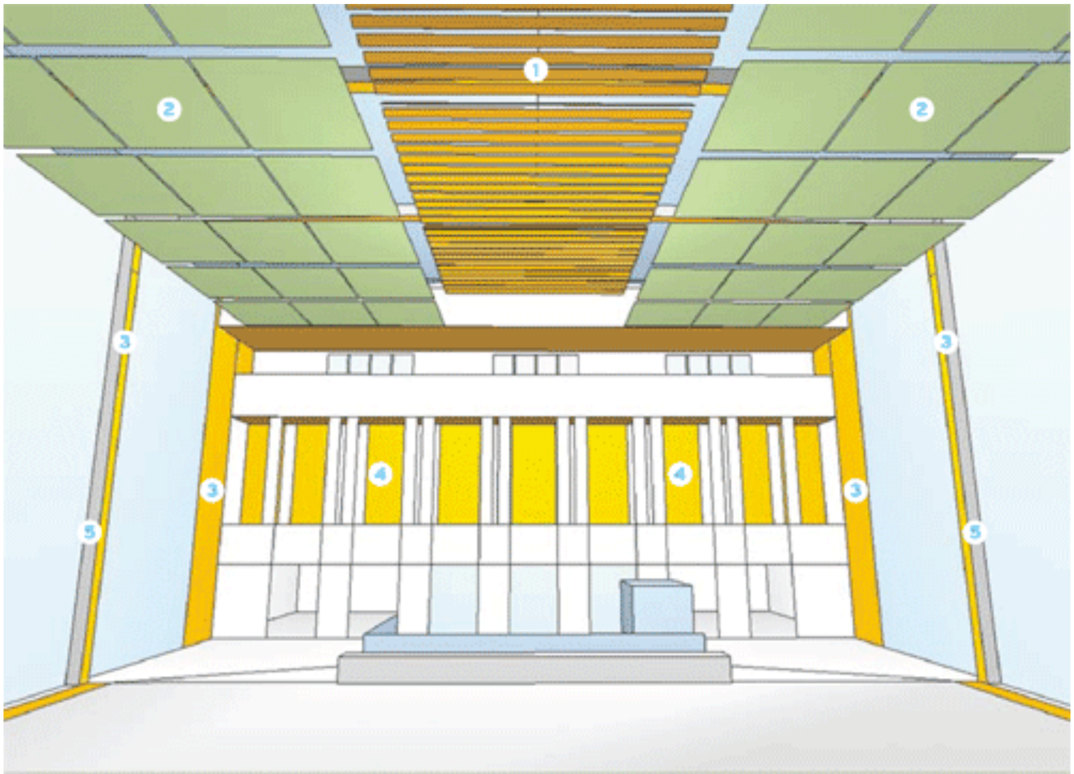
The mostly hard-surfaced grand space serves as the setting for a variety of events, including large banquets.

The auralizations below depict a banquet at the MFA without sound absorption.

This set of auralizations depict a banquet at the MFA with the sound absorption used in its construction.

Elements that control heat gain and glare incorporate the sound-absorbing material.

Photos: Foster + Partners/Nigel Young



1 Perforated metal baffles with glass-fiber cores

2Two-layer perforated vinyl panels

3 Conceled glass fiber

4 Perforated wood fins with glass-fiber cores

5 Column array speakers

The addition of sound absorption would be key. Without that, the hard-surfaced space would be uncomfortably reverberant, making music muddy and speech unclear. But determining just how much acoustical material would be needed, and deciding how to include it without compromising the courtyard's planar purity, would be tricky.

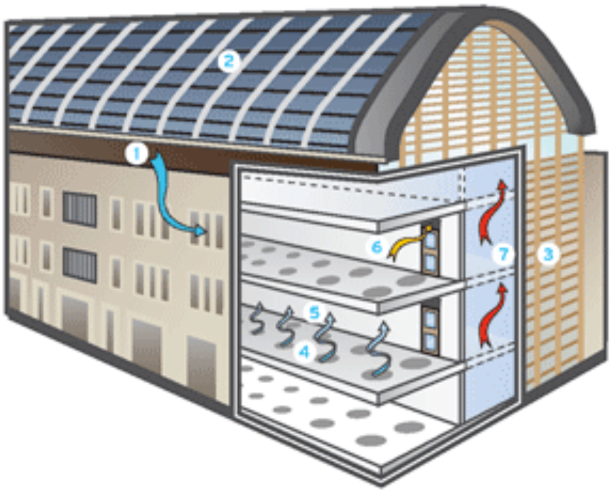
Acentech started by documenting several atria in and around Boston. The engineers took measurements of the rooms and then calculated or estimated various characteristics, including volume, surface area, and reverberation time.

From those spaces, they chose one — an atrium included in a Moshe Safdie and Associates–designed expansion of the Peabody Essex Museum in Salem — as a benchmark for the MFA. It wasn't excessively loud and was comfortable for conversation and general use. As part of the documentation process, they also discovered that the average absorption coefficient (a ratio of sound absorption to surface area) was the most useful metric for evaluating the existing spaces. It was even more telling than reverberation time. The phenomenon can be attributed to occupant expectations that large rooms be at least somewhat reverberant, says Acentech's Markham. "We want our ears to match our eyes."

After completing its survey, Acentech digitally modeled Safdie's court and virtually "populated" the space with various scenarios, including the sounds made by 500 diners at a banquet, with people conversing and dishes clinking. Since it was impractical to make a recording of such a source in an anechoic chamber, the acousticians recorded a much smaller group in a relatively nonreverberant restaurant. They mathematically adjusted the model to compensate for the recording environment and processed the sounds to simulate a large number of diners occupying tables situated around the room making noise at different volumes.

Long and thin Kroon Hall, at Yale University, is organized around a skylit stair that connects the building's four floors. The configuration, combined with the building's ventilation strategy, posed a potential noise-transfer problem between the central circulation space and flanking offices.

Photos: © Morley von Sternberg (top); Robert Benson (bottom)



KROON HALL SUSTAINABLE STRATEGIES DIAGRAM

1 Mixed-mode ventilation
2 Photovoltaics
3 External shading
4 Displacement ventilation
5 Exposed thermal mass
6 Over-door ventilator
7 Exhaust air

With auralization of Peabody Essex serving as a point of reference, the consultants constructed an acoustic model of the MFA scheme. They studied the information garnered from the model to understand the effect of the proposed geometry and materials. They repeated the auralization process, simulating the sound of the unbuilt space with various sound sources and levels of acoustical treatment.

As a result of this benchmarking, analysis, and simulation process, the museum's trustees and the architects reached a consensus that the room would need an average coefficient of absorption of 0.3 at midrange frequencies and a total absorption of about 16,500 sabins (one sabin represents the amount of absorption provided by one square foot of perfectly absorptive material). The ultimate solution included incorporating most of the required acoustic material in the ceiling as part of elements that also help control heat gain and glare: a central band of perforated V-shaped metal baffles running through the center of the space and into the galleries, with translucent panels made of two layers of microperforated vinyl on either side. Glass fiber concealed within column enclosures (where sophisticated speakers are also hidden) and wood fins on an existing masonry wall provide additional sound absorption.

Tolerable transmission

Though most often used to render room acoustics, auralization can also be deployed in other areas of concern to architectural acousticians, including sound isolation between adjacent spaces. Auralization played such a role at Kroon Hall, a building for the Yale School of Forestry completed on the university's New Haven, Connecticut, campus in the spring of 2009.

Designed by London-based Hopkins and the Connecticut firm Centerbrook, with Arup providing multidisciplinary engineering, the long and thin four-story structure is organized around a slotlike stair that cuts through a narrow, skylit atrium. The LEED Platinum–certified building contains many coordinated, aggressively green features, including a mixed-mode ventilation system that supplies fresh air through a raised-floor ventilation system and, depending on the season, operable windows. The system exhausts return air passively through the central atrium, creating a potential privacy issue, since telephone calls or faculty-student conversations might travel from private offices flanking the atrium through vents positioned over doors.

In response, the architects devised a custom U-vent for the office-door transom. However, the proposed assembly allowed an unacceptable level of sound transfer. As an alternative, Arup suggested an advanced off-the-shelf vent, roughly equal in price to the custom solution. The device still allowed some sound to travel through the partition, but it significantly improved the assembly's sound transmission class, or STC, a rating of how well a building component attenuates airborne sound. An auralization convinced Yale officials that the sound of voices coming from offices would be barely audible to anyone standing nearby.

Auralization can similarly be applied to curtain-wall design, helping designers evaluate an assembly's ability to block the noise of a busy highway or a nearby airport. Or it can be used as an aid for evaluating noise-control options for a particular piece of mechanical equipment. But regardless of the application, practitioners of the technique say that it is a powerful decision-making tool. "To both architects and users, auralization conveys the efficacy of an acoustical strategy," says Markham. "It allows them to understand what we are recommending and why."

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