# Aural Architecture

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▸ The audible experience of space and sound exists simultaneously; each communicates its own message; each has its own language; each influences the other. Most people focus on how spatial acoustics changes sound, ignoring the reverse direction: sound makes the contents and geometry of a space audible. The acoustic properties of a space interact with sound sources in a dual way. On the one hand, spatial acoustics changes our experience of sounds because we hear those sounds only after spatial acoustics have changed them. For example, a clarinet sounds different when played at a beach versus in a concert hall. On the other hand, sound allows us to experience spatial acoustics directly. We hear the emptiness of an uninhabited house, the depth of a cave, the nearness of a low hanging ceiling, the refinement of an office with expensive carpets, and the density of a city with cavernous avenues. In these cases, we say that sound sources *"illuminate"*[1] audible properties of space.

*Aural architecture*[2] is the composite of those spatial properties that have an audible manifestation. Spatial acoustics produces dozens of audible cues that can be detected, decoded and interpreted, and when listeners attend to those cues, they are engaging in *auditory spatial awareness*. Those audible cues can produce emotional responses, such as elevated intimacy. Cues can influence behavior, such as choosing a distance for aural privacy; cues can be perceived as recognizable sounds in themselves, such as echoes and reverberation; cues can be experienced as a manifestation of the spatial geometry, such as spatial volume or remote walls; cues can be experienced as an extension of sound sources, such as an organ in a church.

The *soundscape*[3] is the simultaneous experience of both the sound sources modified by spatial acoustics and the spatial acoustics illuminated by sounds. For example, the soundscape of a forest is the combination of bird songs and forest acoustics.[4] The forest changes our audible experience of bird songs, and the sounds of the songs illuminate the acoustics of the forest. Generally, people are aware of sounds in a soundscapes without also recognizing the contributions of aural architecture. In the visual world, a landscape is the combination of light sources and the objects being illuminated.

A non-linear reverberation time of 1.8 seconds or a sea of enveloping sound? In contrast to aural architecture, acoustic architecture is the physical properties of a space described in the scientific language of sound physics. Aural architecture uses the language of human experience, while acoustic architecture uses the language of physical measurable properties. By focusing on aural architecture, we become aware of the range of emotions experienced by inhabitants in a space: intimacy, anxiety, isolation, connectedness, arousal, warmth, and a sense of spirituality.

From the perspective of the inhabitants, space is experienced as the fusion of inputs from eyes, ears, nose, and skin, together forming a composite awareness of place. Every environment has a sensory architecture of place.[5] The answer to the question, "where are you?" thus depends on which sense is being emphasized. Moreover, as the inhabitants move through a space, they experience the space as a sequence of sensory experiences and not as a static image.[6]

Each sense creates its own experience of space, but the sensory representations of space are mostly aligned in real life. Inconsistencies, however, have great value in an artistic context where artists routinely create spatial surprises and contradictions. In a cinema, the audience may see a vast open beach, while hearing music with a flute playing in a bathroom. The effect can be powerful, yet remains unnoticed at the conscious level.

Long before modern civilization, human beings demonstrated an awareness of aural space and it's relation to visual space. Acoustic archeologists[7] suggest that the Paleolithic art found in the caves of Lascaux and Font-de-Gaume were influenced by the acoustic character of the chambers in which they were drawn. Pictures of bison and deer were more likely to be found in chambers with strong echoes, spaces whose acoustics created percussive sounds similar to the hoof beats of a stampeding herd.[8] Cave artists may well have consid-

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[1] The word *illuminate* is borrowed from the visual domain because there is no corresponding vocabulary to describe the aural equivalent. Just as light illuminates objects and geometries to provide a visual experience of them, sound illuminates objects and geometries to give them an audible manifestation.

[2] For more information about aural architecture, consult our book (Blesser, B. and Salter, L., Spaces Speak, *Are You Listening? Experiencing Aural Architecture.* Cambridge; Ma.: MIT Press, 2006) and visit its companion web site www.SpacesSpeak.com

[3] The concept of a soundscape was first formulated by Schafer (Schafer, R., 1977. *The Soundscape. Our Sonic Environment and The Tuning of the World.* New York: Alfred Knopf), and then extended by Truax (Truax, B., *Acoustic Communications.* London: Ablex Publishing, 2001) and others.

[4] Forests have their own unique form of reverberation, which is different from that of enclosed spaces (Richards, D. and Wiley, R., *Reverberation and amplitude fluctuations in the propagation of sound in a forest: implications for animal communications.* American Naturalist, 115, 1980, pp 381—399), and musicians have taken advantage of its uniqueness for concert venues (Rother, L., *Adventures in opera: a "Ring" in the rain forest.* New York Times, May 9, 2005).

[5] Sensory architecture is the composite of all sensory experience. See for example Pallasmaa, J. *The Eyes of the Skin. Architecture and the Senses.* London: Academy Group. 1996.

[6] See Thiel, P., *People, Paths, and Purpose.* Seattle: University of Washington Press, 1996.

[7] Acoustic archaeology is a recent field where researchers explore artifacts to construct how ancient people might have used the aural properties of their space. However, because sound does not leave any artifacts, plausible conclusions remain as speculations.

[8] See Clottes, J. and Lewis-Williams, D., *The Shamans of Prehistory. Trance and Magic in Painted Caves.* New York: Harry Abrams, Inc., 1996; Lubman, D., *Acoustics at the shrine of St. Werburgh.* Presented to the 148th meeting of the Acoustical Society of America, San Diego, 2004; and Waller, S., *Sound and rock art.* Nature 363(6429), 1993, pp. 501., for examples of acoustic archaeology.

ered echoes as a supernatural phenomenon that brought life into the visual images. Extensive observations of ancient sites support the notion that wall art and acoustics were coupled in people's minds.

A more careful examination of aural architecture throughout history shows that the role of hearing depends on cultural values, micro-culture activities, and individual life-styles, rather than being dominated by the neurobiology of our species. The African Hausa people [9], for example, recognize only two senses: seeing and experiencing life, which itself encompasses intuition, emotion, smell, touch, taste, and sound. They use vision primarily for avoiding obstacles. In western culture, we collapse our awareness of vibration, temperature, and texture into the single sense of touch, rather than considering them as three separate senses.

See Stefan Kölsch: Trigger to flight and ability to speak, Page 180

## Spatiality is not Space

In order to avoid the scientific language of physical descriptions, we created the concept *spatiality*, which is the social, psychological, and behavioral experience of space by listening. We have identified five types of aural spatiality: social, symbolic, navigational, aesthetic, and musical. Because spatialities exist from the point of view of the listener, they represent an experience of space that is quite different from the usual description of how physical geometry changes sound waves.

**Navigational spatiality** is the aural experience of space that allows an individual to "visualize" [10] a space in order to navigate around objects and geometries of the space. Using aural cues for this purpose has been called echolocation. [11] Even without special training, almost everyone can hear a nearby wall because the low frequency energy of ambient noise is boosted near its surface. Similarly, a large pillar creates a sharp acoustic shadow at high frequencies for those sonic events that are obscured by it. Small objects at modest distances create low level echoes. A small bathroom has resonances that give a clear indication of its size.

Some blind individuals have refined the art of "seeing" space by careful listening; the French philosopher Diderot first reported in 1749 how a blind friend described to him which cabin doors were open in the room. [12] In laboratory studies, some individuals could distinguish square, circular and triangular objects by listening. [13] The American Dan Kish [14], blind from childhood, tought himself to ride a bicycle by using an echolot systems through clicking his tongue–now he teaches blind teenagers to go on bicycle trips in the mountains. [15]

Those with normal vision are unlikely to depend solely on hearing to move through a space, except perhaps in unavoidable darkness. Nevertheless, navigational spatiality is an important supplement to vision even if not consciously appreciated. Human beings are not unique in this respect. A large number of species use their hearing for sensing objects and geometries. Bats, with specialized auditory neurobiology and matching vocalization structures, are experts at using sound for visualizing space, but other species use auditory spatial awareness of background sound to visualize objects and geometries. [16]

The ability to use navigational spatiality as an alternative to vision illustrates a critically important concept. Blindness by itself does not enhance navigational spatiality, but a visual disability provides motivation to use acoustic cues (which are generally ignored) as part of a cognitive strategy to visualize the external world. Learning is therefore central: our brains respond to the way we live. By the age of 20, a young adult would have spent well over 100,000 hours listening to the sonic cues of space. In a similar way, music conductors acquire improved sensitivity to localizing at the periphery, and acoustic engineers who develop concert halls can hear small shifts in frequency response corresponding to distant surfaces. But almost anybody disposes of simple means of navigational spatiality. Try walking towards a wall with your eyes closed and stop before hitting it. Many people can do it on the first attempt, since the wall changes the audible spectrum of background sounds.

**Social spatiality** is the experience of a space in terms of its influence on social behavior. Hearing provides an important sensory connection to other people, which is strongly influenced by the auditory properties of the space. For example, diners at a restaurant who wish to converse are forced to sit very close to each other if the space amplifies background noise. In this case, social distance is controlled by reverberation. In order to fully appreciate the nature

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[9] See Ritchie, I., *Fusion of the faculties: a study of the language of the senses in Hausaland.* In D. Howes, (ed.), *The Varieties of Sensor Experience.* Toronto: University of Toronto Press, 1991.

[10] Again, language does not provide us a good word for the creation of an internal view of the external world using sound. The obvious choice, auralize, which parallels visualize, has already been used by audio engineers to mean the synthetic creation of a sound field that matches some real or contemplated environment, as to auralize a proposed concert hall design.

[11] Echolocation is an incorrect word that was created at a time when scientists believed that auditory spatial awareness relates to the perception of echoes, having observed that bats have a special vocalization system to produce unique sounds. However, many animals simply use background sound to illuminate the environment.

[12] Diderot, D., *Letter on the blind.* In *Early Philosophical Works*, reprinted 1972, New York: Lenox Hill Publishing, 1749.

[13] See Rice, C., *Human echo perception.* Science 155, 1967, pp. 656—664, and Hausfeld, S., Power, R., Gorta, A., and Harris, P., *Echo perception of shape and texture by sighted subjects.* Perceptual Motor Skills 55(2), 1982, pp. 623—632., for examples of detecting small objects by listening.

[14] See a discussion of his experiences in Kish, D., *Evaluation of an echo-mobility program for young blind people.* M. A Thesis at California State University, San Bernadino, 1995 and Kish and Bleier (Kish, D. and Bleier, H., *Echolocation: what it is, and how it can be taught and learned.* Presented to the Calif. Assoc. of Orientation and Mobility Specialists, 2000. Unpublished manuscript available at www.tiresias.org/research/publications/kish.htm

[15] Other famous blind people that were able to navigate through space without the help of a blindman's stick are the jazz musician Ray Charles and Ved Mehta from Calcutta. Like Daniel Kish, Mehta rode his bycicle as a blind child even through unfamiliar places and jumped from roof to roof. See Charles, R. and Ritz, D., *Brother Ray.* New York: The Dial Press, 1978, Mehta, V., *A donkey in a world of horses.* The Atlantic Monthly 200(1), 1957, pp. 24–30.).

[16] Hamsters (Etienne, A., Vauclair, J., Emmanuelli, E., Lançon, M., and Stryjenski, J., *Depth perception by means of ambient sounds in small mammals.* Experientia 38, 1982, pp. 553—555.), oilbirds (Griffin, D., *Listening in the Dark.* Ithaca N.Y.: Cornell University Press, 1986), and rats (Riley, D. and Rosenzweig, M., *Echolocation in rats.* Journal of Comparative and Physiological Psychology 50, 1957, pp. 323—328.) are a few examples of species that use some form of auditory spatial awareness for navigating through a space, especially in the absence of light.

of social spatiality, we must consider the concept of spatial delimiters in a new way. These are traditionally considered to be physical boundaries that are visually apparent and influence movement through a space. Boundaries that consist of physical surfaces are tangible, readily apparent, and often have legal meaning. In contrast, sound is associated with invisible boundaries that demark the region within which a listener can hear people and events. This is an experiential delimiter, rather than a physical barrier.

From the perspective of a listener, every sonic event that can be recognized is located within an acoustic horizon, which parallels the visual horizon. Beyond the acoustic horizon, sound sources are inaudible; it functions as an invisible boundary that partitions the space. People beyond the horizon cannot communicate with the listener. In the complementary view centered at the sound source, an acoustic arena is the area in which people can hear that source. An acoustic channel is established whenever a listener can hear a sound source. Acoustic horizons, arenas, and channels are three views of the same situation. From a social and emotional perspective, a listener is deaf to all sonic events that are beyond his acoustic horizon and where there is no channel to such events.

The size and shape of an acoustic arena is complex, depending on many considerations: the intensity of the sonic event, the acoustics of the container, the cognitive abilities of the inhabitants, and the masking qualities of ambient sound or reverberation. Acoustic arenas may have unusual shapes. Curved walls can focus sound, thereby extending an arena in one direction while shrinking it in another. Reflecting surfaces act like amplifiers in certain areas of the space, while sound absorption shrinks arenas but makes more arenas possible in a given space. Before citizens of towns acquired information technology, the natural aural architecture of the environment was a dominant component of social cohesion. For example, citizenship was based on the ability of an individual to hear the bells of the town.[17]

Arenas are experiential regions, not necessarily tied to a physical reality. Consider the case of an individual talking on a cell phone while driving a car. Physically he is in his car, while experientially he is sharing an acoustic arena with his conversation partner, and that arena may dominate the arena of the automobile and surrounding traffic. A person can switch among several acoustic arenas at once while never physically moving: he can listen to a conversation directed at him by his neighbour, overhear a conversation among individuals standing nearby, and register the sound of the doorbell. An acoustic arena can be huge, such as the public address announcements in a large train station with a domed roof. It can be very small, such as when the noise of an urban street masks the sound of a walker's own footsteps.

Rules for the use of acoustic arenas are known. Often they match the culturally determined rules for using physical distance as an expression of social relationships that Edward Hall, a social anthropologist, called *proxemics*.[18] To remain with the example of the restaurant: if spatial acoustics amplifies ambient noise, the acoustic arena becomes smaller than the appropriate distance for a collegial relationship. Then they have three unpleasant choices. They can sit at the appropriate distance and not converse; they can sit at a distance corresponding to an undesirably intimate relationship; or they can shout, which is experienced as aggressive.

**Symbolic spatiality** is the experience of those aural attributes that have acquired additional meaning by being associated with activities occurring within particular spaces. Over time, the acoustic properties of spaces, like national monuments or religious spaces, become linked to the symbolic meaning of those places. In the same way, visual symbols acquire their meaning, becoming icons. By symmetry, aural symbols are *earcons*.[19] Any form of memorable acoustics coupled with important events can, with repeated exposure, become associated with the meaning of a particular place.

Consider the enveloping reverberation of a grand cathedral, which acquires religious symbolism. Similarly, the unique acoustics of forests and mountains can become a symbol of nature; the hushed quiet of an elegant office can become a symbol of wealth; and the diffuse echoes of a vast office entry can become a symbol of power. The chirped echo produced by the staircases of the Pyramid of Kukulkan at Chichén Itzá is thought to have been a symbol of Quetzal, the sacred Mayan bird.[20]

**Aesthetic spatiality** is the experience of localized acoustics that provides varying auditory texture. Just as a window seat can provide visual aesthetics, an alcove also provides acoustic variety. Local regions within a single space would have different acoustics. Consider, for example, a wall composed of alternating resonant cavities, absorption panels, and reflective surfaces that change the experience of sound as one moves along its length. The domed ceiling in one region of a corridor at the Houston airport provides a surprising experience while walking through the space. Suddenly one hears a strong echo of footsteps. The change in acoustics creates a sense of a textured space. Similarly, plush upholstery and deep pile carpets create an aural sense of warmth, which arises because they absorb almost all of the high frequency sound energy; marble floors and glass walls create an aural sense of coldness, because they reflect and magnify the high frequency sounds. Just as a mirror expands the visual experience of size, sound absorption can expand aural space.

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[17] See Corbin, A., Village Bells: *Sound and Meaning in the 19th Century French Countryside*. Tr. M. Thom. New York: Columbia University Press., 1998 for an in depth analysis of bells in 19th century French countryside, which was probably very typical of villages through out the world.

[18] See Hall, E., *The Hidden Dimension*. New York: Doubleday & Co., 1966 for an overview of social distances and proxemics.

[19] The concept of an earcon originally arose from specialized sounds in computers that were used for signaling events. It has since been extended to match the visual concept of an icon.

[20] See Lubman, D., *Archaeological acoustic study of chirped echo from the Mayan pyramid at Chichén Itzá*. Journal of the Acoustical Society of America, 104, 1998, pp. 1763, and extended versions at www.ocasa.org/MayanPyramid.htm and www.ocasa.org/MayanPyramid2.htm

Contemporary artists create artwork whose impact in part depends upon changing the sounds around and within them. Eusebio Sempere created the visual equivalent of colored glass prisms: a sculpture composed of a three-dimensional array of polished stainless-steel tubes that rotates at its base. In addition to its visual effect as the moving surfaces reflect in the sunlight, it is also a sonic filter that blocks transmission of particular frequencies. A listener on one side hears a tonal modification of those sound sources located on the other side.[21]

Even though spatial geometries and their embellishing ornaments are almost always considered from the perspective of visual aesthetics, they usually have an aural manifestation as well. However, the aural experience is almost always an accident, an unintentional byproduct of visual design (Brandlhuber). For example, extensive flat surfaces and rectangular geometries may enhance the visual aesthetics of simplicity and clean lines, but they also create strong, and often unpleasant resonances. Domed ceilings and circular walls, while visually impressive, create disconcerting echoes and collapse widely separated physical regions of space into a small acoustic arena. Visual clutter, such as statues, chandeliers, nooks and crannies, can block visual sight lines while also creating diffuse sound fields.

**Music spatiality** represents those acoustic aspects of a space that influence the music performed within that space. While there has been more than a century of research into what makes a concert hall high quality, the focus has been primarily on a detailed analysis of physical acoustics and perceptual psychology rather than on the musical consequence of spatial attributes. When we take a fresh look at musical spatiality, however, we observe that it is composed of only two primary attributes: *temporal spreading* and *spatial spreading*. Although both arose simultaneously in a classical 19th century concert hall, with today's prevalence of modern recordings and computer assisted music, the two forms of spreading are independent.

First, reverberation changes the time structure of music by extending the duration of all musical notes. Reverberation and surface reflections serve to produce temporal spreading. Many instruments can only create sequential notes without any means of achieving chords. Consider a sequence of three notes from a clarinet played in a reverberant space. The pitch of the first note continues as reverberation while the second is being played; and when the third note is played, the pitches from the first and second note are still present as reverberation.

Western classical music requires reverberation. The violinist Isaac Stern said that "as the [violinist] goes from one note to another the previous note perseveres and he has the feeling that each note is surrounded by strength. When that happens, the violinist does not feel that his playing is bare or 'naked'—there is a friendly aura surrounding each note." Similarly, organ music without reverberation sounds dreadful because an organ pipe's valve is an on-off device with no intermediate intensity.[22]

Second, reverberation envelopes the listener in an ocean of sound arriving from all directions; this contrasts with the direct sound, which is perceived as coming from a musician located on stage. A sound source generates an initial spherical wave, which can be decoded by the binaural processing of the auditory cortex, as having a well-defined location. In contrast, when in enveloping reverberation, the listener is within the resonant cavity that creates the sound. He is inside the acoustic process. Spatial acoustics transforms a single sonic event on stage into a non-localizable sound that has no apparent location, hence, spatial spreading. The visual analog corresponds to a spherical room with surfaces of frosted glass illuminated from behind with a uniform light.

While the artistic pleasure of enveloping reverberation is recognized, there is no scientific explanation about how it contributes to the enjoyment of a concert. From a biological and evolutionary perspective, our binaural ability to localize prey and predator had important survival value. Conversely, the inability to localize would have produced increased anxiety, awareness, and arousal. A sonic event that cannot be localized is evaluated differently from one that has a location. For example, a fire truck's siren in a city produces anxiety because the acoustics of many cities prevents a driver from localizing the source. Experiencing enveloping reverberation can be considered *aural caffeine*, a stimulant. Any sound that has attributes that could signal danger unconsciously elevates biological arousal even though our cognitive and conscious experience subsequently dismisses that possibility.[23]

See the Sonic Effect "Ubiquity", p. 150

To more fully appreciate musical spatiality from the perspective of simulated virtual spaces, we need to review the history of musical spaces. The acoustics of cathedrals originated when walls were added to the open air Greek basilicas in order to provide isolation from the weather and to isolate the space from the rest of the town. Similarly, concert halls originated in the music rooms of the 17th century taverns of England where the walls served to isolate the inhabitants from street noise and uncertain weather. In both cases, spatial acoustics were an artifact of social forces unrelated to musical spatiality.

See Steinke, Herzog, Berliner Philharmonie, p. 124—125

The temporal spreading contribution of an enclosed space is actually part of musical instrument design. Spatial resonance of the performance space adds to the other cavity resonances of the instrument, which contribute timbre, pitch, and decay rate. A clarinet without a space might be called a proto-clarinet, and within a particular space it then becomes a meta-clarinet.

Musicians, when abandoning the open spaces of town and streets, needed to adapt to the acoustics of enclosed spaces, which varied greatly. Up until the mid 20th century, a musical space was a single environment for both listeners and performers who shared a common social space. Today, by splitting the

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[21] Sempere's pipe sculpture is part of the collection of Fundación Juan March in Madrid, and can be seen there.

[22] The famous organist, E. Power Biggs, wrote that "an organist will take all the reverberation time that he is given, and then ask for a bit more, for ample reverberation is part of organ music itself."

[23] For a compelling explanation of how unexpected sound attributes stimulates arousal and attention in the context of music see: Huron, D.: *Sweet Anticipation*, Cambridge, Ma.: MIT Press, 2006

creation of music from the listening experience, we now have multiple unrelated spaces and shifts in time. Music can be created in a recording studio, and spatiality is added with specialized signal processing equipment. Listening is distributed across a wide range of environments, from the home theater to portable headphones. This split also decouples temporal and spatial spreading. The former is created in the recording studio, and the latter is controlled by the listener's choice of reproduction technology.

The sonic arts of the 21st century are no longer dependent on a physical space to add the experience of spatiality. Like M. C. Escher's painting of an imaginary space with interwoven staircases that simultaneously lead upward and downward, aural artists also have the freedom to construct contradictory spaces. Space, and hence musical spatiality, becomes playable, like any musical instrument. When a recording engineer adds spatial attributes to each instrument, he is functioning as an aural architect of virtual spaces.

As a conclusion, we can say that historically, spaces were rarely designed by aural architects. Aural architecture is dynamic because it is strongly influenced by the inhabitants who create those sounds that illuminate objects and geometries. The inhabitants of a space also change the amount of absorption, which influences reverberation and spatial amplification of sounds. Nevertheless, even without having full control over aural architecture, professional designers can influence the experience of a space by being aware of how the inhabitants relate to the five types of spatiality. Consider that aural boundaries are dynamic, walls are not. And finally, we note that aural architecture cannot be captured in books to be used as a part of a professional portfolio. ■