PRANA: SOUND AND BREATHING IN ARCHITECTURE, AN INTERACTIVE SOUND INSTALLATION AT WAT UMONG, CHIANG MAI

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Abstract

Background and Objectives: Architectural spaces are often designed with a strong visual focus, yet their sonic potential remains underexplored. Inspired by the concept of "breathing" that symbolizes life, movement, and vitality, the research project *Prana* aimed to create a responsive sound installation that enhances the sonic environment in architectural spaces by utilizing efficient wireless communication, sensors, and algorithms, which can evoke the feeling of breathing life into a space, providing visitors with a novel and engaging sensory experience. The designed system offered flexibility for placement and adaptation across various locations. Conducted within the tunnel of Wat Umong in Chiang Mai, Thailand, the exhibition was presented to the public, and the author collected data from visitors for the evaluation. This project serves as an example of how interactive sound design can revitalize architectural environments by creating a dialogue between sound, space, and audience.

Methods: The study adopts both research-led and practice-led approaches, examining the interplay between technical design and aesthetic expression. The author collected ideas and designed the technical process of developing interactive sound installation, environmental sound design, multi-channel sound system, and wireless communication to develop the installation. The process of developing and installing the work was closely documented, while visitor experiences were assessed through direct observation and questionnaires during the exhibition period for the evaluation. The collected data was analyzed and presented as results in two aspects, sound design and system design.

Results: The sound installation utilized microcontrollers (Arduino) and radio transceivers to process signals from two selected sensors (photoelectric sensor and electric gyroscope) encapsulated in small bells as triggers for algorithmically projecting prepared sounds through a multichannel sound system. The electric gyroscope has been proven to be more effective in representing the movement of the bell in the form of digital data. The collected data from the exhibition reveals that a coherent relationship between sound installation, spatial context, and environmental soundscape forms a vital foundation for innovative sound design. Audience responses emphasized that engagement and satisfaction largely depend on the immersive and experiential qualities of the work, highlighting the significance of site-responsive experimentation and clear design intentions.

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Conclusions: The *Prana* project demonstrates how interactive sound design can meaningfully enrich architectural environments by integrating technology, spatial awareness, and aesthetic intention. The findings show that when sound, space, and audience interaction are thoughtfully aligned, architectural settings can be transformed into dynamic, sensory experiences that evoke vitality and presence, much like the metaphor of breathing that inspired the work. Technically, the use of microcontrollers, wireless communication, and motion-based sensing proved effective in creating a flexible and responsive sonic system, with the electric gyroscope offering particularly reliable data for movement-triggered sound generation in this project. Audience feedback confirmed that the success of such installations depends not only on technological capability but also on the experiential coherence and immersion they create. This highlights the importance of site-specific testing, deliberate sound selection, and a clear conceptual foundation. Ultimately, the project offers a practical and artistic framework for future interactive sound installations, highlighting how responsive technologies can animate architectural spaces and foster deeper engagement through sound. Furthermore, developing simple and user-friendly interfaces can extend the accessibility of interactive sound installations.

Keywords: Site-Specific Sound Installation / Sound Environment / Arduino Microcontroller / Wat Umong

Introduction

The author was deeply interested in the interplay of sound and space, noting how modern innovations have enhanced architectural structures with colorful lights, yet often lack corresponding sonic vitality. Recognizing this gap, the author was inspired to develop a sound installation system that could enrich the auditory environment of architecture. By utilizing efficient wireless communication, sensors, and algorithms, the designed system offered flexibility for placement and adaptation across various locations. An exhibition was conducted to evaluate visitor satisfaction and gather insights on the effectiveness of the designed sound and system. Inspired by the concept of “breathing” that symbolizes life, movement, and vitality, the work aimed to create a responsive acoustic environment that evokes the feeling of breathing life into a space, providing visitors with a novel and engaging sensory experience by enhancing the sonic environment in architectural spaces, exemplified by a proposed installation within the historic Wat Umong temple in Chiang Mai.

Research Project Objectives

1. Study design approach for sound installations to enhance the acoustic environment and visitor satisfaction.
2. Study sound system design, sensor selection, and algorithmic design to create a connection between the acoustic environment, visitors, and the exhibition space, providing a unique experience for visitors.
3. Display a sound installation to assess visitor satisfaction and experience. Knowledge gained from the creation and display is then compiled and presented as guidelines for designing and creating sound art installations for architecture for those interested.

Research Methodology

1. The study gathers concepts, theories, or processes to analyze and identify appropriate approaches to creating sound installations as a research-led practice.

2. The practice-led research process during the creation of the work involves experimenting with the system design and sound design. They allow for the collection of knowledge, concepts, or practices derived from experiments, problem-solving, and also the responses from visitors for the evaluation.

3. The results are then analyzed to draw conclusions on key relevant issues.

Literature Review

Art is often created to express ideas, using materials and communication as its tools. Its design usually serves a purpose. Many artists have explored the link between music, sound, and place, showing that music and architecture often enhance each other's beauty. For example, Giovanni Gabrieli wrote music that matched the shape of St. Mark's Basilica in Venice. Edgard Varèse's *Amériques* captures the feeling of New York City's towering buildings, while Jennifer Higdon drew inspiration from the city of Atlanta. Morton Feldman's music was influenced by the octagonal shape of Rothko Chapel, and Iannis Xenakis's works often reflect his deep interest in architecture.[1]

The relationship between a sound and the object or space that produces it is important for capturing the audience's attention.[2] Because we experience sound and sight together, the materials and shapes of a building can affect how we hear sound inside it. Sometimes the sound source itself can even inspire a design. Other times, the sound source might be carefully designed to fit perfectly into its surroundings or to stand out as something unique. Furthermore, Digital technology has made it possible to capture, edit, and manipulate sound using computers, which can generate different types of sounds, which may be from recordings of the atmosphere or movement in a place, to be fed back into the architecture.[3]

Yalcin Yildrim studied how people at the University of Mississippi feel about different sounds on campus. The study found that people enjoy natural sounds like running water, birds singing, and wind in the trees. But even though insects are part of nature, their sounds were not as well-liked. Urban noises, such as traffic and construction, were considered unpleasant. The university bell is one of the man-made sounds that is preferred by the participants.[4]

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[1] Philipp Oswalt, "Iannis Xenakis' Polytopes," *Contemporary Music Review* 21, no. 2-3 (2002): 35-44, https://doi.org/10.1080/07494460216658; John Wheatley, "The Sound of Architecture," *Tempo* 61, no. 242 (October 2007): 12-17, http://www.jstor.org/stable/4500554.

[2] Josep Llorca, "Virtual Reality for Urban Sound Design: A Tool for Architects and Urban Planners," in *Artificial Intelligence: Emerging Trends and Applications*, ed. Marco Antonio Aceves-Fernandez (London: IntechOpen, 2018), 188-189, https://doi.org/10.5772/intechopen.75957.

[3] Ted Sheridan and Karen Van Lengen, "Hearing Architecture: Exploring and Designing the Aural Environment," *Journal of Architectural Education* 57, no. 2 (November 2003): 37-38, http://www.jstor.org/stable/1425798.

[4] Yalcin Yildirim, "Soundscape Evaluation on Mississippi State University Campus" (Master's thesis, Mississippi State University, 2014), 101-124, https://scholarsjunction.msstate.edu/td/3997.

The use of multichannel audio has become common in sound installations and other creative settings. Sound designers have developed systems using multiple speakers to create more realistic and immersive listening experiences. This is prominently found in film, moving from single-channel sound to three-channel systems (left, center, right) and later to surround sound. Technologies such as Dolby Stereo, Dolby Digital 5.1, DTS, and Sony's systems expanded the number of channels, each improving sound quality and immersion. Beyond film, multichannel sound is now used in other environments, including airports, advertising, and art installations. Unlike film, these works often have smaller budgets and more creative freedom, with sound placement specifically designed for the space and experience rather than following the standards.

Early sound experiments also explored multichannel setups. Pierre Schaeffer used a five-channel system, and Karlheinz Stockhausen created works for four or more channels, even designing installations with over 50 speakers. Edgard Varèse's Philips Pavilion used hundreds of speakers built into the architecture, combining sound and space to create a unique experience. François Bayle's Acousmonium system, with over 80 speakers, is another example of multichannel audio designed specifically for sound art.[5]

Environmental sound design focuses on shaping how people perceive a place by using or modifying the sounds around them. Stevenson suggests that effective designs avoid repetition, emotional cues, speech, or music; instead, they should be minimal, purposeful, and attention-grabbing, often responding to changes in the environment.[6] Some artists use environmental sounds themselves as raw material. For example, Michael Fowler created soundscapes from recordings of Japanese gardens.[7] Max Eastley's *Warburg Building* used wind and water to create an evolving sound sculpture. It featured wind-driven flutes, reflective walls, pools, waterfalls, and hydrophones, all amplifying natural elements to transform the building's atmosphere.[8]

Sensors and computer technology play an important role in creating interactive sound art that responds to its surroundings and audience. Sensors can capture environmental or movement data, which computers then process to generate or modify sounds in real time, often using multi-channel systems. This approach, known as sonification, can translate data into sound through various methods, such as using sound symbols, triggering audio responses, or directly synthesizing sound.[9] Rainer Linz's wearable devices use different types

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[5] David Etlinger, "A Musically Motivated Approach to Spatial Audio for Large Venues" (PhD diss., Northwestern University, 2009), 37-53, ProQuest (3386530).

[6] Ian Stevenson, "Soundscape Analysis for Effective Sound Design in Commercial Environments," in *Proceedings of the Sonic Environments Australasian Computer Music Conference* (Brisbane: Australasian Computer Music Association, 2016), 73.

[7] Michael Fowler, "Transmediating a Japanese Garden through Spatial Sound Design," *Leonardo Music Journal* 21 (2011): 46-48, http://www.jstor.org/stable/41416822.

[8] Max Eastley, "Future Applications of Sound Art and Design to Architectural and Natural Environments," *Contemporary Music Review* 15, no. 3-4 (1996): 143-145, https://doi.org/10.1080/07494469600640641.

[9] Scot Gresham-Lancaster and Peter Sinclair, "Sonification and Acoustic Environments," *Leonardo Music Journal* 22 (2012): 67-70, http://www.jstor.org/stable/23343813.

of sensors (magnetic, motion, pressure, light, and more) to control artworks.[10] Other examples include Peter Sinclair's *RoadMusic*, which turns a vehicle's movements and camera data into sound, and Scot Gresham-Lancaster's *Trees and Vineyard on the Internet*, which converts data from tree sap flow into an online sound experience.[11]

Arduino is a microcontroller that can convert signals from sensors, process data, and send signals to other electrical devices. It can be used with the nRF24L01, a radio transceiver, to create a wireless network system for various purposes. By using the RF24Network Library, the system can have up to 781 processing nodes.[12] This allows for creating an efficient and effective wireless sound installation that can interact with the surroundings. In addition, programming software such as Max 8 can expand possibilities with the self-contained processing algorithms.

Wat Umong in Chiang Mai provided the exhibition site for this project. It is an ancient temple located at the foot of Doi Suthep Mountain. It is also a popular destination for both locals and tourists, boasting a long history and strong connections with the people of Chiang Mai. The tunnel inside the temple has four connected entrances and exits. There are holes in the walls for lighting lamps to provide light for the monks walking and meditating inside.[13] A mathematical study of the tunnel structure recorded the width, length, and height of the entire tunnel structure, demonstrating a non-symmetrical design with freedom to connect the tunnel elements together. The tunnel area near the west exit features mural paintings of various types of birds on the walls, including Chinese swans, peacocks, herons, cranes, and parrots, which alternate with floral patterns such as peony vines and lotus flowers. The northern tunnel, connecting the eastern entrance and western exit, depicts lotus flowers, clouds, and slate patterns. Scientific studies have revealed that the base color of the tunnel is red, often used to represent the sky in the Daowadueng heaven or the cosmic scene according to the Traibhumi cosmology. It carries auspicious meanings and is associated with miracles or special sacred events. The mural paintings in this tunnel are among the oldest in the Lanna culture.[14]

The Production

The production processes of the project include designing sounds, sensor integrated sound system, and an algorithm, that enhance the acoustic environment and create a connection between the exhibition space and visitors.

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[10] Rainer Linz, "Towards the Design of a Real-Time Interactive Performance Sound System," *Leonardo Music Journal* 6 (1996): 101-103, https://doi.org/10.2307/1513329.

[11] Scot Gresham-Lancaster and Peter Sinclair, "Sonification and Acoustic Environments," *Leonardo Music Journal* 22 (2012): 67-70, http://www.jstor.org/stable/23343813.

[12] "Newly Optimized RF24Network Layer 1.0.16," GitHub, accessed March 28, 2022, https://nrf24.github.io/RF24Network/.

[13] "History of Wat Umong," Wat Umong, accessed July 29, 2022, https://www.watumong.org/. (in Thai)

[14] Surachai Jongjitngam, Siriwan Kettapun, and Atichart Kettapun, *Research Project on Mural Paintings and Tunnel Structures at Wat Umong (Suan Phutthatham), Chiang Mai Province, Using Chemical and Basic Mathematical Methods* (Chiang Mai: Faculty of Fine Arts, Chiang Mai University, 2008). (in Thai)

Studies indicate that relaxing music can have a positive effect on humans, as it raises oxytocin levels in post-cardiac surgery patients.[15] Music has also been used across cultures for healing and spiritual purposes, for example, Native American drumming conveys social presence, Hindu mantras and ragas induce relaxation, and Buddhist devotional music with its gentle rhythms is believed to calm the mind and support spiritual practice.[16] Juslin further identified six mechanisms linking sound and emotion: expectation of musical progression, memory-based associations, cross-modal links with imagery, emotional contagion, conditioning through repeated experiences, and brainstem reflexes triggered by sudden sounds.[17] Building on these principles, the sound design of this research project seeks to foster relaxation and contemplation through the resonance of soft, surrounding environmental sounds projected within the tunnel.

The relationship between the murals and the acoustic environment was a key source of inspiration for the author. Since depictions such as birds shown in Figure 1, as well as clouds and flowers shown in Figure 2, relate closely to the natural surroundings, the author conceived the idea of using sound to connect the external environment with the paintings inside the tunnel. By incorporating acoustic elements that mirror ambient sounds and allowing them to move within the tunnel, the design seeks to create a pleasant and immersive auditory experience for visitors.



Figure 1 The painting of bird on the tunnel wall

Source: by author

[15] Mona Lisa Chanda and Daniel J. Levitin, "The Neurochemistry of Music," *Trends in Cognitive Sciences* 17, no. 4 (April 2013): 189, https://doi.org/10.1016/j.tics.2013.02.007.

[16] Nils de Mol van Otterloo et al., "Healing Power of Sound," *International Journal of Innovative Research in Medical Science* 1, no. 6 (August 2016): 254, https://doi.org/10.23958/IJIRMS/VOL01-I06/05.

[17] Patrik N. Juslin, "Seven Ways in Which the Brain Can Evoke Emotions from Sounds," in *Sound, Mind and Emotion: Research and Aspects*, ed. Frans Mossberg, Ljudmiljöcentrum skriftserie, vol. 8 (Lund: Sound Environment Center at Lund University, 2008), 20-21.



Figure 2 The painting of cloud and flower on the tunnel wall

Source: by author

The process of collecting sound recordings associated with architecture and murals aims to reflect the environmental and cultural context of temples while providing structured material for algorithmic sound synthesis in the project. Livingston emphasized that the design of architectural sound art should consider the surrounding environment to reflect the character of a place. He categorized environmental sound presentation into two types: sounds that blend seamlessly with the environment and sounds that are unusual, the latter requiring careful application. Reverberation provides a clear example, as it evokes the listener's imagination of space, with different materials producing distinct patterns of sound reflection.[18] The author collected four categories of sound recordings for integration into the work. Those include the sounds of the wind, various birds around the site, water dripping, and bells.

Wind sounds were drawn from 13 recordings of natural airflow (through trees, leaves, or vents), while urban noises such as vehicles and human voices were excluded. These sounds were refined into four files with similar structures and prepared for algorithmic processing. Water sounds were obtained from seven recordings,

[18] Hugh Livingston, "Listening in the Rose Garden," *Leonardo Music Journal* 26 (2016): 85, https://www.jstor.org/stable/26779226.

focusing on the slow, soothing qualities of dripping water without interference from background noise. These sounds were edited into four three-minute files, enhanced for interest, and categorized for sound synthesis. Bird sounds were collected from 19 recordings in the study area, isolating distinctive bird calls and avoiding urban noise. These sounds were processed into four longer files (each nine to ten minutes long) and four shorter files of distinct phrases, which were further enhanced and categorized for algorithmic use.

The tunnel is relatively dark and quiet, illuminated only by light bulbs along the corridors, which created an eerie atmosphere during exploration. Although occasional gentle winds passed through the space, they did not generate noticeable movement. To address this, the author developed sounds and a system designed to introduce a sense of liveliness within the tunnel. This design decision was inspired by the author's experience of hearing temple bells swayed by the wind, leading to the incorporation of bell sounds to convey the impression of wind-driven movement.

Bells and metal percussion instruments, such as gongs, hold both aesthetic and sacred significance in Buddhist practice, often serving as offerings.[19] Their use is widespread in temples, with historical records noting bells as ancient instruments in Mahayana Buddhism and in the inscriptions of King Ramkhamhaeng.[20] Reflecting these cultural and spiritual associations, the author recorded 27 samples of metal percussion instruments from Chiang Mai province. From these samples, only sounds that evoked calmness and satisfaction were selected, while extraneous noises, such as traffic, human activity, and incidental recording artifacts, were excluded. The recordings of short percussive strikes were then categorized, refined, and prepared for sound synthesis, with selected properties adjusted to ensure clarity and enhance auditory interest, making them suitable for further algorithmic processing.

Each of the four recording categories presents distinct frequency ranges and loudness levels, requiring further synthesis and enhancement to ensure clarity, balance, and suitability for playback through the sound system.

Wind recordings, often containing low-frequency noise from direct contact with microphones, were equalized to achieve a balanced frequency range and combined into continuous soundtracks. Using a compositional method similar to invertible counterpoint, multiple wind layers were arranged with consistent density. Water sounds, which exhibited a narrow dynamic range and low audibility, were processed with subtractive synthesis and vocoder techniques to emphasize key frequencies, reduce noise, and expand dynamic range. An additional echo was applied to enhance spatial perception, creating a clearer and more engaging auditory presence within the tunnel.

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[19] Theerawat Changsan et al., "Development from Belief and Faith to Creative Show 'Buddhist Bell Dance,'" *Narkbhutparitat Journal* 12, no. 1 (January-April 2020): 100. (in Thai)

[20] Sippavich Kingkaew, "Thai Musical Instruments in Sukhothai Period Literature," *Ramkhamhaeng Journal Humanities Edition* 41, no. 1 (January-June 2022): 190-191, https://so05.tci-thaijo.org/index.php/huru/article/view/260202. (in Thai)

Bird recordings posed the greatest challenge due to environmental noise and recording distance. Clear samples were selected, arranged into balanced soundtracks that reflected natural proportions of bird sounds in the environment, and equalized for playback. Short bird phrases were also extracted to provide variation and emphasis to the overall sound. Finally, metal percussion sounds, particularly bells, were recorded and processed to highlight their soft impact sounds, similar to the sound of wind blowing against each other. Vocoder synthesis and compression techniques were applied to eliminate noise, clarify resonance, and maintain consistency.

Through these processes, the recordings were transformed into coherent, noise-reduced, and aesthetically balanced sound materials, ready for integration into the installation.

Once the sound materials were prepared, the author designed a structure that combined these elements into a sequence of sound events over a period of time. The sound system and algorithm were then designed to create a response to the environment within the tunnel by collecting data from sensors and distributing the prepared sounds appropriately to the listeners in the tunnel. Structural freedom and temporal variation follow the principle of indeterminacy adopted by John Cage. And as mentioned by Liljedahl and Fagerlönn,[21] the work should not be annoying or boring. Looping sound is simple but difficult to surprise the listener. Artists can program an algorithm for a computer to automatically generate designed sound, though the artistic value should be considered over the technological process.[22]

The structure of the work follows a compositional approach similar to music, drawing from three primary sound groups (wind, water, and birds) that are linked to the mural paintings. These sound events are algorithmically generated in real time using environmental sensor data, making the outcomes indeterminate. The sequence begins with wind sounds, as their volume can be naturally varied, followed by water sounds, reflecting the association between wind and moisture, and finally bird sounds, representing life and movement. These sound events form cycles that may overlap or leave intervals, depending on the algorithm, ensuring variability and continuity in the work.

Wind flows periodically through the tunnel, potentially causing lightweight suspended objects to move. Measuring these variations was therefore a key objective and closely aligned with the concept of the work, *Prana: Sound and Breathing in Architecture*. The wind served as a central input for the algorithms designed to generate responsive environmental sounds.

To achieve this objective, the author developed sensor-integrated devices specifically adapted to the cultural and architectural context of the site. Bells, commonly found in temples, associated with wind and

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[21] Mats Liljedahl and Johan Fagerlönn, "Methods for Sound Design: A Review and Implications for Research and Practice," in *Proceedings of the 5th Audio Mostly Conference: A Conference on Interaction with Sound* (New York: Association for Computing Machinery, 2010), 2, https://doi.org/10.1145/1859799.1859801.

[22] Manuel Rocha Iturbide, "The Sound Installation," *International Conference on Mathematics and Computing* (2007): 20, http://hdl.handle.net/2027/spo.bbp2372.2007.114.

spiritual beliefs, and valued for their distinctive acoustic qualities, were chosen as the basis for this design. Custom-designed bells with built-in sensors were created to measure wind movement within the tunnel. Two sensor types were tested: a photoelectric sensor, as shown in Figure 3, and an electronic gyroscope, as shown in Figure 4. The collected wind data were transmitted to the algorithm, which generated corresponding bell sounds. These experiments served as a prototype for the final installation.

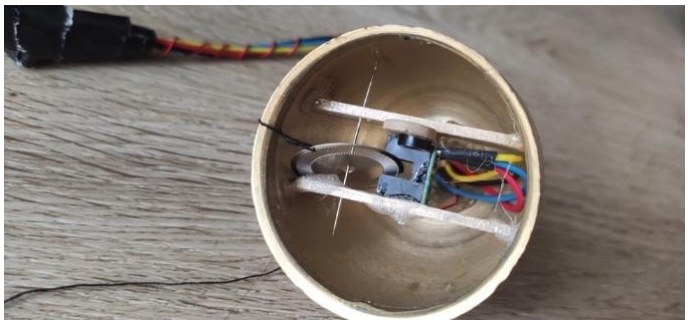


Figure 3 A photoelectric sensor installed in the bell

Source: by author



Figure 4 An electric gyroscope mounted in a bell

Source: by author

Receiving and converting signals from sensors into a computer requires a microcontroller as an intermediary. In this work, an Arduino microcontroller was employed due to its ability to process both analog and digital signals and transmit data efficiently to a computer via a serial connection. To enable wireless communication between sensors and the computer, as shown in Figure 5, the author designed a system using an nRF24L01 wireless transceiver, as shown in Figure 6, which operates on a 2.4 GHz radio frequency with a data transmission rate of up to 2 Mb/s. This wireless system allowed for flexible sensor placement throughout the exhibition space while maintaining a neat installation that did not obstruct visitor pathways.

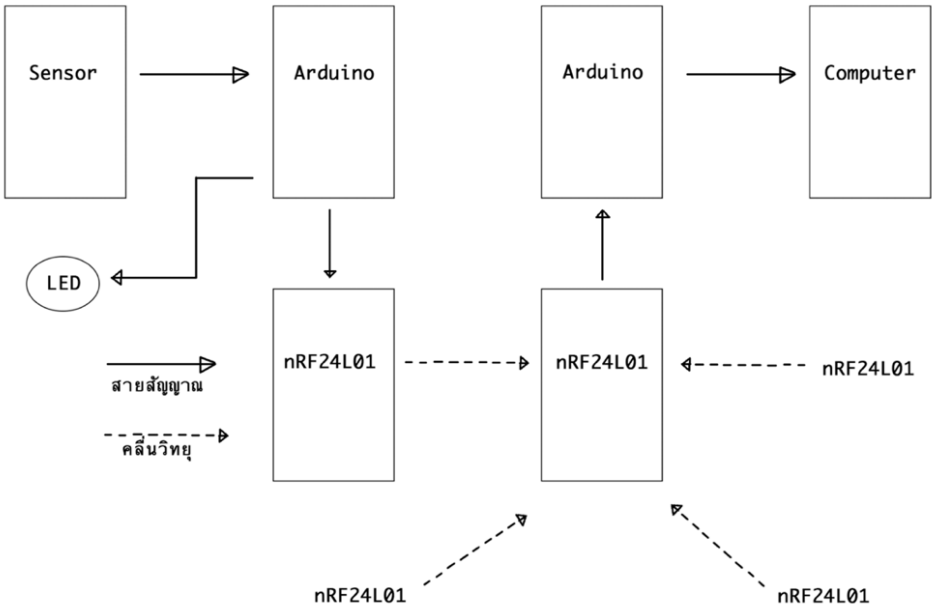


Figure 5 A prototype scheme of the communication system between the sensor, microcontroller, and computer

Source: by author

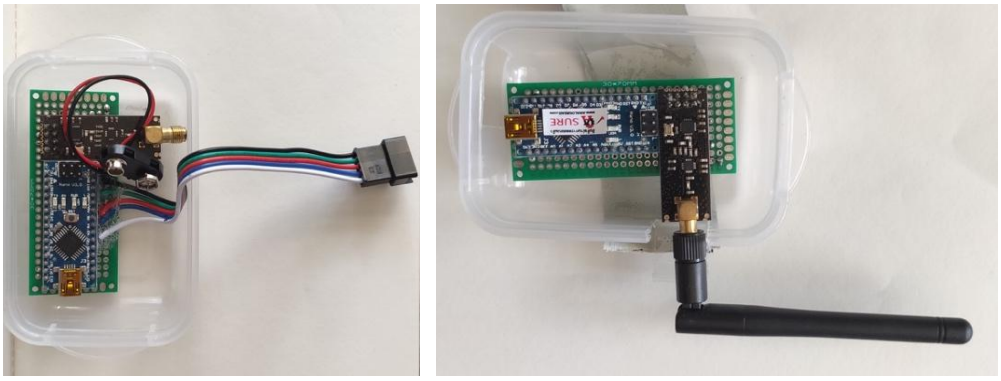


Figure 6 The wireless transmitter and receiver kits

Source: by author

The author tested and compared the performance of the two sensor systems. The photoelectric sensor, installed inside the bell, was found to be less effective. The movement of the yarn inside the bell was minimal, and at times the yarn's swaying caused the metal spokes to block the sensor's light beam for extended periods. This produced signal characteristics that did not accurately reflect the actual oscillation of the bell. In contrast, the electric gyroscope demonstrated a response that closely corresponded to the bell's true motion. By measuring rotational speed along all three axes, the gyroscope was able to capture the precise oscillatory behavior of the bell. This allowed the author to identify the specific numerical data transmitted to simulate the impact points, thereby representing the unique characteristics of each strike.

Using input from the electric gyroscope across the X, Y, and Z axes, the data were fed into the computer program, Max 8, to generate the sound for the work. The algorithm was designed to use specific sensor values

as triggers. These triggers randomly activated different bell sounds while simultaneously initiating a counter that sequentially played three groups of processed sound files (wind, water, and bird sounds) according to a predefined order. Increased sensor-detected movement resulted in additional triggers, which in turn activated more bell sounds and accelerated the overall progression of the work's sound cycle.

Speaker placement in sound installations can follow either symmetrical or free arrangements, each with distinct implications for perception and practicality. Symmetrical placement, commonly used in controlled environments such as cinemas and specialized sound art venues, allows for virtual sound source simulation but requires high precision and is sensitive to listener position, speaker type, and room reflections.[23] While effective under ideal conditions, this method is less suitable for general or irregular spaces.

Free speaker placement, in contrast, emphasizes spatial adaptability and aesthetic integration, prioritizing distribution from chosen points rather than virtual localization. Examples include Edgard Varèse's Philips Pavilion[24] and Stuart Jones's site-specific arrangements.[25] This approach is widely applied in exhibitions and installations due to its flexibility.

In the Wat Umong tunnel, the author tested both methods. Symmetrical placement proved impractical due to the tunnel's irregular proportions, architectural constraints, and visitor pathways, which led to obstructions and uneven sound distribution. Free, non-symmetrical placement, however, provided an orderly appearance, avoided interference with walkways, and enabled more consistent sound coverage. Although virtual positioning was only partially achieved, the method was deemed effective for the site, balancing acoustic, aesthetic, and logistical considerations.

The Exhibition

The exhibition *Prana: Sound and Breathing in Architecture* was presented at Wat Umong, Chiang Mai province, on October 13th, 20th, 23rd, and 30th, 2022. A short video clip showing parts of the exhibition can be watched using the QR code in the Figure 7. The work was installed in the morning, as shown in the Figure 8 and Figure 9. It was opened to the public from 12:30 to 16:30. Visitors were invited to complete a questionnaire, available both in print and online via Google Forms, which gathered their experiences, opinions, and suggestions. Participation was encouraged through project signage and introductory talks. In addition, qualitative data were collected through observation and informal semi-structured interviews conducted during the exhibition.

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[23] Nozomu Nishikawa et al., "The Spatial Real and Virtual Sound Stimuli Optimization for the Auditory BCI," in *2012 Conference Handbook - Asia-Pacific Signal and Information Processing Association Annual Summit and Conference, APSIPA ASC 2012* (Hollywood, CA: Institute of Electrical and Electronics Engineers (IEEE), 2012), 3-4.

[24] David Etlinger, "A Musically Motivated Approach to Spatial Audio for Large Venues" (PhD diss., Northwestern University, 2009), 44-45, ProQuest (3386530).

[25] Stuart Jones, "Space-Dis-Place: How Sound and Interactivity Can Reconfigure Our Apprehension of Space," *Leonardo Music Journal* 16 (2006): 22-25, http://www.jstor.org/stable/4540589.

Figure 7 QR code for a short video clip of the exhibition[26]

Source: by author



Figure 8 Photograph of the intersection area inside the end of the tunnel showing the placement of speakers inside the tunnel (camera facing north)

Source: by author



Figure 9 Photograph of the intersection area inside the end of the tunnel showing the placement of speakers inside the tunnel (camera facing southwest)

Source: by author

Throughout the exhibition, the tunnel and its artworks were constantly visited by both Thai and international visitors. The peak visitor time (10-30 people per hour) was between 1:00 PM and 3:00 PM. The author observed visitors without participation from outside the tunnel. Some interested visitors attempted to look for or ask about the exhibit organizers and interact with the author. By observing and talking with visitors, the author learned of the diverse feelings, opinions, and experiences of the visitors. Data were then recorded on visitors' reactions to the exhibition.

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[26] Arsid Ketjuntra, *Prana: Sound and Breathing in Architecture* (sound art exhibition, Wat Umong, Chiang Mai, October 2022), MP4 video file, Google Drive, last modified October 20, 2026, https://drive.google.com/file/d/1hJn7T2WT3CBHhiBjW78RG5VcPNxPuxnk/view?usp=drive_link.

The questionnaire consisted of six questions to explore visitors' experiences of visiting a sound art exhibition, their feelings of relaxation after visiting the artwork, their sense of movement within the space, their level of satisfaction with the experience, and their level of liking the sounds heard in the artwork. 29 respondents completed the Google Forms questionnaire (28 Thais and one foreigner). 23 respondents completed the printed version (17 Thais and six foreigners). The author compiled the questionnaires and organized the data.

Result

Data from the authors' records of experiences, problems, and findings during the production and exhibition, non-participant observation records, informal semi-structured interview records, and questionnaires regarding visitors' experiences, post-visit satisfaction, and preferences for the sound elements after visiting the exhibition were analyzed according to key areas, including sound design, sound system design, sensor selection, and algorithm design.

Among the sound elements, wind was the least preferred, reflecting both its limited uniqueness and weak connection to the tunnel's architecture, murals, and environment. Its continuity and minimal variation made it resemble background noise, reducing its appeal. Water sounds, by contrast, received higher ratings. Although not strongly tied to the tunnel context, the soft, intermittent dripping effectively modulated the acoustic space, producing a relaxing atmosphere that listeners could follow without fatigue. Bird sounds were highly recognizable, as they mirrored the natural environment surrounding the tunnel and corresponded to bird motifs in the murals. While some visitors expressed surprise at their similarity to real birds, preferences ranked third overall, suggesting that environmental familiarity did not strongly influence aesthetic preference. Bell sounds, triggered by electric gyroscopes responding to wind or touch, elicited active engagement. Many visitors experimented with touching the bells, a familiar behavior at a temple. Respondents often rated bells most highly, appreciating their gentle resonant qualities and the responses to the touching, especially visitors with prior exposure to sound art.

Visitor responses highlighted curiosity and engagement, with remarks such as "What are those sounds? Let's listen to them!" suggesting that the use of diverse, categorized sound materials effectively sustained interest. The structural sequencing of sounds, modeled on musical composition, also enhanced listenability by providing a sense of continuity.

Out of 52 survey respondents, 23 had prior experience with sound art. All reported feeling relaxed after the exhibition and noted that the sounds conveyed spatial movement. Satisfaction levels were high, with 46 respondents rating their experience at the highest level, five at the second highest, and one at a moderate level. Comments such as "The sound is so beautiful" and "I like the sound of the water" reinforced the positive reception, demonstrating that the sound design contributed meaningfully to both the aesthetic and experiential dimensions of the exhibition.

Some visitors misinterpreted the installation as part of a television recording, documentary filming, or temple activity, often due to the visibility of equipment such as speakers, sensor stands, and cables. While the sound system of *Prana* was intentionally designed to remain visible to respect the integrity of the historic temple tunnels, where no alterations could be made, visitor feedback frequently suggested that speakers should be hidden or minimized without compromising sound quality. This aligns with practices in sound installation, where dividing sound sources into full-range and high-frequency groups and using fewer, strategically placed high-powered speakers can reduce visual intrusion. Moreover, visible speakers were a source of dissatisfaction for some tourists who sought unobstructed photographs of the site, reinforcing the recommendation that future works consider discreet speaker placement to balance artistic intent with architectural aesthetics.

Visitor reactions were shaped by their experiences within the sound art exhibition. Most recognized the works as part of a research project, as indicated by information signage placed at both tunnel entrances; some expressed curiosity and engaged directly with the author. A group of Thai visitors inquired about the sound system and algorithms used, reflecting interest in the technical aspects of the installation. Interactive elements, particularly the bells, drew attention from both children and adults. For example, a young boy touched a bell and said, "It has lights," while other visitors, Thai and foreign, experimented with turning the bells upside down or asked questions, such as "How can I play it?" "How does it work?" and "What is this?," demonstrating curiosity and playful engagement. Some responses, such as "I will come back to play," suggested that visitors perceived the works as interactive activities as well as artistic experiences. Supportive comments, including "I really like it," "There should be more of them," and "I support (having more exhibitions)," further indicated positive attitudes toward the project. One foreign visitor expressed appreciation for the sensor system and stated, "I like it." Overall, while no visitors engaged with the deeper technical or algorithmic aspects of the work, their feedback highlighted interest in the novelty of using responsive technologies in an art context and affirmed the value of interactive sound installations.

Discussion

The *Prana: Sound and Breathing in Architecture* project integrated sound art design, sound system configuration, sensor technology, and algorithmic processes to investigate the relationship between sound, architectural space, and audience interaction. The creative process emphasized experimentation and problem-solving, demonstrating that the successful design of interactive sound installations depends on balancing technical implementation with artistic and experiential considerations.

The findings suggest several directions for future development. Interactive sound systems constructed from low-cost electronic components have the potential to support practical applications beyond artistic installations. However, broader adoption requires simplified hardware and software platforms that reduce the need for specialized knowledge in electronics and programming. Future research could therefore focus on developing modular devices and user-friendly software that improve accessibility and functionality. In addition,

the selection of sound materials should be guided not only by their contextual relevance but also by their psychoacoustic characteristics, ensuring that they enhance visitors' experiences while remaining consistent with the artistic concept.

Visitor feedback highlighted the importance of preserving the visual integrity of the exhibition space. Although the installation successfully demonstrated interactive sound design, visible speakers and cables were perceived as distracting elements that diminished the aesthetic quality of the architectural environment. Concealing technical equipment may strengthen the immersive experience. While the looping structure of the soundscape provided continuity, excessive repetition risked monotony. The incorporation of randomness and algorithmic variation effectively sustained listener interest and demonstrated the value of adaptive sound generation. The study also showed that careful sensor selection is essential during the design stage. Choosing reliable sensing technologies can reduce technical problems during installation and exhibition, allowing greater attention to artistic development. Furthermore, visual feedback integrated into the installation, such as responsive lighting, can reinforce the relationship between visitors' actions and the generated sounds, thereby encouraging greater engagement.

From a technical perspective, the wireless sensor transmission system developed using Arduino microcontrollers and nRF24L01 transceivers provided reliable 2.4 GHz communication at data rates of up to 2 Mb/s. This system enabled flexible installation layouts without obstructing visitor movement and demonstrated that wireless sensing can effectively support interactive sound installations. Beyond artistic applications, the system could also be adapted for fields such as environmental monitoring, local communication technologies, and healthcare.

Artistically, the bell sounds emerged as the conceptual and aesthetic focus of the installation, inspiring future exploration of multiple spatially distributed sound sources. Short, high-frequency sounds originating from different directions were particularly effective in creating a dynamic and immersive listening experience. While the current installation relied on computer-based processing for sound spatialization and audio effects, future works could employ embedded microcontrollers together with actuators such as servo motors or relays to generate sound mechanically. Such an approach could reduce production and exhibition costs while increasing portability and flexibility. Eliminating the dependence on a computer would also create opportunities for standalone installations powered by renewable energy, deployment in environments unsuitable for conventional computers, and the development of decentralized sound art systems.

Conclusion

The *Prana* project demonstrates the potential of interactive sound design to enrich architectural environments through the integration of technology, spatial awareness, and aesthetic intention. The findings indicate that when sound, space, and audience interaction are coherently aligned, architectural settings can be transformed into dynamic sensory experiences that convey vitality and presence, reflecting the metaphor of breathing that underpins the work. This study provides a practical framework for future interactive sound

installations and highlights their potential to foster meaningful engagement with architecture, particularly within the culturally diverse contexts of Southeast Asia.

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