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Article

The Biophilic Instrument Pavilion: Spatialisation across disciplines

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Abstract

This article explores biophilic (nature-centred) instrument design and its intersection with architecture and music. While the connection between these disciplines is often discussed figuratively, they are less often combined in practice. The Biophilic Instrument Pavilion (BIP), a site-responsive sound and light installation, serves as a model for such a collaboration using biophilic design as a unifying principle. This multidisciplinary project demonstrates spatialisation in ecological, sonic, visual and social contexts, offering insights into environmental instrument practices and collaborative creative processes.

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1. Introduction

The Biophilic Instrument Pavilion (BIP) is a site-responsive sound and light installation at San Luis Obispo, California. It is an interactive instrument inviting attunement to the natural environment using biophilic (nature-centred) design principles from both architecture and music. The BIP addresses the challenges of integrating an ecological approach into musical and architectural experiences by creating a semi-permeable interactive environment. It amplifies the natural environment by sonifying physical movement and lighting conditions using solar-powered embeddable sensors and microcomputers in tandem with dichroic (colour-filtering) light prisms. These components work together to reflect auditory and visual aspects of the surrounding canyon and exemplify biophilic approaches to musical instrument design.

In this article, we examine ecological connections within the disciplines of architecture and music. This includes interdisciplinary approaches to biophilic instrument design within environmental sound art and land art. These practices address space, interaction, collaboration and design from a multidisciplinary perspective and serve as conceptual and practical models for our collaborative approach.

2. Background

The term 'biophilia' was initially codified by Erich Fromm (1973) and subsequently popularised by Edward O. Wilson (1984). It denotes the affinity that humans have towards their environment – a heightened sense of wellbeing when connecting with the natural world. This notion was further explored in *Biophilic Design*, which maps the concept to specific design principles (Kellert et al. 2008). Architectural biophilic design principles prioritise the natural environment in the way that sunlight, plants, geographic features and seasonal weather patterns are incorporated into the built structure. These nature-centred designs consider the footprint of contemporary construction practices on the natural environment and its impacts on the climate. Such design principles are applied to wide-ranging projects, from individual homes (Minguet 2024) to city planning (Beatley 2017). Furthermore, the mental health benefits of these sorts of spaces are increasingly well documented, as seen for example in 'A Biophilic Architecture Typology for Mental Health' (Vickers 2021), 'Biophilic Architecture Used to Improve Patient Outcomes and Recovery in Behavioral Health Centers' (Valdez 2022) and 'Healthy Dwelling: Design of Biophilic Interior Environments Fostering Self-Care Practices for People Living with Migraines, Chronic Pain, and Depression' (Huntsman and Bulaj 2022).

While much is being written on biophilic architecture, there is considerably less investigation of biophilic practices in musical instrument design, despite ample research on the beneficial connection between nature and music (see following discussion). Material uses of nature in musical contexts often focus primarily on recorded soundscapes, which has been extensively explored (Schafer 1977; Truax 1996; Westerkamp 1996). Such works frame field recordings, the manipulation of nature sounds, and even listening itself as active components (Neuhaus 1966). While this work is invaluable, it can tend to fall into the categories of extraction or superimposition in that it either extracts a sound from its context in the environment or superimposes a narrative onto existing environmental sounds.

A discussion of biophilic instrument design must take a critical look at the interaction between music and the natural environment and the reciprocal exchange of materials therein. This includes investigating the materials with which music is made and their environmental implications. Such an approach not only decolonises the extractive practices of humans and their surroundings but also strives to establish a symbiotic relationship. In doing so, biophilic instrument design can capitalise on the established connections between music and nature. Recent studies explore the psychological link between awe-inspiring and spiritual experiences of nature and music by both adults and children (Silvia et al. 2015; Adams and Beauchamp 2019) and the advantages of cultivating

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active listening in immersive, spatialised sonic environments (Matthews 2019).

Digital musical instruments (DMIs) provide an opportunity for reframing interactions with the environment. Microcomputers and microcontrollers allow for portability and flexibility, especially when paired with solar power. Sensors can be used to track any number of stimuli, both human and environmental. When they are used in combination with embedded audio, diverse variations in the environment can be sonified – from atmospheric humidity to the temperature changes of a performer. This creates the potential to remap the relationships between composer, performer, audience and instrument using an ecological lens prioritising interconnections and engagement (Hunter 2021). Hayes and Stein offer a thorough example of how DMIs and ecology can intersect to invite interaction, build community and represent the history of a given place (Hayes and Stein 2018). To further a discussion of instrument design and ecology, the visual arts provide additional context.

Environmental art, or eco art, emerged in the 1970s as a movement concerned with the interactions between humans and the ecosystem. Originating from land art, it often incorporates sound and can serve as a connection point between architecture, concerning place, and music, concerning the sonic dimension (Kastner and Wallis 1998; Cheetham 2018). Eco art engages directly with natural forces, at times intervening in environmental processes. For example, Walter De Maria's *The Lightening Field* (1977) in New Mexico consists of 4,000 polished stainless-steel poles, designed to attract lightning strikes. The legacy of environmental art has continued resonance in sound art and instrument design.

Environmental sound art highlights the potential for sound to impact both the ecological and the social. In *Exploring the Ecologies of Music and Sound*, Makis Solomos (2023) positions artists as influential across environmental, mental, and social ecologies. These three ecologies were initially proposed by Guattari (1989) and expanded by Solomos in the context of music and sound art. Solomos emphasises the importance of studying 'how artistic approaches influence their environments: how they shape the social, how they transform human relationships, how they can, through their symbolization and their immediate actions, open up new ways of listening and feeling' (Solomos 2023: 5). This influence is mutual between artists and environmental spaces. For example, sound recordings of healthy coral reefs have been used to attract biodiversity to a degraded reef (ibid.: 1). These sorts of symbiotic interactions underscore collaboration as integral to biophilic design, involving artists with communities and their natural surroundings (Kellert et al. 2008). Installations by artists such as Philip Blackburn and David Dunn further illustrate how sound art can actively engage environmental and social dynamics (Bianchi and Manzo 2016).

2.1. Examples of biophilic instrument design

The Biophilic Instrument Pavilion applies principles of biophilic design to musical interfaces, taking as its foundation conceptual practices of environmental art and sound art. We built upon examples of instruments and installations that engage with the elements – not in a metaphorical sense, but rather those that are literally activated by the four elements – to create sound. These examples include: wind (air) – Phil Dadson's *Kōea o Tāwhirimātea: Weather Choir* (2022–23) demonstrates durability, community engagement and weather-responsive sound; water – Peter Richards and George Gonzalez's *Wave Organ* (1986) informed spatial dynamics, rhythmic scale and use of recycled materials; land (earth) – Ellen Fullman's *Long String Instrument* (1983–) guided considerations of portability and scale; and light (fire) – Julie Herndon's *Shadow Prism* (2021–) provided a model of interactivity, transparency and passive activation via ambient conditions. We took these site-responsive instruments as our models along with traditional weather-activated devices such as windchimes and aeolian harps. Each of these projects offered features that we incorporated into our own design.

2.1.1. *Wind:* Kōea o Tāwhirimātea: Weather Choir *(2022–23) by Phil Dadson and the Breath of Weather Collective*

As a constellation of aeolian harps, this piece is a collection of eight wind-activated instruments distributed across the Polynesian Pacific to coastal climate-impacted locations. Phil Dadson, based in New Zealand, worked with members of the Breath of Weather Collective (a group of local artists participating in the project, formed in 2022) by supplying DIY wind-harp kits to construct free-standing structures with locally sourced materials. The harps were then documented using smartphone audio/video for one year to capture shifting timbres in changing weather. Soft wind, for example, creates a gentle, harmonious chord. A storm produces a dissonant roar (Dadson 2022–23).

This project illustrated our goals regarding durability of materials, community and sonic content. We sought to incorporate a free-standing structure strong enough to withstand the impact of heavy weather over the period of at least a year. Likewise, we worked to form an intentional community throughout the build process. The musical material of a drone – an ambient sound which 'rewards attention but does not demand it' – also served as a reference point for our sound design choices (Eno 1996: 148).

2.1.2. *Water:* The Wave Organ *(1986) by Peter Richards and George Gonzalez*

In the Marina district of San Francisco, a cobbled jetty of granite and marble protrudes into the bay. Nestled among the stones repurposed from a demolished cemetery, an assortment of PVC and concrete pipes of various lengths and sizes reach to the water's edge and emit a percussive glugging sound as the tides slap the ends of the tubes (Exploratorium n.d.). Some tubes jut up like periscopes, to which a listener may hold an ear. Some are loud enough to be audible from a distance, even approaching the jetty. The variation in tide and tube size provides a chorus of pitches and rhythms.

This instrument served as a touchstone for our notions of space, time and materials. That the sounds can be audible from afar but offer a more nuanced experience with time and interaction reinforced our goal for the listener's experience to change with proximity and position in space. Similarly, we noted the inclusion of longer biorhythms in the way the time of day and month (tides) affects rhythmic motion. We also sought to incorporate repurposed/recycled materials in the design wherever possible, not only for the ecological benefit, but also for the character these found items can provide.

2.1.3. *Land:* Long String Instrument *(1983–present) by Ellen Fullman*

This 100-foot long 56-string instrument sonifies movement across space. Stainless steel and phosphor bronze strings are stretched between frames and resonate with Fullman's rosin-coated fingers. Weights distributed across the length of the wires create shimmering chords in just intonation as Fullman slowly walks

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up and down the length of the strings. Inspired by Alvin Lucier's *Music on a Long Thin Wire* (1980), the instrument is often accompanied by traditional instruments and ensembles, including performers such as Theresa Wong, Kyle Bruckman, and the JACK Quartet (Beaumont-Thomas 2016).

This instrument and its ongoing performances blend the sculptural qualities of sound art (the piece is different in every space) with the practical considerations of music performance (the instrument is portable enough to bring on tour). It posed a goal for our project: that the instrument could function in place as an installation and be portable enough to move to other locations.

2.1.4. *Light:* Shadow Prism *(2021–present) by Julie Herndon*

The author's light-activated *Shadow Prism* instrument is a portable sphere that creates warbling drones in response to changing lighting conditions. Left unattended as an installation, the solar-powered electronic instrument resonates in response to ambient lighting. The prism is also used in a performance context, as handheld light sources and shadows shape the chord dynamically. The sound design references moving water, derived from recordings of a trickling creek analysed for salient frequencies and movement. Light exposure changes low-frequency oscillators that vibrate individual pitches in the central chord, creating more movement in brighter light and stillness in darkness (Herndon 2021). Similar to installations like Craig Colorusso's *Sun Boxes* (2011) and Rucyl's *Sound Prism* (Mills 2016), the instrument combines passive qualities with playability.

This instrument demonstrates the sort of interactivity we wanted for our installation. It is activated by the environmental qualities of light and also responsive to animated gestures. We sought to incorporate a degree of transparency and communication in the design itself to demarcate where and how for audiences to engage, providing visual and structural cues as to sensor placement and points of interaction.

2.1.5. Additional Digital and Visual Examples

In addition to the installations by Dadson, Richards, Fullman, and Herndon, we discussed other electronic musical interfaces and digital musical instruments. Instrument design by Bethany Younge (*//Atavist II*, 2023), Chris Kallmyer (*Los Angeles Department of Weather Modification*, 2014) and Chris Chafe (*Tomato Quintet*, 2007) were touchstones for creating musical interfaces that interconnected with ecological forces.

Each of these instruments are multimodal, combining distinctive sounds with striking visual design. Our visual aesthetics were further inspired by the work of Olafur Eliasson and James Turrell. Specifically, Eliasson's work with dichroic glass, such as *Slow Solar Event* (2007) invite the viewer to observe from multiple angles at different times of day. The colour-filtering material shifts in response to variables such as the angle of the sun and the perspective of the viewer. Turrell's work, especially in its approach to light and sky in *Skyspaces* (1970–present) and *Roden Crater* (1979–present) provided further guidance for visuals. Not only do these installations create a form in the environment, but they also use openings of various sizes to frame a viewer's perception of the surrounding environment. These designs underscore the importance of negative space in biophilic design. Our goal became to locate specific elements in the natural environment and to frame/amplify them through visual design and embedded musical interfaces in order to shape audience engagement.

2.2. Assembling a team

The BIP was created by an interdisciplinary team with expertise in architecture, construction, engineering and music. Led by professors Thomas Fowler (Architecture) and Julie Herndon (Music), participating students included Joseph Galicinao (Computer Engineering, Music), Eddie Sanchez-Pascua (Construction Management), Anita Shanbhogue (Architecture), Drew Thomas (Electrical Engineering, Music) and Sloan Woodward (Architecture). We chose an existing structure for our installation called the Centering Center, a flat-packable dome designed and fabricated in a collaboration between Cal Poly students led by faculty Thomas Fowler and Kevin Dong and artist clients Marcos Lutyens and Cynthia Campoy Brophy (Figure 1). While our BIP team gathered for the purpose of exploring ecological spaces, the group itself was a deliberately maintained social environment.

To effectively manage this interdisciplinary team, we used an original method centring on Curation, Accountability, Trust, and Structure – CATS. This method emphasises social space as an integral part of the creative project (Lefebvre [1991] 1974; Low 2016; Cortez 2023) and builds on the success of other Science, Technology, Engineering, Art, and Mathematics (STEAM) programmes. The collaborative methodology of these programmes is well documented in health (Walshe et al. 2019), education (Khine and Areepattamannil 2019), and museum settings (Bedewy et al. 2024; Hodgson et al. 2024), but is as yet underrepresented in creative projects (Ness 2018; Robertson et al. 2003).

Our implementation of the CATS method exemplifies how visual, auditory and social spaces can be in dialogue with the natural environment, highlighting the role of collaborative methods within environmental installations. Details on our methods are provided. Reflections from team members, edited for brevity and clarity, are used throughout.

3. Concept

As the team developed material responses to the visual and auditory aspects of Poly Canyon, we documented and collaboratively analysed key spatial and sonic features. Each aspect was considered both as an independent element and as an interlocking part informing the totality of the installation. Approaches to visual, sonic, and social space are discussed in the following sections.

3.1. Visual space: dichroic vinyl prisms

To heighten the qualities of light within the canyon, the team, led by Shanbhogue and Woodward, designed a set of dichroic vinyl prisms (Figure 2). Dichroic material displays different colours depending on the angle and brightness of sunlight. The prisms cast colourful shadows within the pavilion while refracting onto the white vinyl exterior walls. In addition to reflecting the light, the prisms also trigger sounds from one of the electronic instruments, Hue. Woodward explains:

> We developed a design goal to make a space where visitors can experience a concentrated reflection of the changes to the canyon through the day and night. After this design goal was developed, we conducted material research until finding dichromatic material which is both transparent and reflective and creates beautiful light patterns and shadows. Anita and I worked together to develop a method to volumise the existing geometry of the structure with prisms that grow out of the pavilion. While developing this, we coordinated our plan with Drew so that he could create a system that

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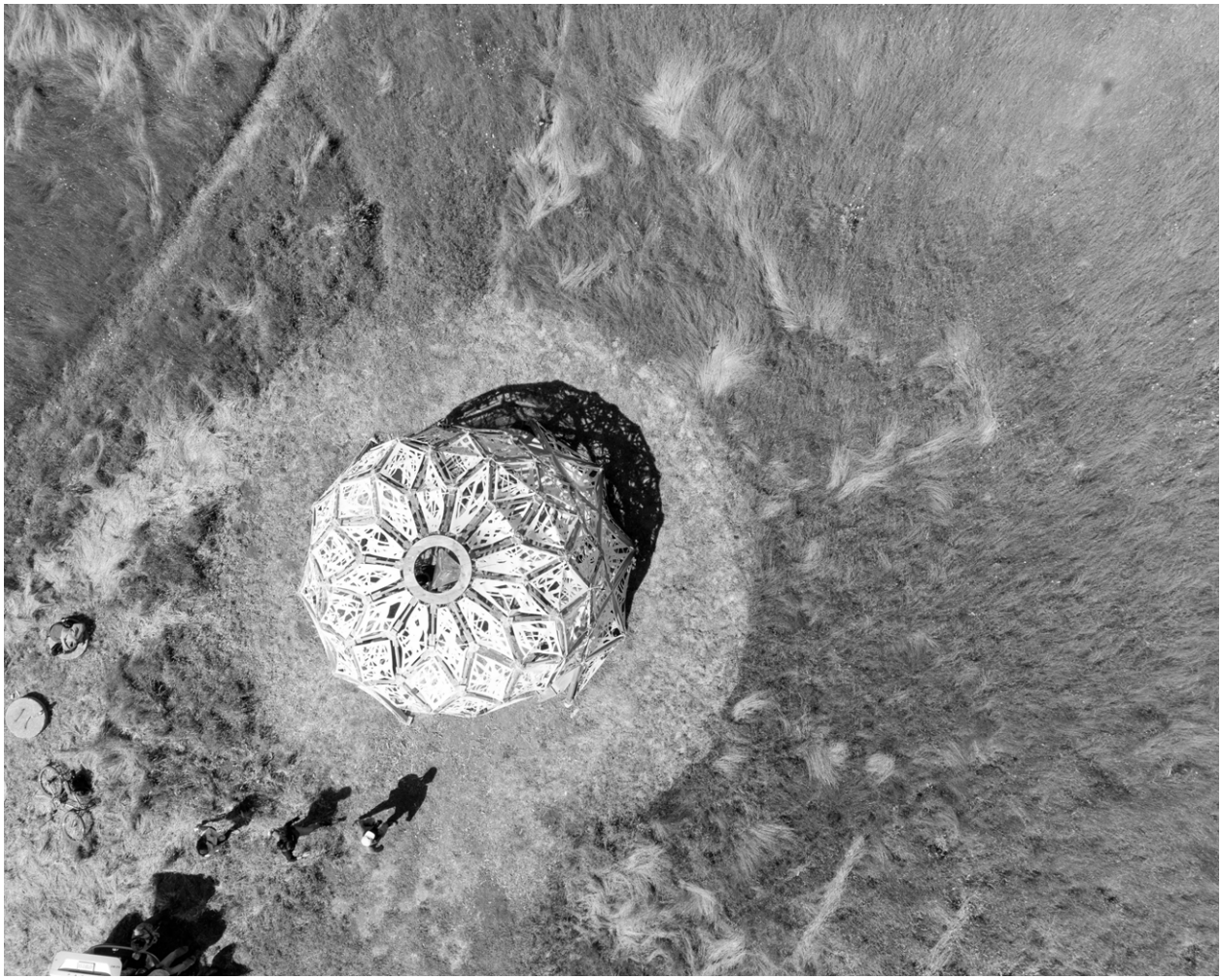


Figure 1. Aerial photo of BIP in Centering Center housing, San Luis Obispo, CA. Photo credit: Alicia Zimmerman.

> changes elements of a soundscape by responding to the changing colours of the prism and consequently the changes of the canyon throughout the day.

To determine the best placement of the prisms, Shanbhogue and Woodward made a sun map of seasonal light changes on the structure as oriented within the canyon (Figure 3). Woodward and Thomas worked together to strategise the placement of the prisms and responsive Hue instrument so that colours would be directly visible to the instrument's camera. The prisms were fabricated with aluminium pipes and custom-cast aluminium joints to make them lightweight enough to mount. Custom-casting the joints allowed for variation in the size of the prisms and facilitated their attachment directly to the geometries of the existing wooden structure. As Shanbhogue describes (Figures 4 and 5):

> Casting was a five-step process that involved digitally modelling all connection feet and joints, 3D printing them with PLA [polylactic acid, a bioplastic made from corn, sugar and sugar beets], creating wax trees [moulds], investing the wax trees, and finally pouring the forms with aluminium and removing them from the trees. We also required a method of attaching the vinyl to the frames we had created, so we cast custom clips that then slid onto the aluminium pipes of the frame and secured the vinyl through rivets.

The prisms draw attention to the sky and its changes, shifting in tone and colour throughout the day and night and referencing Eliasson's colour-filtering installations. The design also considered negative space, as inspired by Turrell's sky framing. Our execution focused on maintaining portability and durability of materials, using vinyl rather than glass and aluminium over wood. We also created visuals that would interface with aspects of our approach to sonic space.

3.2. Sonic space: Miles and Hue

The BIP houses two interactive digital musical instruments: Hue, which tracks light changes, and Miles, which tracks movement (Figure 6). These solar-powered instruments respond to colour, motion, and distance using cameras and sensors, microcomputers/controllers, and embedded audio programmed in Faust (Functional Audio Stream, a programming language for real-time signal processing). They were mounted onto the perimeter of the structure and oriented so that they could be activated by audience members approaching, entering and moving about within the structure. A Hue instrument was placed above each doorway in the pavilion: one faced outward towards the approaching trail and surrounding hills; one faced into the structure to focus on the colour changes of the prisms. Two Miles instruments were mounted on the inside of the pavilion over the side benches. Each

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Figure 2. Vinyl prism studio photography, San Luis Obispo, CA. Photo credit: Anita Shanbhogue.

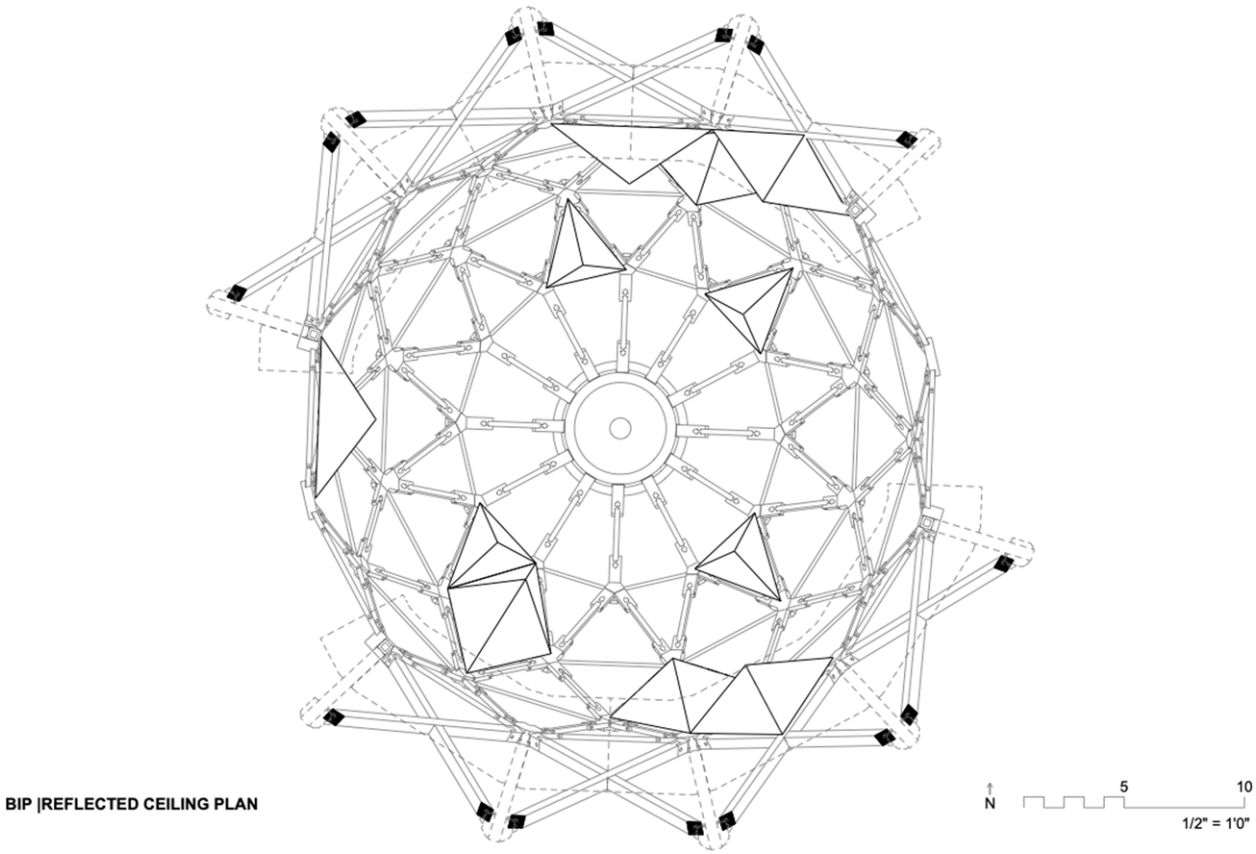


Figure 3. Reflected ceiling plan with prism placement derived from sun map, San Luis Obispo, CA. Photo credit: Anita Shanbhogue, Sloan Woodward.

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Figure 4. Wax 'tree' moulds, San Luis Obispo, CA. Photo credit: Anita Shanbhogue.



Figure 5. Placement of prisms within existing structure, San Luis Obispo, CA. Photo credit: Anita Shanbhogue, Sloan Woodward.

of the instrument's two speakers was installed on either side of the electronics casing so that they created an equally spaced ring around the interior of the pavilion.

By mapping camera and ultrasonic sensor values to pitch, rhythm and filters, the instruments create continuous sound in response to natural elements. Hue creates a drone that is filtered according to qualities of daylight and colour; Miles creates a percussive kalimba sound that changes in pitch and rhythm according to motion created by wind, people, or other creatures inside the pavilion. Visitors entering the BIP can hear their presence and motion change the soundscape. Depending on where they are standing, they hear different chords. Standing near Hue will sound lower, with more emphasis on the drone as it responds to light, clothing colour, and prism reflections. Standing near Miles will bring out percussive sounds that chime higher in pitch when closer to edges and lower when further away.

Team members visited second-hand stores to source eco-conscious materials for experimentation. Several wooden, metal and ceramic materials were purchased to explore as potential windchimes but were later set aside due to time constraints. Apple Pro desktop speakers, found to be durable and water-resistant, were adopted from a music department closet. The eye-like shape of the speakers gives the instruments a creaturely quality, which we appreciated since they would be a visible part of the design. The microcomputers and controllers were housed in watertight boxes mounted to the roof beams. Solar battery packs were purchased for power.

To explore the sonic materials of the environment, the team began by collecting field recordings from distinct locations at different times of day to make a sound map of the canyon. The spectral and observational content of these recordings informed the sound design for both instruments. Each team member took notes on time, location, weather and any other salient details during the recording process (Figure 7). This was compiled in a shared folder. Next, we ran a spectral analysis on the recordings to look for salient frequencies. Hallmarks included an airplane roar that resonated in the canyon around 70 Hz (roughly C-sharp) and creek sounds with a resonant peak around 1200 Hz (roughly F-sharp). Other notable sounds included crickets and bird song. The pitches of the electronic instruments were chosen to mirror and harmonise (quite literally) with these frequencies, based around the C-sharp pentatonic scale.

3.2.1. Miles

Designed by Galicinao, Miles responds to motion using an ultrasonic sensor and Teensy microcontroller. Miles produces short, percussive sounds programmed with a kalimba physical model in Faust. It chimes higher and faster when a listener is closer, and lower and slower when further away, alluding to the bird song of a Black Phoebe in the nearby creek. The sparse percussive elements allow sonic space for existing sounds in the canyon and for Hue, the colour-sensitive instrument. Galicinao reflects on his process:

> I first started by getting familiar with the Faust programming language. I prototyped with a temperature sensor and a simple synthesiser to understand how to integrate all the components together. After getting comfortable, I experimented with distance sensors to create the final product. I based Miles off a C-sharp pentatonic scale – in a pentatonic, five-note, scale, you can't play any wrong notes.

These instruments invite direct physical engagement. As listeners come into the pavilion and move towards the benches, Miles responds to their motion, inviting listeners to move in curious and playful ways as they approach the edges of the space. Creating this sense of embodiment builds an awareness of the self as a contributing part of the soundscape and a participating force in both the installation and the surrounding environment.

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Figure 6. Hue (left) and Miles (right), San Luis Obispo, CA. Photo credit: Eddie Pascua.

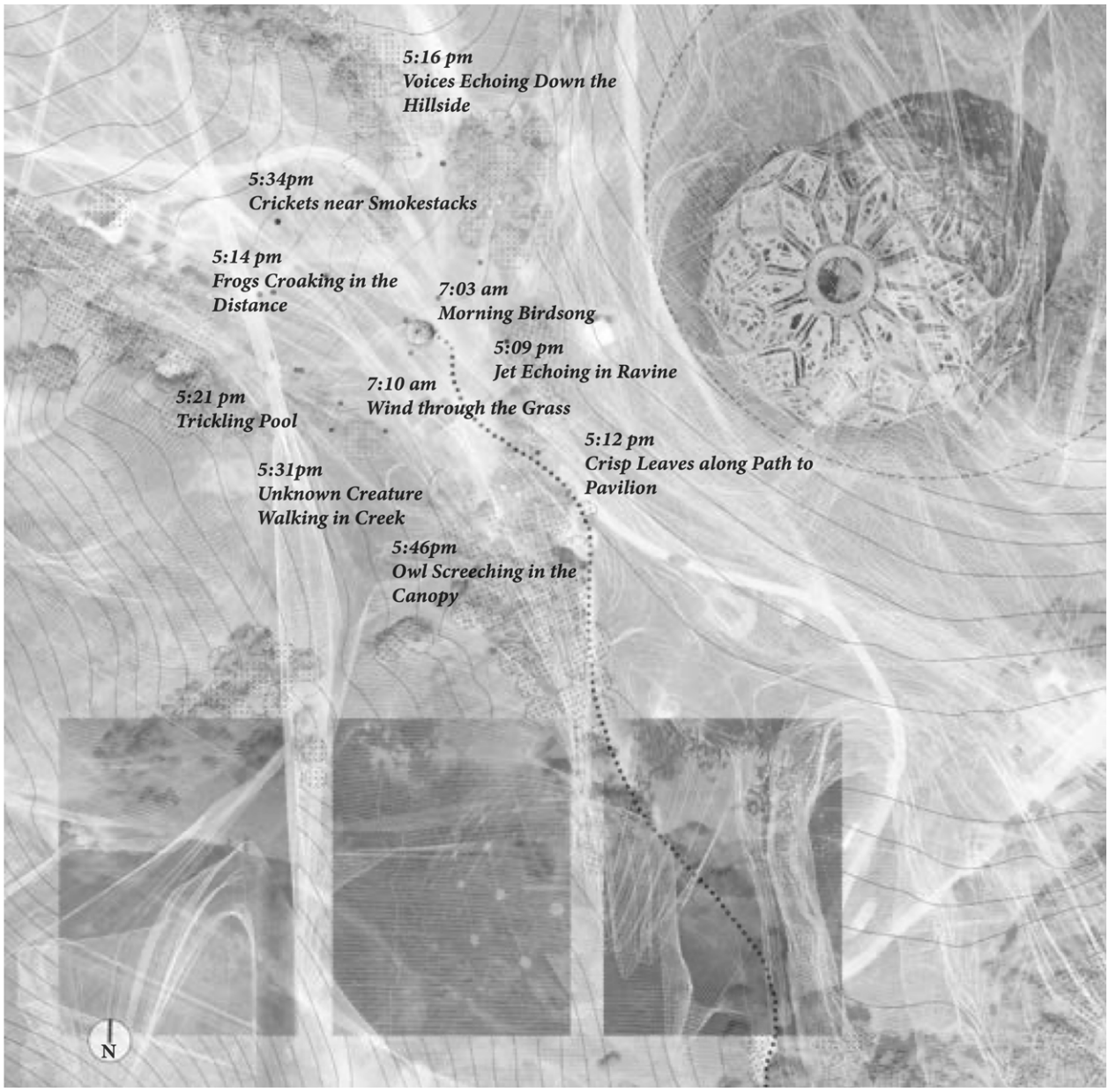


Figure 7. Site and sound map of Poly Canyon, San Luis Obispo, CA. Photo credit: Sloan Woodward.

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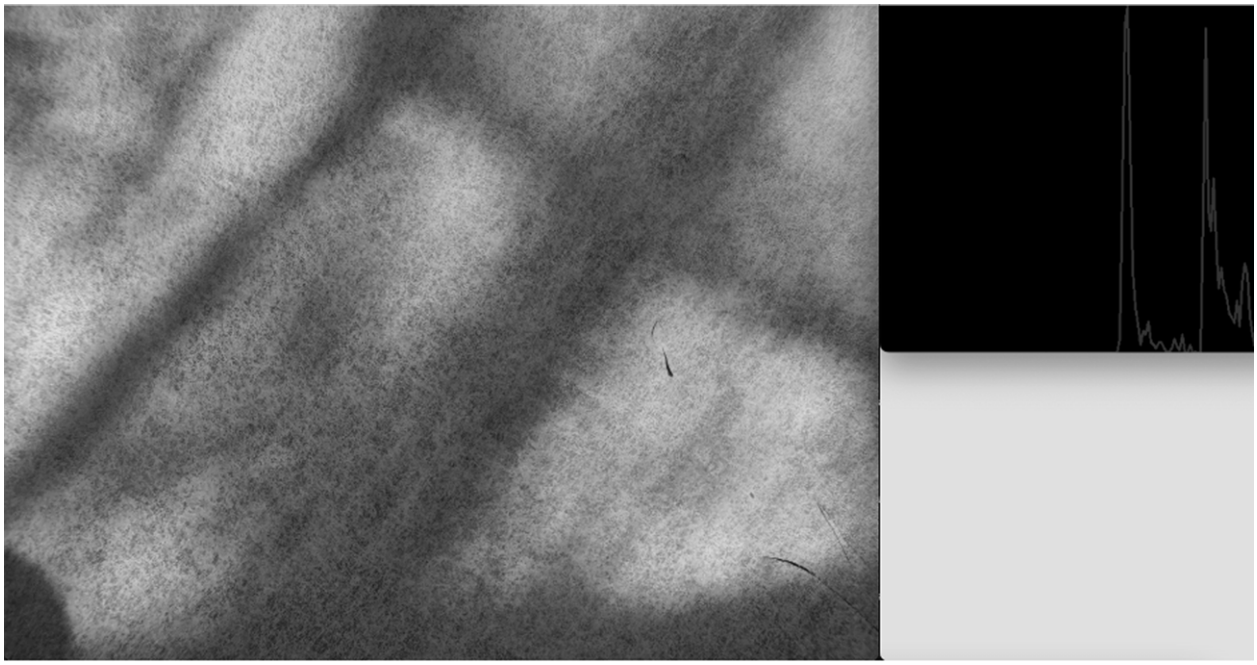


Figure 8. Camera image captured (left), Hue histogram (top right), max Hue (bottom right). Photo credit: Drew Thomas.

3.2.2. Hue

Designed by Thomas, Hue sonifies light and colour changes with a small camera processed with a Raspberry Pi microcomputer (Figure 8). Hue takes snapshots from the colour prism reflections and surrounding hills and maps them to shift a filter on a pulsating C-sharp suspended chord programmed in Faust. For example, if blues dominate the colour scale, the full frequencies of the chord pass through the filter. When pinks are dominant, the filter cuts the bass note and passes the F-sharp and G-sharp. When yellows dominate, the filter only passes the G-sharp. This gives a subtle sense of cadential movement over the course of the day. The changes are slow, imperceptible at times, much like the lighting changes themselves. Thomas describes his process:

> I decided it would be cool to get musical sounds from the colours of the canyon, so I used computer vision to inform my synthesiser. The original idea was to look at the grass and sky as it changes throughout the day, but with Sloan and Anita's idea of the colour panels, the team got excited about those, and I chose to follow that direction.
>
> On a Raspberry Pi, I capture an image and compute the most commonly seen hue in the HSV colour scale using OpenCV. This value is sent over a UART connection to the Teensy. This value adjusts the corner frequency of a low-pass filter in the Faust code filtering a C♯sus chord. The Hue modulo gives a value for the low-frequency oscillator modulating this chord. This repeats as soon as the processing of the previous image finishes, about every 50 seconds.

Hue offers a sense of constancy with its slower pacing. As the day progresses, the chord changes as gradient light contracts and expands the filters and control frequencies. The alternate orientation between the two Hues (one pointed outward, one inward) also provides variation to the drone.

The instruments work together to create a counterpoint between two biorhythms in the canyon: ultradian, the visitor's interaction period, and circadian, the day's cycle. The dichotomy reinforces that the listener is at once immediately impactful and simultaneously contingent upon greater forces. The instruments expose this duality while also leaving space for environmental sounds to inhabit the pavilion.

In developing both visual and sonic components, the team began by collectively observing and documenting existing environmental stimuli through recordings and observational sketches. This shared process generated a collaborative mental map of ecological space, which guided architectural and sonic decisions within the pavilion. Engaging the full team rather than smaller subgroups in this process fostered connectivity and proved essential in maintaining momentum, accountability and team cohesion throughout the project, particularly during busier periods.

3.3. Social space: CATS

The BIP, as a collaborative space, models an original approach to concept development and problem solving we call CATS (Curation, Accountability, Trust and Structure). These four tenets were cultivated throughout the process, from assembling the team, to scaffolding the work, to supporting the final installation. Because social ecologies are a crucial part of biophilic practices, we considered the social space to be of equivalent value to the fabricated space.

To *curate* the team, we implemented an application process with the goal of finding students with interests in multiple disciplines and proficiency with both concept development and material production in their given fields. The five students we selected demonstrated prior experience working in diverse groups as both designers and fabricators.

To scaffold the project work over a six-month timeline, we instituted 50-minute weekly meetings. Availability for this crucial shared meeting time was factored into our interview process. This consistent time commitment proved essential in establishing *accountability* and maintaining progress. Our first meetings

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Figure 9. 1:8 scale model of BIP, San Luis Obispo, CA. Photo credit: Anita Shanbhogue.

focused on building a shared vocabulary. In addition to the installations mentioned earlier, team members also brought in their own examples of musical interfaces and biophilic designs, including short-form videos from Instagram and TikTok. Next, we established a method for prototyping by assembling a 1:8 scale model of the pavilion in the studio (Figure 9). This was used to brainstorm ideas and demonstrate progress each week. We documented weekly achievable goals for the team, carefully clarifying who would do what and following up on how these goals were met. We occasionally split into subgroups to work through discipline-specific challenges such as sound design and material development. For example, Herndon led Faust workshops and Fowler workshopped prism fabrication.

A pivotal moment in establishing *trust* and momentum in the group was a 'Trust Battery Survey' distributed at the midpoint of our timeline in December. This confidential questionnaire was adapted for the classroom by Fowler and Dong using principles discussed by Tobi Lütke (Bryant 2016). The survey asked students to provide reflexive comments on their own contributions to the group and to give anonymous feedback to each individual group member. It also asked them to rate their trust in the group on a scale from 0 to 100%.

We collected the surveys and shared feedback anonymously in the following group session. Overall, students indicated an above-average level of trust for one another (65% mean) and offered compassionate and insightful feedback. The format of pairing self-commentary alongside external commentary likely contributed to reflections that were both empathetic and frank. Examples from the Trust Battery Survey demonstrate the quality of feedback, their divergence and occasional consistency:

Group strengths:

- Diverse skillsets across the five of us.
- We do a great job at listening to each other's ideas and giving people opportunities to try things out.
- Flexibility.
- Everyone's enthusiasm.
- Really good collaboration between members. The whole group shares a commitment to making something cool.

Group weaknesses:

- Conflicting schedules across the five of us makes it hard to find a time to meet and work together.
- We all have very different schedules, so it is hard to meet at the same time.
- Different schedules and difficulty finding time to work together.
- We don't have time to meet outside our 11–12 meeting.
- Everyone's schedules conflict.

Example self-reflections:

- Can be resistant to change if especially excited about an idea.
- Could communicate better sometimes but works hard to include everyone in creative process.
- I usually am able to be productive within a team, but within this initial stage of the project, I feel like I have not contributed as much as I would have liked to.

Example individual general commentaries:

- Could have a little more engagement in suggesting ideas that he is excited about, usually present but unclear on motives.
- Enthusiastic and hardworking, struggles with direction sometimes but is a strong team member.
- Quieter than the others but opens up when comfortable, something which seems to happen as the project goes on and the team works together more.

Fowler and Herndon shared this anonymous feedback with the group, structuring it by offering each student one point of positive validation and one point for improvement. While sharing feedback in this way had the effect of equalising praise and criticism, which helped contribute to a sense of cohesion, in retrospect we believe that sharing more information with the group beyond only one affirmative and one constructive point could have resulted in more transparency and accountability. Especially when points were repeated by multiple team members, such as the case with the student struggling with direction, the consistency in these surveys was a valuable insight.

We *structured* a timeline to support the team as we moved into the final installation process. To ensure the group would have the necessary resources, we prompted advance planning for material and scheduling needs by running a mock install day to troubleshoot potential issues. We built documentation into the final installation process, naming Sanchez-Pascua as the team historian, designating Shanbhogue and Woodward to assemble a print publication, and coordinating with a photographer and videographer.

The final installation for the Design Village festival in April 2024 took place over two days. The prism modules were installed first, followed by Miles and Hue. Hundreds of people visited the structure and interacted with the installation. The success of the

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final install day was largely due to the mock installation conducted the previous week, with issues of scaffolding and instrument mounting resolved in advance.

4. Conclusion

As climate change continues to impact the environment, it is essential to amplify our positive interactions with nature. These interactions have the potential to strengthen our constructive relationship with the environment and invite creative and productive solutions for healing and repair. The Biophilic Instrument Pavilion demonstrates a unique, multisensory approach to interfacing with ecological space, successfully engaging visual, auditory and social experiences in a site-responsive installation. Visitor interactions ranged from active exploration to quiet contemplation, indicating the flexibility of this multimodal approach (Video Example 1). Future iterations could expand interactivity with acoustic instruments and further develop team-building methods. The project's modularity has broad applications, inviting further explorations into multimodal biophilic spaces.

Community members who visited the structure participated both actively and passively. Some moved within the pavilion to trigger different sounds. Some were still and listened to the constant drone. Some used lights to create colours under the dichroic vinyl, others observed the sun as it shone through. The interface between the natural elements and audience provided multiple points of interaction while remaining semi-permeable to the environment. The spatialisation of the instruments cultivated an intentional listening environment. Several visitors remarked on the calming nature of the installation, one observing it felt like listening to 'the voice of the canyon'.

Though the sensor instruments invited a sense of playfulness, the inclusion of acoustic instruments could add complexity to the soundscape and lead to a continued period of visitor interaction. Wind harps and chimes resurfaced in group conversations but were not realised due to time constraints. Including this sort of physical interface, playable by both audience and elements, could add another dimension to the sonic activation. Using acoustic sound sources in tandem with digital instruments could be a direction for future exploration in groups undertaking similar biophilic work.

While the BIP is site-responsive, mapping sound and light from a particular location, the execution is flexible, and the process could be applied to a variety of situations and/or structures. The Centering Center was originally installed at Descanso Gardens for the 2022 Tonalism festival before being moved to its current location in San Luis Obispo. Our repurposing of the dome with interactive instruments maintains the meditative quality of the original design concept while refocusing it towards the ecological environment. A similar process could be followed in other architectural spaces with distinctive results.

Exit surveys from each team member provided insights on the collaborative process. Their notes include the importance of building a shared language, defining group direction, trust-building, patience and meeting weekly:

- The multidisciplinary team was wonderful for many reasons. It was refreshing to see and hear unique perspectives to design problems and aspirations. At first, our group struggled to speak the 'same language'. It took time for us to all come to a similar working strategy and mindset. I recommend future groups spending many of the initial design conversations working together as a whole. It is important to learn how your teammates think and problem solve, while also getting the opportunity to hear from their diverse knowledge and skillsets.
- Collaboration is not always easy and making sure the chosen direction is something the whole group is happy with can be difficult but well worth the time. It is easy to get lost in semantics in the definition phase of the project. While this phase is important, these disagreements often have no real bearing on the actual project. Sometimes it is better to start working and finish defining as the designs get fleshed out.
- Be patient with those who are not in the same discipline as you. You may know what you are doing technically, but others may have good ideas for you to implement. Do not let your ego stop progress.
- What helped a lot was the weekly meetings and trips to the structure to test some of the installations. The research also helped us narrow down the concepts we wanted to work with. I think taking notes every meeting about the updates as well as progress pictures help with documentation.
- A concrete timeline for moving through the process can mitigate many problems. Define expectations for each phase before the project begins.

Overall, the CATS structure helped to maintain momentum and consistency throughout the build process. Possible points for improvement include an additional Trust Battery Survey immediately before the build to further communicate expectations and group needs. Likewise, beginning the group prototype process earlier, as an exit survey mentioned, could have helped the group progress sooner with less of a rush at the end.

By integrating sonic, visual and social dimensions of environmental design, this project aims to provide methodologies in support of future biophilic projects. Approaching spatialisation across these three levels promotes holistic, multimodal interactions with the natural environment, affording valuable opportunities for embodied reflection on human–ecological relationships. We anticipate that the modularity of our design will support adaptation across diverse contexts and promote accessibility to multimodal biophilic spaces.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S1355771825100605

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