Zen-PCB: Material Honesty and Structural Metaphor in a Naked PCB Granular Looper Instrument

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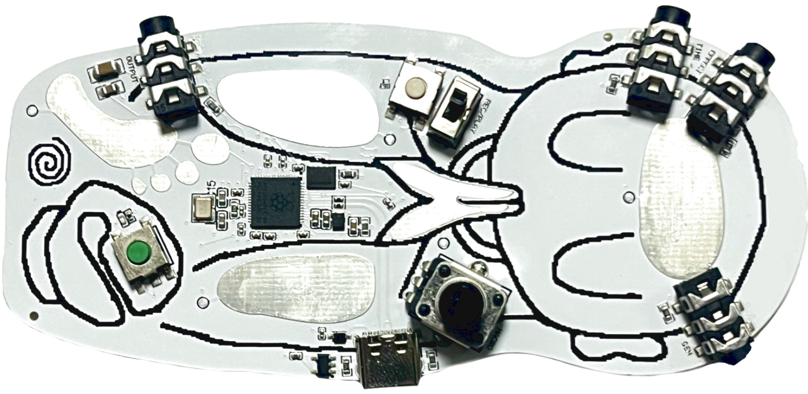

Figure 1: A handheld device where the printed circuit board serves as the primary interface. The design integrates exposed matrix pads and graphical elements directly onto the copper and silk layers.

Abstract

Zen-PCB is a musical instrument conceived as a counterpoint to the over-rationalized world and the passivity fostered by automated systems. It draws inspiration from ancient Japanese religious symbolism, the "kawaii" aesthetic, and the principle of material honesty: utilizing the naked printed circuit board as the instrument's visual and tactile skin. Zen-PCB aims to reintroduce "ambiguity" and "spirituality," qualities often absent in today's functionalist designs.

Zen-PCB encourages human initiative and celebrates the act of embracing "aimlessness." It employs low-latency granular synthesis and destructive overdubbing. Zen-PCB features "matrix patching," allowing users to interact with the PCB's traces using conductive styluses. This interaction requires active participation, pushing back against the reliance on automated tools and sparking a creative tension between human and machine.

Through structural metaphors, we reframe standard sampler functions as spiritual exercises. By incorporating the Buddhist concept of "impermanence" into its DSP architecture, Zen-PCB encourages users to engage with a continuous cycle of sonic creation and destruction. This pursuit of non-utilitarian experience offers a fresh perspective on creativity. We report on the design, implementation, and the reception of Zen-PCB, discussing how it transcends its function as a simple instrument, becoming a tool for physically embodying the cyclical nature of existence.

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CCS Concepts

• Human-centered computing → Haptic devices; **• Applied computing → Sound and music computing**.

Keywords

Material Honesty, Structural Metaphor, Naked PCB, Destructive Looping, Tangible Interaction

1 Introduction

In the modern design of electronic musical instruments, we observe a process of black-boxing where internal structures are hidden to ensure precise control and the perfect preservation of sound. Loopers and samplers, in particular, are designed for creating a perfect loop that repeats indefinitely without any degradation. We believe that this design could offer many benefits in terms of reliability, and repeatability, but it could actually hinder the spontaneous power of human creativity and serendipity.

We introduce Zen-PCB, not as a tool for music production, but as an instrument for the creative process. Figure 1 shows the overall appearance of Zen-PCB. It is a loop instrument that explores the beauty of unpredictable change and sonic erosion: a performer can instantly reset the accumulated complexity by pressing a single button, allowing for a new beginning. By using the raw PCB as its skin, the instrument strips away the black box of modern design, forcing the performer to engage with the raw, naked reality of the circuitry.

2 Related Work

The intersection of electronics and aesthetics has been defined and explored as PCB Art. Drimer [3] reimagined the circuit board as a visual medium. Zen-PCB extends this into the performative domain as an instrument, where the visual layout is essentially linked to the output. Commercially, Teenage Engineering's

Pocket Operator series [11] proved that an instrument does not need a case. However, while those are tools for making beats, Zen-PCB is built for improvisation. It does not use quantization; instead, it allows for raw changes in sound and unstable user input, enabling a freer creative process. Devices like the FM3 Buddha Machine [4] focus on spirituality, but they can be considered as passive machines for listening. In that respect, Zen-PCB is different since it is an active instrument that requires the interpreter to constantly create, transform, and erase audio.

Zen-PCB joins the history of "naked" and touch-based hardware. The STEIM Cracklebox [10] and BugBrand BoardWeevil [2] started the idea of touching exposed circuits to make sound. In Peter Vogel's "Sound Walls" [13], the analog connections are visible to the user. In contrast, Zen-PCB accepts that digital processing is naturally hidden. We use the PCB matrix as a "symbolic" interface rather than showing every wire. Also, while instruments by Serge Tcherepnin's modular instruments [7] or Peter Blasser [1] use complex and random patching, Zen-PCB uses a simple 3×5 matrix. This matrix connects digital tasks to clear spiritual metaphors.

3 Design Philosophy

Zen-PCB is guided by two core principles: Material Honesty and Systemic Metaphor.

3.1 Material Honesty as Skin

Material Honesty means respecting the true nature of a substance as it is. In Zen-PCB, the FR4 substrate is not just a carrier but the structural skin of the instrument. We chose a HASL (Hot Air Solder Leveling) finish over gold plating to prioritize visual unity. Since the components and solder joints are silver, HASL makes the whole board look clean and unified. This simple palette reduces visual noise, forcing the user to focus on the functional parts of the instrument. We cannot see the digital code inside the chip. However, the exposed PCB surface works as a symbolic bridge. It connects the invisible computer tasks to physical actions through metaphors.

3.2 Systemic Metaphors

We do not view the instrument's functions as just technical operations. Instead, we treat every action as a symbolic metaphor. The instrument follows a cycle of creation, change, and destruction:

- **Loop (*Samsara*):** A destructive loop. Unlike standard non-destructive loopers, every new layer permanently changes the past. This symbolizes an inescapable cycle of cause and effect.
- **Reset (*Katsu*):** A sudden severance. Triggering the reset plays a gong sound and clears the buffer to return the state to silence. This act cuts off all attachment to the previous sound, allowing for a fresh beginning.
- **Tempo (*Mokugyo*):** An organic pulse. Instead of a rigid digital clock, we use a simple spring-like tempo model. The timing has a physical wobble like a living creature.
- **Connect (*Namu*):** A committed link. The instrument only works when the performer physically bridges the circuit. This forces a physical commitment, requiring the performer to become one with the circuit.

4 Implementation

Zen-PCB is built on a high performance architecture designed for low latency audio.

4.1 Hardware Logic

We use the **Raspberry Pi RP2350** microcontroller, overclocked to 250 MHz. To keep the audio stable, we split the workload into its two cores: Core 0 (Audio) is dedicated to digital signal processing (DSP). It runs the granular engine, looper and effects chain. We place the critical code in RAM to ensure the timing is always precise. Core 1 (Control) manages the User Interface (UI) like knob inputs, and LED feedback.

By separating these tasks, occasional heavy UI processes are less likely to interrupt the sound. We use hardware FIFOs (First-In, First-Out) structures and shared memory for fast communication between the two cores. This dual mechanism ensures that the UI data reaches the audio engine with minimal delay. Rather than chasing high quality audio, we focused on making the device responsive for increasing engagement. For this reason, we set the sampling rate to 22.05 kHz. While this setting is a compromise between audio quality and memory (RAM) pressure, it also gives the instrument a distinctive low fidelity ("lo-fi") character.

4.2 Exposed Matrix Patching

The interface of Zen-PCB is a 5×3 matrix of traces exposed directly on the PCB surface, as shown in Figure 2. Unlike common capacitive touch sensors, it requires a physical, conductive circuit closure between a Row and a Column to trigger an input.

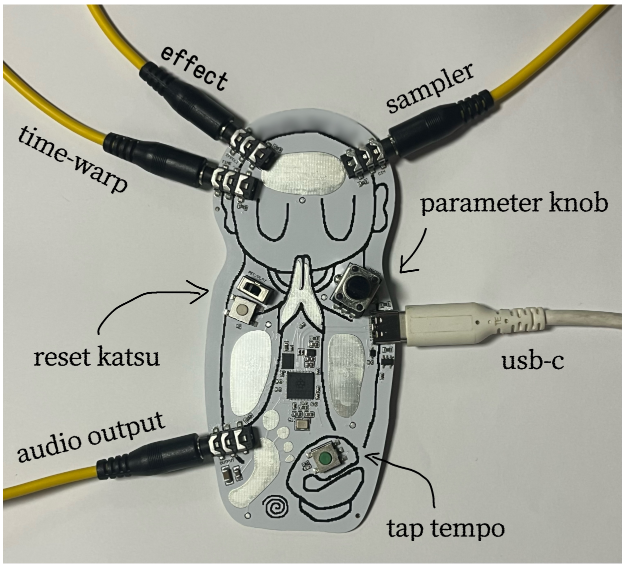

Figure 2: Matrix Scan Concept. When a user connects a Column (time-warp, effect, sampler) to a Row pad via a cable, the system interprets the connection as an active input.

We use a "Modal Patching" system where the function of the rows shifts depending on which column (sampler, effect, time-warp) is connected to a row (pads on the forehead, hands, left and right lungs, and foot of the figure, respectively):

- **Column 0 (sampler):** Rows 0–4 trigger playback from five different grain start positions within the buffer.

- **Column 1 (effect):** Rows 0–4 toggle the destructive effects (Pitch Shifter, Disperser, transGate, repitch delay, and vibrato) one at a time.
- **Column 2 (time-warp):** Rows 0–4 engage the time-warp modes (Stutter, Reverse, Ascension, Sludge, and Teleport).

The implementation of these techniques is explained below. Cables act as physical probes, forcing a user to bridge a Row pin (driven LOW) to a Column pin (input with pull-up). This makes every interaction a conscious, mechanical act of commitment.

The system scans the matrix approximately 10,000 times per second. We implemented a software debounce to make the stylus interaction solid and reliable.

4.3 DSP Architecture and Sound Erosion

The audio engine allows the user to record into a buffer at all times while permanently changing the sound as they play.

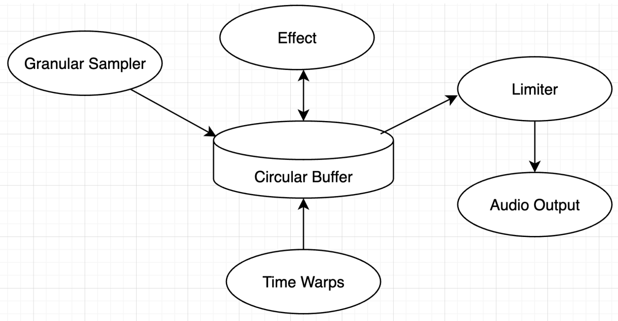

Figure 3: DSP Signal Flow. Processed audio is fed back into the buffer, permanently altering the recorded history.

As illustrated in Figure 3, a granular sampler input is continuously recorded into a shared circular buffer. In recording mode, users can layer new sounds instantaneously allowing for an intuitive performance without the typical constraints of a looper. We refer to this as "Seamless Overwriting Experience."

One of the most important features of Zen-PCB is that processed sound is written back into the buffer. Applying an effect is not just a temporary decoration; it is a physical rewrite of the recording. Every time a user adds an effect, they are evolving the buffer into unpredictable textures. This process of collapse, where the sound breaks down and is reborn, is the core of Zen-PCB's creative experience. We call this process "Design for Creative Destruction." The DSP chain processes the audio and immediately writes it back to the RAM buffer at the current record head position, changing the sound permanently.

Technically, Zen-PCB comprises three main components:

4.3.1 Granular Player. A Granular Player which supports 16 grains using the Waveform Similarity Overlap-Add (WSOLA) algorithm [12] to smooth the pitch and time manipulations.

4.3.2 Destructive Effects. A battery of Effects whose outputs are permanently imprinted onto the audio history. This component includes: a pitch shifter based on granular time-stretching techniques [9]; a disperser implemented as a cascade of all-pass filters to smear transients and reduce peak amplitude [5]; a transGate (rhythmic gating) based on synchronized amplitude modulation [14]; a repitch delay, a variable delay line where modulation of the delay time induces Doppler pitch shifts [6]; and a vibrato which applies low-frequency oscillation to the playback rate to create periodic pitch variation [14].

4.3.3 Time Warp. The playback head allows for non-linear traversal of the buffer, independent of the recording head [8]. We include five modes to warp time:

- Stutter: Rapidly repeats a small segment of the buffer by manipulating loop points.
- Reverse: Inverts the playback direction for classic backmasking effects.
- Ascension: Increases the playback speed, shifting the pitch upward over time.
- Sludge: Simulates the physical inertia of a tape-stop effect through exponential deceleration.
- Teleport: Instantly relocates the read-head to random grain positions, creating unpredictable sonic juxtapositions [9].

4.4 Organic Timing Model

Zen-PCB uses a simple spring-like model for tempo control. When the performer taps a new tempo, the BPM does not change immediately. Instead, it gradually oscillates toward the new tempo according to the spring model. Perceptually, this creates a small delay and wobble, so the pulse feels less mechanical and more organic during performance.

5 Community Reception

We shared a demonstration video of Zen-PCB on social media, where it received over 7000 likes, 1000 reposts, and 74 quotes in 1 week. This high engagement shows a strong public interest in the project. Analysis of the feedback suggests that the audience was drawn to the contrast between the clean PCB aesthetics and the aggressive, complex sound. This reception suggests that an instrument such as Zen-PCB could work as a physical narrative. It also indicates that when circuitry is designed with visual intent, it stops being a hidden black box. Instead, the exposed hardware becomes an accessible medium that helps people connect with the electronic sound.

Figure 4: Social Media Reception. The contrast between the visual design and the sonic output drove significant engagement.

In addition to this informal evaluation, we conducted a formal one to assess the usability and engagement of Zen-PCB.

6 Subjective Evaluation

We recruited 15 volunteer adult participants (mean age 27.1, SD = 12.7), mostly male (13), with normal hearing thresholds (self-reported). Most participants had 4–6 years of music training. This evaluation was conducted in accordance with the institutional ethics framework and the University of Aizu's procedures.

After a brief explanation about the project, we asked participants to utilize Zen-PCB until they were satisfied, and then we asked them to complete a 20-question survey. For this evaluation, we used a simplified survey inspired by the AttrakDiff survey, but our survey presented a 3-level scale.

6.1 Quantitative Results

Answers from the survey were grouped into four categories: pragmatic quality, hedonic stimulation, hedonic identity, and attractiveness. As shown in Figure 5, the scores achieved by Zen-PCB in each category were positive and different from zero. In particular, hedonic stimulation (HQS) reached 0.98 (SD = 0.06) indicating that Zen-PCB was regarded as highly engaging. The lowest score was obtained for Pragmatic Quality (0.55), which fits our initial goal: prioritizing "aimless" play over utility.

6.2 Qualitative Feedback

In addition to the scores analyzed before, the survey also included open-ended questions for the participant to express their opinions freely. In general, participants enjoyed the "naked PCB" look. The "Katsu" (Reset) metaphor felt like a "sudden awakening" to many. Some noted that even children could use Zen-PCB without instructions, indicating that the design is sufficiently intuitive. Future work should address some drawbacks mentioned by the participants, such as adding audio inputs and improving sturdiness.

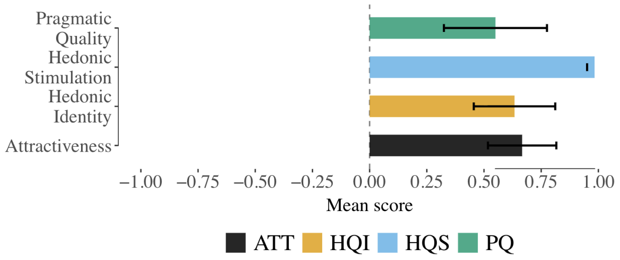

Figure 5: User study results (Mean and SD).

7 Conclusion

We introduced Zen-PCB. This instrument shows that it is possible to build expressive musical interfaces using low cost hardware and focusing on transparency and strong metaphors. By exposing the PCB, the design encourages users to connect directly with the machine's mechanism. By mapping audio parameters to spiritual metaphors we intend to help the performer stay mindful and focused. This project also suggests that the raw medium of a circuit board, when designed with intent, could be a powerful platform for creating new and expressive instruments.

8 Ethical Standards

This study involved volunteers in a short subjective evaluation. Participants joined voluntarily and were informed about the purpose of the study. We report only anonymized and aggregated questionnaire results. The evaluation followed the institutional procedures of the University of Aizu. Public social media responses are used only as aggregated metrics.

Acknowledgments

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