Entangling with Light and Shadow: layers of interaction with the pattern organ

Jasmine Butt*
jasmine2.butt@live.uwe.ac.uk
Expressive Computer Interaction Research Group,
Computer Science Research Centre, UWE
Bristol, UK

Benedict Gaster
Benedict.Gaster@uwe.ac.uk
ECI Research Group, CSRC, UWE
Bristol, UK

Nathan Renney
Nathan.Renney@uwe.ac.uk
ECI Research Group, CSRC, UWE
Bristol, UK

Maisie Palmer
Maisie3.Palmer@live.uwe.ac.uk
MICA Lab, UWE
Bristol, UK

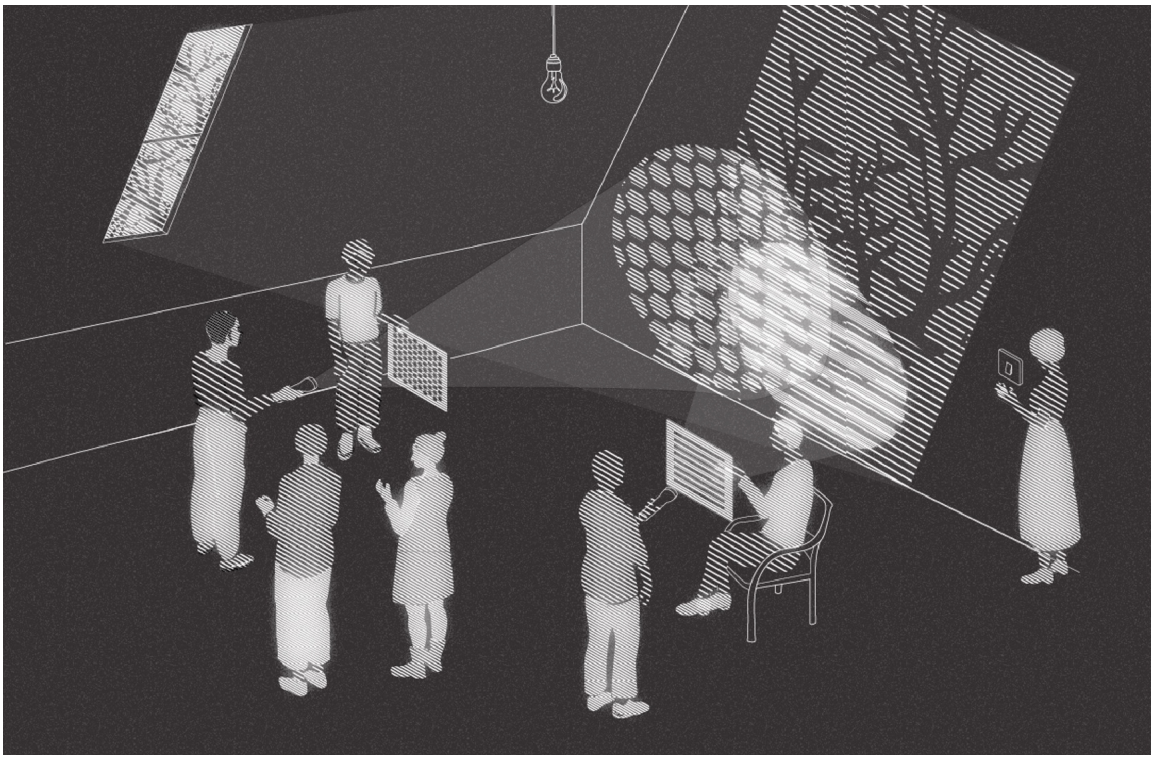

Figure 1: An illustration of an interference pattern; an entanglement of humans, materials, light and shadow

Abstract

This paper explores the design and use of a camera-based digital musical instrument as a thinking tool for considering entangled, post-human perspectives. The design of the pattern organ, inspired by experimental optical sound-on-film practices, employs a method of visual-to-audio synthesis that responds closely to the material behaviours captured by its camera input.

Drawing on findings from exploratory workshops and short material experiments, we describe how interactions emerge and are shaped by both the physical configuration of the instrument and the material behaviours captured by its camera. We consider how frugal mappings and the 'rawness' of data can give rise to instruments whose inputs remain open to material complexity, extending the sound engine beyond their enclosures.

In the case of the pattern organ, this complexity emerges through overlapping and interfering interactions, where structural forms, human influence, light, shadows, lens distortions, and system quirks all contribute to the shifting harmonic content of the wavetable. We reflect on the instrument as a fluid assemblage, composed of human and non-human entanglements, encouraging us to think beyond traditional notions of human-centred control.

NIME '25, June 24–27, 2025, Canberra, Australia

Keywords

Entanglement, Materialism, Post-Humanism, Audification, Optical Sound, DMI Design

1 Introduction

In a recent interview discussing the materiality of technical objects, Katherine Hayles described two ways of reading a book;

> "One way is just to immediately decode all the symbols in your mind as you read, and in that case, the book becomes more or less a transparent vessel. You're simply picking up the ideas that the author put there, and you are processing them in your own way. But a very different way to read a book is to pay attention to the texture of the page, the exact shade of the ink, the kind of font that's being used, and in that case, you are combining your understanding of the signifiers to an intense attention to the material form." [21]

Offering a post-human understanding of embodiment, Hayles questions the lines we draw between information and the material world, arguing that the world is 'not a split creature, but a co-evolving and densely interconnected complex system' [20]. She proposes a distributed understanding of cognition, one that flows dynamically between humans, animals and technical systems [19, 22]. Hayles's entangled understanding resonates with Barad's *Agential Realism*, describing a world made up of *Material-Discursive Practices*, where material and information continually co-constitute each other [2].

Recent engagement with entanglement theory in HCI and Music Technology research has seen the emergence of a new line of questioning, probing at the boundaries and assumptions that have been sedimented into these fields over time. These inquiries shift attention towards materiality [39, 55], ambiguity [35, 46] and amorphous assemblages [6, 51], informing new understandings of design, composition and performance practice.

Aligning ourselves with these post-humanist theories, we explore the design and use of the pattern organ, an instrument that uses minimal mapping, seeking to respond closely to material behaviours captured in its camera input.

In Section 2, we describe the materialist underpinnings of this research. We account for the work of the materialist film makers who explored visual to audio synthesis through experimental analogue darkroom practices. We present recent discourse around practices and understandings of 'raw data', and describe emerging design practices that aim to attend closely to material and decentre the human. In Section 3, we present the current design of the instrument. We describe a shift in our understanding of the instrument leading to a simplification of the interface, moving away from a representation of analogue optical sound, and instead leaning into the material peculiarities of a digital system. In Section 4, we outline a method for 2 workshop studies exploring interactions with the instrument. In Section 5, we present five entangled observations arising out of these workshop studies. We further considered the instrument in a different setting, conducting three short interaction experiments, linked in Section 6. In Section 7 we reflect on the design and use of the instrument through the lens of entanglement as *material-discursive practice*, where patterns constitute themselves within a continually shifting apparatus. Where behaviours, relations and attentions reshuffle, setting the conditions for new patterns and interactions to emerge.

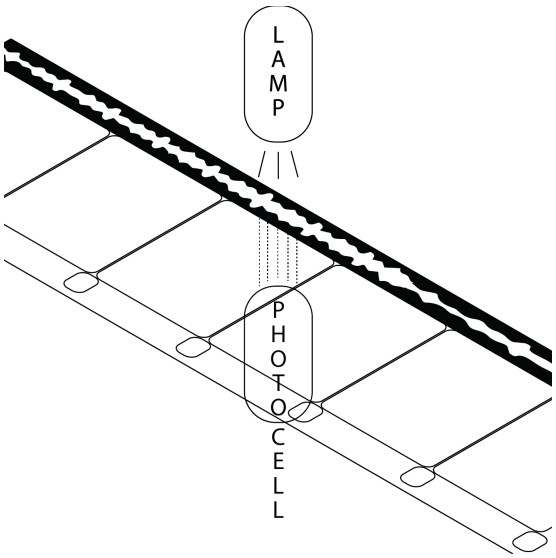

Figure 2: A diagram of Optical Sound on 16mm film

2 Related Work

2.1 Audification

> "patterns are built up , intricate patterns, patterns of waves, ready to be transduced into sound."
> *Daphne Oram on magnetic tape, An Individual Note [41]*

In the context of NIMEs, the sonification of camera data could be understood as falling into two categories. The first involves extracting features from image data to trigger or modulate sound parameters. This approach is evident in projects like the reacTable [30], or audiovisual installations such as Akiko Hatakeyama's *chitose momotose* [18] among others [8, 13, 17, 32, 40, 43, 47]. Another approach makes use of 'audification' [23], where each pixel's luminance data is more directly translated into audio signals, with minimal intermediary mapping. The first form of sonification affords a higher degree of intentional control and the ability to work with a wide spectrum of sounds. Audification can be limited in sonic palette, but offers a direct translation of visual micro-structures into audio at a waveform level. Both abstracted and unmediated mappings offer fertile ground for engaging with materiality, tangibility, and post-humanist thought. This paper focuses specifically on the *audification* of camera data, approached through a materialist and entangled lens. To frame this perspective, we draw on analogue materialist film-making practices, particularly those exploring optical sound.

The audification of image and light sensor data has been a recurring theme in Digital Musical Instrument (DMI) design [1, 10, 16, 24, 37, 42], and has been further popularised in recent years through the work of contemporary artists such as Ryoji Ikeda [25] and Electronic Fantasticos [11]. One-to-one mapping between luminance and amplitude has been used to investigate processual crossovers between image and sound that open up new sonic and visual synthesis possibilities [29, 53, 54].

2.2 Materialist Optical Sound Film-making

This research is part of a wider project around analogue optical sound practices. Optical sound is the principal method for recording and playing back soundtracks in analogue cinema. As

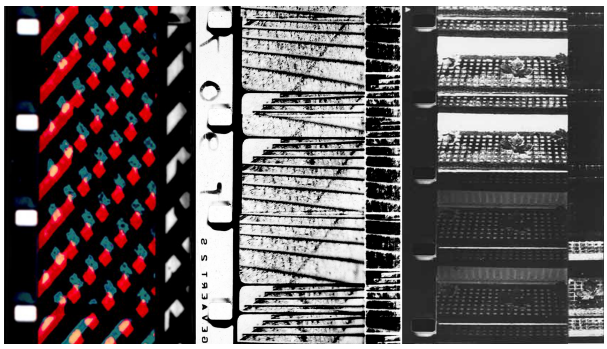

Figure 3: Scans from optical sound films from the London Film-Maker's Co-op: Left to right: Dresden Dynamo (1971) by Lis Rhodes, Railings (1977) and Musical Stairs (1977) by Guy Sherwin. Credit: Lux Online

illustrated in Figures 2 and 4, optical sound allows audio information to be printed and read as a continuous graphic waveform that spans the film strip. From the late 1920s, audio engineers have experimented with replacing optically recorded waveforms with graphic ornaments, employing cut up, resampling and physical modelling techniques to explore hitherto unknown sounds [7, 27, 31, 50].

In the 1970s, optical sound met with a further period of radical experimentation. Members of the London Film-Maker's Co-op, [4] were exploring ways of subverting the film apparatus by dismantling the boundary between the image and the printed soundtrack. Peter Gidal, a founding member of the co-op, published a 'Theory and Definition of Structural/Materialist Film' in 1978, calling for film-makers to step away from creating illusory '*phantasies*', and instead seek to understand a film work not as a reproduction or a representation, but as 'a record of its own making' [14].

This materialist thinking was prevalent among members of the co-op. Optical sound artists Lis Rhodes and Guy Sherwin used a sweeping range of techniques and materials to explore patterns and synthesise sound in their films, shown in Figure 3. Lis Rhodes used letracet, discarded typewriter ribbons, hand-drawn lines and computer generated patterns to synthesise sound optically in her works [34]. Guy Sherwin produced a huge number works making use of both camera-less and in-camera techniques [33, 49]. In 'Musical Stairs', Sherwin filmed a staircase, employing methods that spilled the image into the soundtrack area of the film. Tilting the camera up and down, and adjusting the aperture of the lens, he could play with altering pitch and amplitude.

> "The fact that the staircase is neither a synthetic image, nor a particularly clean one (there happened to be leaves on the stairs when I shot the film) means that the sound is not pure, but dense with strange harmonics." [48]

Optical sound and enlarging and shrinking filmic processes give film-makers tangible access to the minute details of an audio signal. Our research explores this concept through the design and use of a digital instrument that employs audification, preserving the 'rawness' of sonified data.

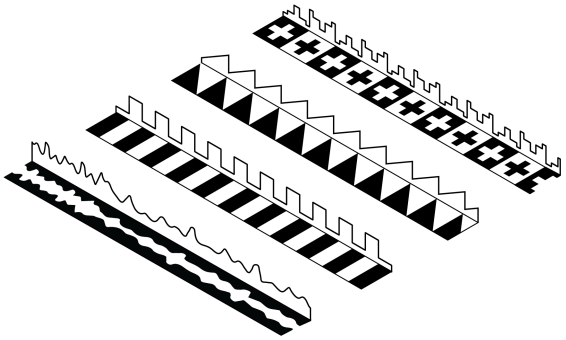

Figure 4: An illustration of an averaged one-to-one luminance to amplitude mapping

2.3 Raw Data

Recent music technology research argues that preserving 'rawness' of data through minimal mappings or frugality of components can lead to playful interactions, by leaning into ambiguity and the messiness of a signal [5, 6, 45, 46]. Exploring the use of electromyography (EMG) signals as a performance tool, Reed and others assert that their understanding of 'rawness' of a sensor signal does not assume a closer proximity to the sensed (in their case, the body). Instead, rawness can be defined by 'a simple refusal to infer conceptual meaning from the signal through digital feature extraction' [45]. Bowers and others have developed a design approach that emphasises 'rawness' of materials and data, creating artefacts which 'stay close to the materials from which they are made'. They propose that a frugal, perhaps aesthetically brutal approach can enable 'interrogation of human/non-human relationships, performativity, musical ecologies, aesthetics, and other matters' [6]. These 'monstrous assemblages' make up 'zones of entanglement' that work in unexpected ways, challenging the notion of tidy dataflow from source to destination.

2.4 Materiality and Decentring through Design

A materialist turn in Research Through Design is challenging the notion of materials as passive objects, acknowledging material 'vitality', and calling for approaches that decentre the human. In 'The Textility of Making' [26], Ingold describes the making process as 'a matter of finding the grain of the world's becoming and following its course'. Elsewhere this has been termed 'enabling material drift' [15]. Considering this in a digital context reframes the practice, 'moving beyond representationalism and perceiving the performative unfolding of a situation of material' [39]. Nicenboim and others assert the importance of a close attention to material in regards to digital media; 'Given that the materials used in design are evolving into complex assemblages of both humans and non-humans - such as data and algorithms - it becomes essential to consider how practices of attunement might be extended to broader temporal and physical scales' [38]. In this light, smaller, situated experiments can serve as crucial sites for developing these attunements, thinking beyond static objects and fixed contexts.

3 Designing the pattern organ

> "The real voyage of discovery consists not in seeking new landscapes, but in having new eyes"
> *Marcel Proust* (sic [52])

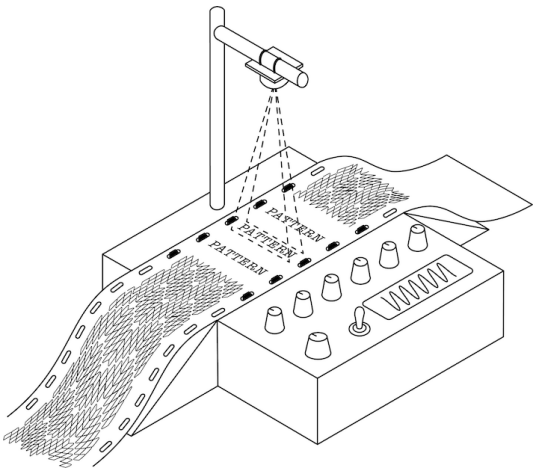

Figure 5: An illustration of the initial instrument concept

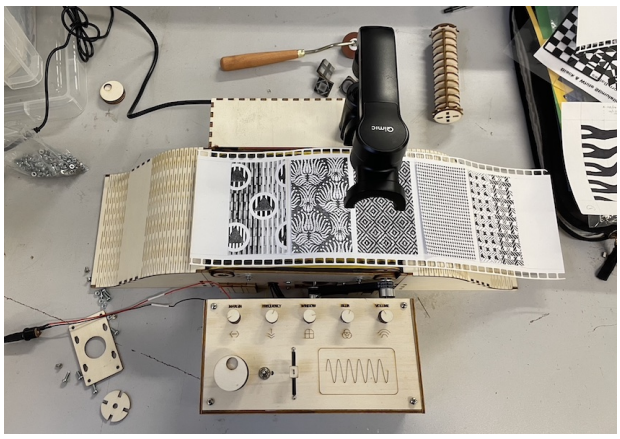

Figure 6: An early prototype of the instrument embedded into a conveyor-belt paper transport mechanism

Mikael Wiberg uses this paraphrased Proust quote in his book, The Materiality of Interaction [52] to emphasize a shift in perspective from the pursuit of novel artifacts to a re-examination of existing technologies through a new lens. In this research, the design process and design artefact became thinking tools for exploring entangled perspectives. The pattern organ was initially intended to be a *digital metaphor* of analogue optical sound technology. It makes use of a one-to-one luminance-to-amplitude mapping in order to closely couple the sound engine with material inputs. As we will explore in this and later sections, the perception of the instrument has shifted over the course of the design process, although its core operation has remained relatively unchanged.

3.1 Pure Data Patch

The pattern organ comprises a Raspberry Pi running a Pure Data (PD) patch which processes graphics using the Graphics Environment for Multimedia (GEM). The patch takes a 1-500 pixel variable horizontal slice from the middle of a 2448 x 1080 pixel live camera feed. To construct a wavetable, the mean average pixel luminance across the height (y dimension) of the slice is computed for each x pixel, resulting in a one dimensional array that refreshes at the camera's frame rate. This process is illustrated in Figure 4. This dynamic array is normalised to a float in the range -1.0 to 1.0, and written into a wavetable, to be scanned at a controllable speed. The graphical interface, visible in Figures 15 to 17, shows a black and white slice of the camera feed, a visual graphic of the one dimensional array, and a visualisation showing the shape of the shifting wavetable.

The pattern organ has limited active controls, including:

- Output volume
- margin (changes the height of the matrix slice taken)
- blur (smears data in time - between frames)
- frequency (a course frequency control of the wavetable scan rate)
- capacitive touch - currently uses a Trill sensor for fine control of the wavetable scan rate.

Using a USB camera that has manual lens control allows for further passive control of the visual / audio signal, through zoom, aperture and focus. The pattern organ is an open source design. Pure Data patches can be found here. A demonstration of the zoom, focus and margin controls can be seen here.

3.2 Simplifying the Interface, Enabling Complexity

The instrument's original concept emerged out of the lead author's analogue optical sound film practice, and a desire to bring features of this practice out of the darkroom and into live workshop settings. Due to close proximity with analogue film practice, the original form of the instrument embodied certain skuemorphic features, such as a sprocketed mechanism. Initially, the instrument was embedded within a table-top mechanism that used 3D printed sprocketed gearing adhered to a belt, illustrated in Figures 5 and 6. The intention was for the instrument to read patterns that were drawn onto or adhered to long strips of paper (the sprocketed paper serving as stand-in for celluloid film). Further design iterations retained a table-top configuration, using a light box and a pinch-roller mechanism to explore flat, paper patterns.

Responding to observations made in the workshops, described in Section 5, the decision was made to permanently uncouple the machine from any paper transport or table-top configuration. The interface was simplified to a control box, a graphic interface and a manual lens camera that can be fixed to a mount, or hand-held.

As we explore in this paper, moving away from skeumorphism and simplifying the device in this way set the conditions for different kinds of complexity to emerge. What initially appeared as a process of de-constraining the camera interface, introduced a new, shifting web of constraints. The key difference of this uncoupled interface was a fluidity of structure: the instrument became more able to expand and extend, adapting to its environment and reconfiguring itself to capture patterns in the world, while also allowing for direct interactions with hidden behaviours within the digital system.

4 Method

Through a loosely structured qualitative analysis based on the method outlined here, this paper builds toward a larger diffractive analysis, providing a basis for a future diffractive reading of these observations and reflections.

The pattern organ was used to run five workshops in conferences and community settings in 2024. Two of the workshops were recorded as part of formal studies. Each was set up slightly differently, but both involved using the instrument to explore a range of materials laid out on a table. Next to these materials

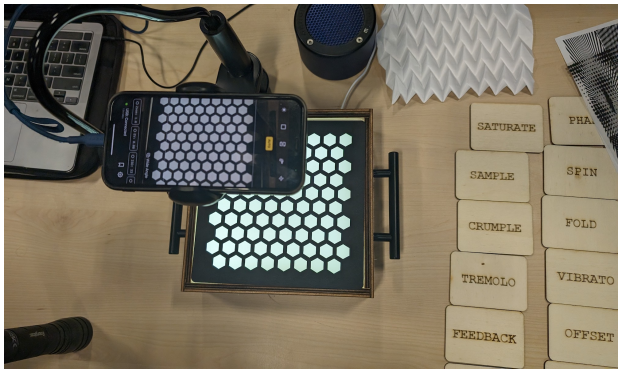

Figure 7: An image from the first workshop, containing some of the prompt cards used to inform early interactions

Figure 8: A photograph of the NIME - exploring shadows with transparencies and torches

were a series of prompt cards, visible in Figure 7, reading: *phase, distort, pitch, decay, vibrate, tremolo, vibrato, saturate, filter, fold, sample, sequence, feedback, stretch, crumple, fade, ripple, pucker, offset, smudge, blur, copy, collage, strobe, spin.* Often deliberately ambiguous in their referring to audio or visual media, these words were chosen to inspire thoughts around audio-visual-material correspondences.

Pre-CHI, UWE, Bristol, UK. April 2024 was a 2 hour session. 8 Participants attended. Participants were invited to openly collaborate and discuss as they explored different materials under the camera of the instrument, which was initially set up in a table-top configuration, pointing at a light box. The wavetable was set up at a consistent 64 Hz scan rate. The value was not chosen specifically, but was tuned to a low frequency with a potentiometer. The instrument settings were kept the same throughout, so that changes in sound were solely a result of interactions captured by the camera. Discussions in this workshop occurred in tandem with participants' interactions.

NIME, HKU, Utrecht, Holland. September 2024 was 3-4 hours long, with 7 attendees. It differed from the Pre-CHI session in that it placed more emphasis on individual exploration of the prompt cards. We used two later iterations of the pattern organ (referred to as the 'toneLamp' at the time of the workshop). This time, the scan rate of the wavetable was controlled by a Trill capacitive touch sensor [3], so that participants could choose their own speed and pitch while they explored the instrument. The sensor had been damaged in transit and was behaving erratically for the first half of the workshop, but could still output constant scan speed when pressed firmly. The participants were asked to choose a word from the prompt cards and to investigate the instrument in relation to the word. They were then asked to reverse this process, choosing a material and exploring the audio parameters or characteristics that it afforded. Discussions in this workshop happened in a round table format at points throughout the workshop.

Transcripts were made from audio recordings captured at both workshops. Interactions were recorded through a screen recording at Pre-CHI, capturing the graphic interface of the instrument. Still and moving image documentation were recorded at key points during the NIME workshop. To aid in reflection and comparison, transcripts separated engagement into individual interactions. These were defined by moments of participant inactivity, material being taken out of the frame, setting down the camera, and discussions pausing or changing tack entirely. Techniques were used to deeply familiarise the lead author with the recorded data, such as post-workshop discussions, hand transcription and graphic time stamping and coding. Collectively considering and discussing this material weekly over a period of months, nebulous observations gradually coalesced into clearer reflections, described in Section 5.

Rather than framing this as a process of finding underlying patterns, we approached these materials as sites of *differential becoming*, tracing how the instrument enacted itself differently across moments and contexts. Inspired by diffractive methodologies, we paid attention not only to what appeared stable or shared, but to reconfigurations of meanings, roles, and agencies that occurred across these intra-actions.

Building on these observations, a series of short material experiments were conducted, described in Section 6. Each experiment was centred around a different medium: Salvaged cans, sand and torchlight. These experiments were not designed to test hypotheses or confirm insights from the workshops, but to explore different unfoldings of the instrument in a quiet, solo setting, offering opportunities to attend to subtle shifts in attention and material response.

5 Five Observations from the Workshops

Though broken down into parts, these five observations are all related and overlapping, constituting a larger whole.

5.1 Ambiguity and Self-Sustaining Interactions

Longer interactions were marked by uncertainty about the source of changes in the output. Both workshops began with the instrument in a tabletop configuration, the camera facing downwards onto a lightbox. In both workshops, a noticeable shift occurred when the camera was redirected to capture the surrounding environment. Before this, interactions were mostly under one minute long. Afterward, increasing numbers of participants and materials became enfolded into the interactions. Features of the room, patterns on transparencies, the diffused shape of torchlight all overlapped, windowed and obscured each other to create one integrated pattern, scanned into the instrument's wavetable. Figure 9 shows an example of this layered interaction. These interactions were sustained for increasing lengths of time, from

Figure 9: stills from the Pre-CHI workshop recording, using an early iteration of the instrument. A layered input, made up of transparencies, bodies, torches, ceiling tiles and strip lights.

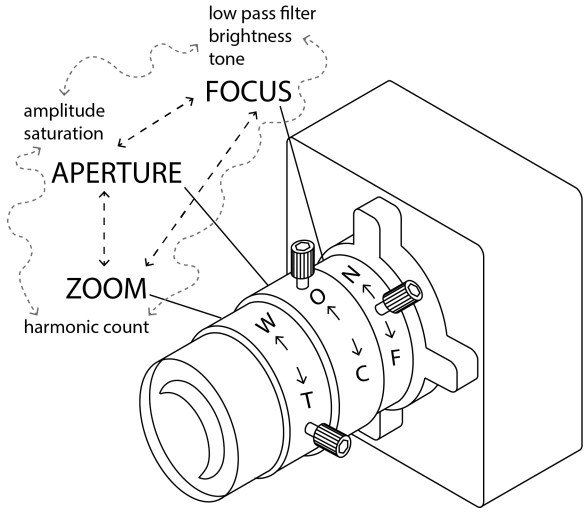

Figure 10: An illustration of interdependence in a manual camera lens

3 minutes up to 15 minutes. Previously, interactions ended when materials were intentionally removed from view. Now, they were sustained by a continuity of visual and sonic textures, with increasingly ambiguous sources. Every movement would alter the timbre of an ongoing drone, and participants became suspended in the interaction, engaged in constant discussion, exploration and investigating the sources of change, and noticing increasing unexpected, peripheral patterns. Moments of confusion sometimes shifted attention to features of the environment.

> "you're making more of a difference"
> "oh me?"
> "no I don't actually think.."
> "we have got the light above us as well so if we.."

5.2 Shifting Attention and Peripheral Patterns

As attention became more cyclical, moving between material, sound, and image, unexpected patterns and material behaviours began to surface. Early workshop interactions often began with comments about intention or material qualities, and concluded with a comment on the sound.

In one instance, when the camera was removed from its tabletop mount, participants appeared *tuned in* to one element at a time, even as other elements visibly and audibly influenced the output.

The patterned carpet was explored sonically while being significantly obscured by participants' own shadows; shadows that went unacknowledged. Later, while using transparencies and torches to project shadowed patterns onto the floor, participants discussed horizontal arrangements for clearer sound, without noting the vertical carpet pattern underneath.

As interactions continued and participants encountered features beyond their control, comments began to shift less predictably between material, sound, and image. For example, a feature of the sound would draw attention to the graphic interface, which would in turn draw attention to the material, light, system or environment.

> "there's a drone underneath us"
> *The speaking participant twisted the camera to line up with the regular grey and white pattern of the ceiling tiles. Seen in Figure 9*

5.3 Prompt Cards, Parameters and Intentions

The prompt cards, as seen in Figure 7, often created rigid intentions that did not allow space for open exploration.

The NIME workshop placed more emphasis on prompt cards, involving less open and collaborative exploration of the instrument. Participants were encouraged to choose a card or two, and explore it using the materials in the room. Although the cards were introduced to inspire curiosity, many of these early tabletop interactions were marked by disappointment. The words on the prompt cards encouraged interactions that often clashed heavily against the limitations of the instrument. The constraints of the prompt didn't allow space to respond to emergent behaviours of material or instrument, cutting interactions short.

> "Yeah I had vibrato and phase, I was interested in the height as well, so what happens - it gets quite blurry on top where the focal point is, I was a bit under-impressed with this one.. "
>
> "so basically I was trying to create noise in this, I think it didn't quite work because I think it's really because no matter what you are changing you are changing the harmonics of it so the fundamental is determined in a way. And the thing about noise is its inharmonicity"
>
> "So I started thinking of what could I distort, so it could be moving the paper in a distorted way or other things, but for example moving it sideways is not changing a lot because it's limited by the frame rate.. "

5.4 Material and Spectral Entanglements

Although a manual lens is split into separate rings for zoom, focus, and aperture, these controls are linked. In a phenomenon called '*Lens breathing*', illustrated in Figure 10, adjusting one subtly affects the others. This entanglement becomes sonically noticeable when using the manual lens within the pattern organ. Perceived pitch, tone, and amplitude are all affected, but not separately.

> "Yeah cause I'm trying to do like a blurring, and like the focus worked for the blurring but so does the zoom kind of cause it makes it blurrier and then the ultra-wide does funny things to the lines.. "

The camera lens here becomes a site of optical and sonic entanglement. This was not limited to lens control: similar entanglements revealed themselves across interactions. A clear example appeared at NIME, where a piece of paper was latticed with scissors, shown in Figures 11 and 12. The instrument produced varied sonic behaviours from this material: pulse-width modulation, wave-folding, even gated amplitude as the participant ran out of steam colouring the paper black. These attributes were entangled in the material itself. Moving or stretching the lattice affected many sonic properties simultaneously, though only one when considering the waveform as a whole.

▶ Lattice

At the Pre-CHI workshop, a piece of striped t-shirt material was stretched with the intention to alter perceived pitch. Later, as someone else explored the lens settings, stretching the fabric revealed the jersey knit of the material. As light passed through each stitch, high harmonics emerged alongside lower pitches. As it slipped out of focus, each stich was encircled with a soft bokeh circle, smoothing the waveform, shown in 13.

5.5 Automation and Emergent System Quirks

The interactions that were sustained for the longest were those that revealed and then leaned into hidden behaviours of the instrument. These behaviours were often uncovered using wave-emitting objects like torches and screens.

In one case, with the instrument back in a tabletop position, a phone was placed beneath the camera, displaying a subtle colour-shifting gradient. The mismatch between the camera's frame rate and the LED refresh rate created noticeable banding, outputting an undulating waveform.

> "ooh it's trying to adjust for the frame rate so it's.."
> "this is pretty interesting, we've got a kind of a strobing feedback screen weird thing."
> "it's pretty weird you can actually see the refresh rate of the light scrolling along and changing the waveshape."
> "I wish we were in a room with bad lighting for a temporary moment so we can see if the flickering of the lights would affect it.. "
> "do you mind if we, does anyone mind if we temporarily turn the lights off?"

Figure 14 shows a moment at the NIME workshop where a feedback loop between two instruments sustained a fifteen-minute experiment. Torchlight, narrowed with fingers, was used to explore the impulse response of a cascading wave of harmonics.

▶ Feedback

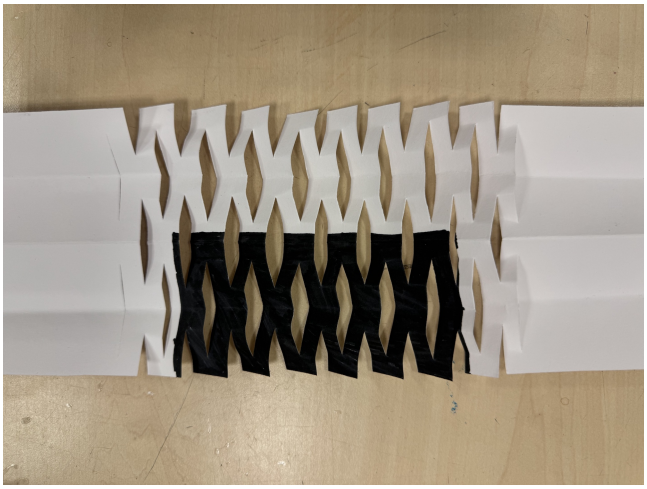

Figure 11: A latticed paper experiment from the NIME workshop

Figure 12: An interaction with the latticed paper input at the NIME workshop

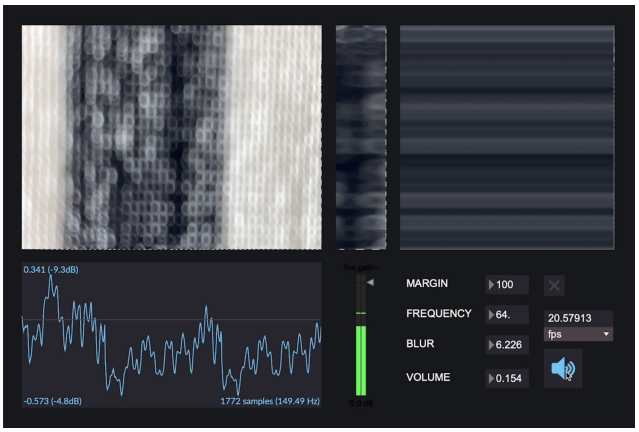

Figure 13: Stretched striped t-shirt material with bokeh circles, at the Pre-CHI workshop

6 Material Experiments

In response to observations and reflections from the workshops, we conducted three material experiments with the pattern organ,

Figure 14: A still from a video of the NIME workshop. Investigating light impulses, triggering cascading bands of light in a latent drone feedback loop.

exploring salvaged cans, sand and torchlight. Stills from video documentation can be seen in Figures 15 - 17, and videos with descriptive captions are linked below:

- ▶ Salvaged Cans
- ▶ Sand
- ▶ Torchlight

During the can experiment, considerable time was spent investigating the ambiguous source of a momentary high pitch. The can was crumpled in places, creating irregular areas of light. The sound seemed to come from both these reflections and a printed E, whose horizontal white stripes created a small portion of regularity in the waveform, visible in Figure 15. Hearing a pattern on an automated, motorised loop allowed us to tune in to the rhythmic spacing of the graphic design as well as sonic artifacts from the crumpled can's history of wear and tear.

Though unintentional, we had pre-loaded each material with expectations of possible sonic affordances. This was especially the case with the sand experiment, as the act of raking sand was immediately evocative of a cultural aesthetic that seemed to implicitly encourage a gradual, mindful approach. This expectation led to a spike of disappointment responding to the overpowering sound of the wooden rake tool. Attending to the sound, and making space for it, placed the tool at the centre of the interaction. The sound of this tool became composited with the sound of the ridges left in the sand. This prompted further thoughts about the use of mark making tools to entangle sound actions [28] with recorded sound.

The emergence of a system quirk prompted a new experiment involving torchlight. The torch, tall and stable enough to stand on end underneath the camera, made for a surprisingly hands-free interaction, while the visual banding of the rolling shutter effect sustained a pulsing tone. This automation lent space and time to tune in to the unfolding behaviour of the instrument, adjusting the instrument settings and using the manual lens.

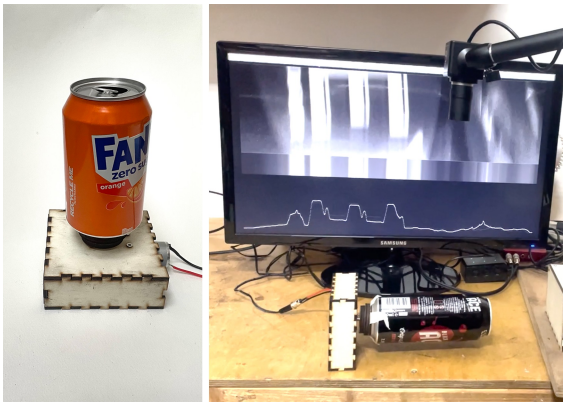

Figure 15: A still from the salvaged can experiment, next to an image of a can adhered to a 10rpm motor

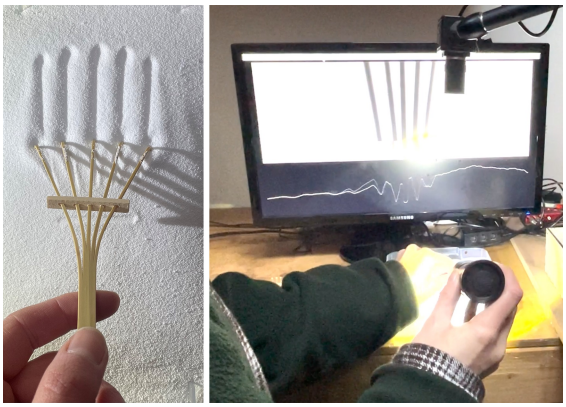

Figure 16: A still from the sand experiment next to a photograph of the sand and a small rake with gathered tines

Figure 17: A still from the torchlight experiment, next to an image of a torch.

7 Discussion

7.1 Beyond Control: Enabling Material Drift

In moving away from separate control of defined parameters like 'amplitude' or 'timbre', and instead influencing the waveform as a whole, the instrument made space for unfolding spectral entanglements that were bound up with different material behaviours. This helped to embrace mutual influence of human, machine, environment and objects. Through the three material experiments, we engaged in a process of *tuning in* to a new configuration of the instrument, one that involved leaning in to the emergent behaviours of simple objects.

In attending to a moment-by-moment unfolding of the material [39], and enabling material drift [15], we were able to embrace the differences between co-emergent material behaviours, side-stepping a traditional notion of control and user-centred interaction. Though de-centring the human 'user', these interactions were rich with unexpected behaviours and discoveries

that prompted creative thought, encouraging exploration of the material history and embodied information in discarded objects, entanglements of material and gesture, and hidden system behaviour.

7.2 Fluid Assemblages and Complexity

Grounding this research within an entanglement paradigm helped us to recognise the instrument's lively and unstable edges, seeing its different configurations as a continuous, dynamic process of mattering.

The ongoing design process, coinciding with the workshops, involved a rethinking of the interface as a boundary drawn between the 'material world' and the 'sound engine'. Through understanding the camera as a *vital* and *vibrant* part of the instrument, we were able to explore its agency within the apparatus. Previous design iterations treated the camera as a transparent window, passing details of an image into the sound engine. Through uncoupling the camera from a fixed enclosure and the use of a manual lens, the camera becomes a powerful actor in the instrument's apparatus, greatly extending the possibilities of the system, and allowing us to zoom into the finer details of material and spectral entanglements.

Taking a situational viewpoint, we can see that the instrument came to matter differently in different environments. For example, collaborative Pre-CHI workshop involved multi-layered interactions that gathered in optical complexity, allowing for diffractions, interference, and layers of patterned obstruction, shadow and reflection. The material experiments on the other hand resulted in a probe-like instrument that examined emergent audio-visual couplings with different objects.

We found that some of the most compelling interactions turned the instrument's focus in on itself, revealing diffracted features of its inner architecture through glitched, or mal-functioning behaviours. These investigations brought the instrument closer to the practices that inspired it: those of the materialist filmmakers who worked to dismantle and explore the film apparatus through diverse approaches and constant experimentation, involving minute gestures or vast landscapes, but always with an aim of illuminating the materials and processes involved in the making itself.

Through understanding the analogue film equipment as assemblages, rather than totalities, the materialist film-makers discovered an endless world of re-configurations, characterised by emergent properties. This approach, aligning with Redström and Wiltse's notion of *Fluid Assemblages* [44], has been a vital touchpoint when considering how we ourselves might design fluid instruments with re-configurable constraints that can attune themselves to different material complexities.

7.3 Future Work

This ongoing re-configuration also applies the outcomes of our research. Over the course of this work, the pattern organ became a thinking tool for exploring entangled interactions. As Frauenberger points out in writing on Entanglement HCI; [12]; had we conducted a controlled user testing study in a lab, the pattern organ may have become a functional tool, or a cultural artefact if subject to an interview study.

The work presented here is part of a larger research project exploring analogue optical sound practices. Through engaging with the experimental film community, we are gathering accounts of materialist film-makers' understandings and practices. These accounts will be read through material from workshops and our ongoing design process using diffractive methods [36]. One limitation of this research can be found in the time constrained interactions with the instrument. In future research we will explore lengthier processes of composing and performing with the pattern organ, delving into the implications of entangling material, choreographed interactions and structured sound, using a 4Es model of cognition (embodied, embedded, extended and enactive) [9]. We are also planning to investigate patterned making techniques, where the pattern organ is explored with a focus on the sonic possibilities of different material crafting processes.

8 Conclusion

The entanglement paradigm takes a step beyond a focus on embodiment and gestural control, de-centring the human in a way that destabilises our understandings of interaction. Understandings of Human Computer Interaction are already subject to strange new forces in the wake of rapid technological and social change. This instability offers an inroad for new research, inviting researchers to attune themselves to entanglements, and challenge thinking that aligns with a traditional notion of control.

What are the implications of interaction design within the paradigm of a distributed *locus of agency*? How can we decentre the human while acknowledging that we ourselves and our own boundary-drawing practices are intimately bound up in the world's becoming, and that we have ethical responsibility for the unfolding of networks, assemblages, discourse and environments that make us what we are?

Frauenberger proposes that in order to deepen our understanding of the mutual dependence between humans and objects, we might lean into material-centred interaction design, and explore the notion of fluid assemblages, creating 'hybrid things with ambiguous boundaries and proposed programs of actions that seek to reconfigure agency and power with moral responsibility'.

In this research we use the design and use of a camera-based instrument as a way of re-framing our understanding of interaction design. We explore an interface that enables material drift and acknowledges non-human agency, attuning itself to complexity within the environment. The camera's capacity to entangle with its environment allows the apparatus to expand and contract, drawing attention to complex, layered patterns of difference. This work highlights the expansive potential of a materialist approach to digital musical instrument design, where repositioning our understanding of agency invites productive engagement with unfolding material and spectral entanglements.

9 Statement of Ethics

This work was ethically approved by our university's Faculty Research Ethics Committee. Participants volunteered to take part in workshops while attending the two conferences. All participants were provided with an information pack and gave their consent for recordings to be made.

Acknowledgments

Much thanks to Matthew Olden for his help and advice with GEM.

TJM gratefully acknowledges funding from UKRI (grant number MR/X036103/1)

References

[1] D Arfib and J Dudon. 1999. A Digital Version of the Photosonic Instrument. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Beijing, 288–290.

[2] Karen Barad. 2007. *Meeting the universe halfway: quantum physics and the entanglement of matter and meaning*. Duke University Press, Durham London.

[3] bela. 2019. About Trill. https://learn.bela.io/products/trill/about-trill/. Online; accessed 14 October 2024.

[4] BFI. 2024. London Film-Maker's Co-op. https://player.bfi.org.uk/free/collection/london-film-makers-co-op. Online; accessed 07 December 2024.

[5] John Bowers, John Richards, Tim Shaw, Jim Frize, Ben Freeth, Sam Topley, Neal Spowage, Steve Jones, Amit Patel, Li Rui, and Will Edmondes. 2016. One Knob To Rule Them All: Reductionist Interfaces for Expansionist Research. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Griffith University, Brisbane, Australia.

[6] John M. Bowers, John Richards, Tim Shaw, Robin Foster, and Akihiro Kubota. 2023. Raw Data, Rough Mix: Towards an Integrated Practice of Making, Performance and Pedagogy. 417–427. https://doi.org/10.5281/zenodo.11189230 ISSN: 2220-4806.

[7] Richard H. Brown. 2012. The Spirit inside Each Object: John Cage, Oskar Fischinger, and "The Future of Music". *Journal of the Society for American Music* 6, 1 (Feb. 2012), 83–113. https://doi.org/10.1017/S1752196311000411

[8] Doga Cavdir, Chris Clarke, Patrick Chiu, Laurent Denoue, and Don Kimber. 2021. Reactive Video: Movement Sonification for Learning Physical Activity with Adaptive Video Playback. https://doi.org/10.21428/92fbeb44.eef53755 ISSN: 2220-4806.

[9] Isabela Corintha and Giordano Cabral. 2021. Improvised Sound-Making within Musical Apprenticeship and Enactivism: An Intersection between the 4E's Model and DMIs. https://doi.org/10.21428/92fbeb44.56a01d33 ISSN: 2220-4806.

[10] Alexander Dupuis and Carlos Dominguez. 2014. Digitally Extending the Optical Soundtrack. In *Proceedings of the 2014 International Computer Music Conference*. Athens, Greece.

[11] Electronicos Fantasticos. [n. d.]. Works. https://www.electronicosfantasticos.com/en/. Online; accessed 14 January 2024.

[12] Christopher Frauenberger. 2019. Entanglement HCI The Next Wave? *ACM Transactions on Computer-Human Interaction* 27, 1 (Nov. 2019), 2:1–2:27. https://doi.org/10.1145/3364998

[13] Anders Friberg and Anna Källblad. 2011. Experiences from Video-Controlled Sound Installations. 128–131. https://doi.org/10.5281/zenodo.1178017 ISSN: 2220-4806.

[14] Peter Gidal. 1976. *Structural Film Anthology*. British Film Institute.

[15] Bruna Goveia Da Rocha and Kristina Andersen. 2020. Becoming Travelers: Enabling the Material Drift. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference*. ACM, Eindhoven Netherlands, 215–219. https://doi.org/10.1145/3393914.3395881

[16] Shawn Greenlee. 2013. Graphic Waveshaping. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. 287–290. https://doi.org/10.5281/zenodo.1178534 ISSN: 2220-4806.

[17] Tim Hankins, David Merrill, and Jocelyn Robert. 2002. Circular Optical Object Locator. 80–81. https://doi.org/10.5281/zenodo.1176420 ISSN: 2220-4806.

[18] Akiko Hatakeyama. 2021. — chitose momotose. In *International Conference on New Interfaces for Musical Expression*. https://doi.org/10.21428/92fbeb44.1ed5b69a

[19] Katherine Hayles. 1999. *How we Became Posthuman*. University of Chicago Press, Chicago, USA and London, UK.

[20] Katherine Hayles. 2006. Unfinished Work: From Cyborg to Cognisphere. *Theory, Culture Society* 23 (2006), 159–166. https://doi.org/10.1177/0263276406069229

[21] Katherine Hayles. 2024. We Need a More Comprehensive View of Cognition. https://lab.cccb.org/en/katherine-hayles-we-need-a-more-comprehensive-view-of-cognition/. Online; accessed 16 January 2025.

[22] N. Katherine Hayles. 2016. Cognitive Assemblages: Technical Agency and Human Interactions. *Critical Inquiry* 43, 1 (Sept. 2016), 32–55. https://doi.org/10.1086/688293 Publisher: The University of Chicago Press.

[23] Hunt Andy Neuhoff John G. Herman, Thomas. 2011. *The Sonification Handbook*. Logos Verlag.

[24] Derek Holzer. 2020. *Vector synthesis: a media archaeological investigation into sound-modulated light*. The Author, Helskini, Finland. OCLC: 1140261117.

[25] Ryoji Ikeda. [n. d.]. Works. https://www.ryojiikeda.com/. Online; accessed 14 January 2024.

[26] T. Ingold. 2010. The textility of making. *Cambridge Journal of Economics* 34, 1 (Jan. 2010), 91–102. https://doi.org/10.1093/cje/bep042

[27] Richard James. 1986. Avant-Garde Sound-on-Film Techniques and Their Relationship to Electro-Acoustic Music. *The Musical Quarterly* LXXII, 1 (1986), 74–89. https://doi.org/10.1093/mq/LXXII.1.74

[28] Alexander Jensenius. 2022. *Sound Actions: Conceptualizing Musical Instruments*. The MIT Press. https://doi.org/10.7551/mitpress/14220.001.0001

[29] H Jo and N Nagano. 2008. Monalisa: "see the sound, hear the image". In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Genova, Italy.

[30] Sergi Jordà. 2003. Sonigraphical Instruments: From FMOL to the reacTable*. 70–76. https://doi.org/10.5281/zenodo.1176519 ISSN: 2220-4806.

[31] Thomas Y Levin. 2003. "Tones from out of Nowhere": Rudolph Pfenninger and the Archaeology of Synthetic Sound. *Grey Room, Inc. and Massachusetts Institute of Technology* 12 (2003), 32–79.

[32] Paul Modler and Tony Myatt. 2008. Video Based Recognition of Hand Gestures by Neural Networks for the Control of Sound and Music. 358–359. https://doi.org/10.5281/zenodo.1179601 ISSN: 2220-4806.

[33] Aimee Mollaghan. 2014. Audio-visual moiré patterns: Phasing in Guy Sherwin's Optical Sound films. *The Soundtrack* 7 (April 2014). https://doi.org/10.1386/st.7.1.47_1

[34] Aimee Mollaghan. 2017. Rebalancing the Picture-Sound Relationship: The Audiovisual Compositions of Lis Rhodes . In *The Music and Sound of Experimental Film*. Oxford University Press.

[35] Landon Morrison and Andrew McPherson. 2024. Entangling Entanglement: A Diffractive Dialogue on HCI and Musical Interactions. In *Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24)*. Association for Computing Machinery, New York, USA, 1–17. https://doi.org/10.1145/3613904.3642171

[36] Karin Murris and Vivienne Bozalek. 2019. Diffracting diffractive readings of texts as methodology: Some propositions. *Educational Philosophy and Theory* (Dec. 2019). https://www.tandfonline.com/doi/abs/10.1080/00131857.2019.1570843

[37] Peter Nelson. 1997. The UPIC system as an instrument of learning. *Organised Sound* 2, 1 (April 1997), 35–42. https://doi.org/10.1017/S1355771897000083

[38] Iohanna Nicenboim, Doenja Oogjes, Heidi Biggs, and Seowoo Nam. 2025. Decentering Through Design: Bridging Posthuman Theory with More-than-Human Design Practices. *Human–Computer Interaction* 40, 1-4 (Jan. 2025), 195–220. https://doi.org/10.1080/07370024.2023.2283535 Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/07370024.2023.2283535.

[39] Charlotte Nordmoen and Andrew P. McPherson. 2022. Making space for material entanglements: A diffractive analysis of woodwork and the practice of making an interactive system. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference (DIS '22)*. Association for Computing Machinery, New York, NY, USA, 415–423. https://doi.org/10.1145/3532106.3533572

[40] Olsen, Taylor. 2020. Animation, Sonification, and Fluid-Time: A Visual-Audioizer Prototype. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Birmingham UK.

[41] Daphne Oram. 1972. *An Individual Note*. Galliard Ltd, Queen Anne's Road, Great Yarmouth, Norfolk, UK.

[42] owl project. [n. d.]. Log Pile. http://owlproject.com/?q=Log_pile_2015. Online; accessed 14 January 2024.

[43] Nikita Pashenkov. 2004. A New Mix of Forgotten Technology: Sound Generation, Sequencing and Performance Using an Optical Turntable. In *Proceedings of the 2004 Conference on New Interfaces for Musical Expression*. Hamamatsu, Japan.

[44] Johan Redström and Heather Wiltse. 2018. *Changing Things: The Future of Objects in a Digital World*. https://doi.org/10.5040/9781350004368

[45] Courtney Reed, Landon Morrison, Andrew P. McPherson, David Fierro, and Atau Tanaka. 2024. Sonic entanglements with electromyography: between bodies, signals, and representations. In *Proceedings of the 2024 ACM Designing Interactive Systems Conference*. Loughborough University, IT University of Copenhagen, Denmark. https://doi.org/10.1145/3643834.3661572']

[46] Courtney N. Reed, Adan L. Benito, Franco Caspe, and Andrew P. McPherson. 2024. Shifting Ambiguity, Collapsing Indeterminacy: Designing with Data as Baradian Apparatus. *ACM Transactions on Computer-Human Interaction* (Aug. 2024). https://doi.org/10.1145/3689043

[47] Michael Rohs, Georg Essl, and Martin Roth. 2006. CaMus: Live Music Performance using Camera Phones and Visual Grid Tracking. 31–36. https://doi.org/10.5281/zenodo.1176997 ISSN: 2220-4806.

[48] Guy Sherwin. [n. d.]. Musical Stairs. https://lux.org.uk/work/musical-stairs/. Online; accessed 14 October 2024.

[49] Guy Sherwin. 2008. Guy Sherwin - Optical Sound Films 1971-2007 (Phase Loop / Sound Shapes / Cycles 1 / Newsprint / At the Academy / Soundtrack / Musical Stairs / Railings / Night Train / Interval / Interval #2 / N. https://re-voir.com/shop/en/guy-sherwin/638-guy-sherwin-optical-sound-films-1971-2007.html

[50] Andrey Smirnov and Matt Price. 2013. *Sound in Z: experiments in sound and electronic music in early 20th century Russia*. Koenig Books, London.

[51] Simon Waters. 2021. The entanglements which make instruments musical: Rediscovering sociality. *Journal of New Music Research* 50, 2 (March 2021), 133–146. https://doi.org/10.1080/09298215.2021.1899247

[52] Mikael Wiberg. 2018. *The Materiality of Interaction: Notes on the Materials of Interaction DesignNotes on the Materials of Interaction Design*. https://doi.org/10.7551/mitpress/9780262037518.001.0001

[53] Woon Seung Yeo and Jonathan Berger. 2006. Application of Raster Scanning Method to Image Sonification, Sound Visualization, Sound Analysis and Synthesis. (2006).

[54] Woon Seung Yeo and Jonathan Berger. 2006. Raster Scanning: A New Approach to Image Sonification, Sound Visualization, Sound Analysis And Synthesis. In *Proceedings of The Inter- naional Computer Music Conference*.

[55] Jianing Zheng, Andrew Mcpherson, and Nick Bryan-Kinns. 2023. When Materials Meet Sound: Discovering the Meaning of Deformable Materials in Musical Interaction. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference (DIS '23)*. Association for Computing Machinery, New York, NY, USA, 312–325. https://doi.org/10.1145/3563657.3596010