Sound design as human matter interaction

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Figure 1: WYSIWYG weaving mapping nearby movement and bodies to sound, Marguerite Bromly, Daviid Gauthier, Elliot Sinyor et al.; Topological Media Lab, XS Labs (Concordia University); IDMIL (McGill University); Hexagram.

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Abstract

Recently, terms like *material computation* or *natural computing* in foundations of computer science and engineering, and *new materiality* in cultural studies signal a broader turn to conceptions of the world that are not based on solely human categories. While respecting the values of human-centered design, how can we begin to think about the design of responsive environments and computational media while paying as much attention to material qualities like elasticity, density, wear, and tension as to social and cognitive phenomena? This question understands computation as a potential property of matter in a non-reductive way that plausibly spans formal divides between symbolic-semiotic, social, and physical processes. Full investigation greatly exceeds one brief paper. But we open this question in the concrete practices of computational sound and sound design.

Author Keywords

Materiality; Material Computation; Computational Media; Computational Physics; Digital Sound Synthesis; Movement; Gesture; Dance

ACM Classification Keywords

H.5.5 [Information interfaces and presentation (e.g., HCI)]: Sound and Music Computing — Signal analysis, synthesis, and processing; C.1.3 [Processor Architectures]:

Other Architecture Styles — Analog computers; D.2.6 [Software Engineering]: Programming Environments — Interactive environments; H.5.1 [Information interfaces and presentation (e.g., HCI)]: Multimedia Information Systems — Audio input/output; H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces — Auditory (non-speech) feedback.; C.3 [Special-Purpose and Application-based Systems]: Signal processing system.; C.3 [Special-Purpose and Application-based Systems]: Real-time and embedded systems.

General Terms

New Materiality; Phenomenology; Non-anthropocentric Design

Introduction: Computational Sound and HCI Design

We start by describing some particular examples of people making music and dancing in a responsive environment, i.e. an environment in which the sound and video is computationally modulated in concert with people's live, contingent activity as well as prior design. The examples come from the Topological Media Lab's work with dancers and musicians, but they have a double valence. On one hand, they are motivated by questions of making realtime systems that can support the most nuanced and expressive action by participants in a social event with aesthetic value. On the other hand, they are motivated from, and inform questions about continuous gesture and the processual formation of experience. We have written about these computational environments as experimental apparatuses for philosophical inquiry elsewhere [12] [14]. This paper focuses on implications from the making of such realtime, continuously responsive environments for the design of technical systems for human-computer interaction design.

We introduce three recent installation-performance environments: WYSIWYG sonic weaving, Tabletap sonified kitchen as stage, and a prepared piano coupled to computational sound synthesis. All but particularly the last application exemplify how sound designers blend computational techniques with qualities of physical materials and human activity to condition and co-create live events. Then we'll contextualize this in a broader discussion about locus of computation in alternative models of what's called material computation, and suggest some implications for design and HCI.

We have always been material(ly computing)

The conventional distinction between analog and digital computation is more a distinction between academic disciplines than a distinction in materials that change in concert with human activity. Computation, in the sense of a determined and designed set of well-defined transitions as a function of a given state to another state of an event, is always material. Under the fiction of the digital there is always the hiss of electrons and of matter-energy fields in physical, even quantum mechanical transmutation. It just happens to be under the radar as far as HCI is concerned. But as K. Barad, J. Bennet, the first author, and many others have argued, physics, suitably understood, figures equally with social field and narrative in modulating our computationally mediated experience. It is true that, to pun on Bruno Latour's critique of the distinction between social and natural categories ([7]), we have never been digital. This paper rests on the observation that we have always been computational, because matter that is not formed into digital architectures can also carry out computation. (By architecture we will adopt the sense implied in [1], and cited later in this paper.)

Figure 2: Tabletap: Dancer / chef with sonified utensils, table, food. Navid Navab, Tony Chong, Jerome Delapierre, Michael Montanaro, 2012-2013.

WYSIWYG [5]
One legacy of the intense growth of HCI during the invention of the personal computer and office automation is the model of the user experience as a personal and thus solipsistic activity. Considering the medium of sound however, one quickly learns how no object is physically isolate. So acoustic interaction is necessarily distributed, and continuously so. Pursuing this thought in the gestural control of sound, the TML built in collaboration a 6m x 1.2m "tapestry" (Figure 1) woven of conductive thread made into capacitive sensors. We designed custom electronics and sound processing instruments to map proximate movement to sound. Being much larger than a human body and sensitive to *any* nearby presence, WYSIWYG is an instrument designed to be modulated by not a specific "agent" doing discrete actions, but by *continuous distributions* of activity.

Tabletap [8]
Another legacy from designing for the personal computer and office automation is the establishment of gesture sampling and screen refresh in the 30-60Hz range, as well as fragile system architectures that drop frames or gesture samples under computational stress. Newer applications such as gaming, music, and those integrating multiple sensory modalities need higher data rates and lower jitter than the legacy standards provide. Encoding gestures in audio [17] has the advantage of leveraging a high reliability signal path into computers (optimized because audio clicks are very noticeable) with high data rates (44.1-198kHz) and low jitter (better than 1nS). In addition to transcoding gestures from touch or pressure into acoustic energy, sounding objects such as fruit, vegetables, floors and human bodies [4] can host useful computational operations such as band-limiting, resonance and spatial encoding.

By sonifying the utensils and gestures of a chef, Tabletap (Figure 2) symbolically charges everyday actions and objects in ways that combine the choreographer's and composer's design with the performer's contingent nuance. Tabletap replaces the design of interaction as discrete action-response by the composition of time-based media that can recalibrate themselves on the fly (within 30 frames, i.e. 0.6 ms under ordinary load), according to contingent action. Also, there is no "non-grammatical" action; any movement at all may potentially be made by the performer or the objects. The meaning comes from the context established in the moment of performance together with the theatrical apparatus of expectation.

One way we have designed the continuous richness of potential computational response to non-schematized gesture is via an architecture that implements physical models coupled with acoustic sensing. (Figure 3 shows an example architecture which incorporates many fairly sophisticated sound analysis, mapping, and synthesis systems such as [6].)

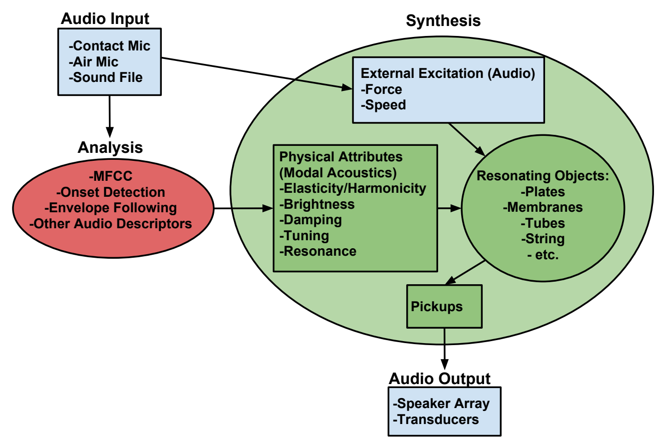

Figure 3: System for sonifying matter using physical modeling.

Figure 4: Whole-body movement workshop, TML, December 2012.

Acoustic Conditioning, Material Computing
Acoustic and sound processing present concrete examples of material computing in analog media as well as electrical or computational media. For example, in George Crumb's *Ancient Voices of Children*, composed for an ensemble of analog folk, toy, and prepared classical western musical instruments, the composer instructed the mezzo-soprano Jan DeGaetani to cluck-sing into a prepared piano, which acted as a complex realtime filter and extension of her voice.

In a recent workshop at the TML on whole-body movement and realtime media, the second author hybridized computational and physical techniques to prepare the entire room as an instrument. (Figure 4) In the preparations, we encountered the very common problem that the chosen space, a dance teaching and rehearsal studio, was poorly suited for the sound aspects of the interactivity. The shape was a typical rectangular prism with sound reflective windows on one side and mirrors opposite. The remaining walls were concrete. The floor was optimized for dancers and therefore acoustically reflective. We are able to employ mid-weight curtains around the space to absorb most of the difficult flutter echos and other artifacts that interfere with speech intelligibility and sound quality. The price to pay for this choice was a "deadening" of the room requiring some kind of amplified support. We couldn't solve this by employing the usual "public address" approach because we wanted the performers: actors, dancers, musicians, live-media artists, and casual visitors to move in the space unimpeded and unencumbered by microphones. An elegant solution is typified by the Meyer Sound Constellation system: an array of microphones and small speakers spread throughout the space that engage the room and an array of processed signal streams into a recursive network of acoustic and digital convolution calculations.[10]

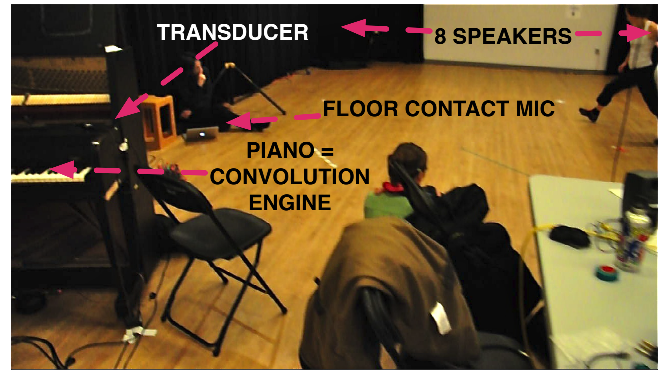

Figure 5: Using piano as convolution engine, transducers, microphones, speakers and live sound processing to acoustically condition the entire room.

Limitations on time and budget ruled out a Meyer Constellation system so we employed another programmable convolution engine that can be found in most dance studios: an upright piano.(Figure 5) Sound from contact microphones on the floor and air microphones in the space, plus synthetic sound from media computing systems were sent to an array of bending mode transducers attached to the wooden sound board of the piano. These excited the sound board and strings of the piano but typically at sound levels that were barely audible in the room. Sound from an array of piezoelectric contact microphones in the piano were amplified and sent to a ring of 8 loudspeakers in the room. Sound engineers will recognize this approach as similar to the plate reverberators common in the late 1950's that were an important shaper of the sound recordings of the Beatles and Pink Floyd in the 1960's. Actually this approach is closer to the sympathetic resonating strings found commonly in Indian musical instruments. The most similar historical antecedent though is the Ondes Martenot – an early sound synthesizer system designed in the 1930's that included a loudspeaker with attached sympathetic vibrating strings.

With care in the design and choice of materials, connections, electronics and signal processing implementation, each component of such a reverberation system can be made linear enough to be modeled using the same powerful Linear Time-Invariant system theory (LTI). We can view this as a general model of computation where a large number of signals are continuously delayed by varying amounts and summed with varying weights. Such systems can be characterized completely by an impulse response, *which can be viewed as the program for such a computer*. This is in fact the most popular approach for digital reverberators now, where room reverberation can be simulated by convolving recorded impulse responses.

Material convolvers such as the room, soundboard and strings present characteristic advantages over digital computations that were important in our whole body interaction workshop. The first one is latency. Although latency minimization has been an important research area in convolution reverberators[3], practical implementations still add many milliseconds of delay. More important than this is the dimensionality of the signal flows. Digital systems model the acoustics as if they are propagating in a one-dimensional medium. The piano sound board allows us to diffuse and collect effects from a large array (88) of strings. Each string supports primarily two independent lateral modes of vibration and the propagation in the sound board is multi-dimensional. The sonic impact of this richer dimensionality is much easier to experience and evaluate in person than via a written account. The impact from an interactivity perspective is readily apparent when we look at how we tuned the piano / room / floor / loudspeaker systems. We did this by directly generating sounds with percussive interactions between our bodies, the bodies of the room, and the instruments, thereby injecting sound into the room-ensemble at various points while listening to the outputs. We tuned the room-ensemble by repositioning the transducers on the piano and indeed repositioning the piano itself. The piano had a particularly interesting affordance in that we could individually enable the dampers on each string. It was useful during the whole body interaction experiments to play the piano as conventional instrument and by directly accessing its strings and soundboard.

(Such acoustic design is by no means restricted to art applications. Public PA systems in cavernous noisy spaces are now orders of magnitude more intelligible than they were 40 years ago. Acoustic engineers can treat the entire building interiors as complex resonators with many points of excitation and damping. Some are fixed – e.g. speakers or walls, some are moving – e.g. walking people, bodies as dampers.)

"Matter matters": Material Computation

HCI has tended to regard the computer as a machine for (human-human) communication. It is equally a machine for calculating physics. (In a sense, this mirrors the historical branches of LISP vs FORTRAN.) The turn from the symbolic / semiotic to the material can be summed up in a motto after Barad: "matter matters" ([2], 137). In the context of user interface design – it matters whether the user places a finger on a piece of hard plastic, or manipulates something soft and plushy. This is the material analog to saying that prosody matters as much as the lexical in the meaning and experience of speech.

But how can HCI, which recently has turned to using some conventional tools of late 20c social sciences and psychology designed to detect conventionally human-sized subjects and social phenomena, such as ethnography, capture enough of the aspects of people's experience that matter for material computational design? How can HCI synthesize such observations into insights that designers can use to create computational media and environments?

New materiality
To help stimulate fresh insight for design, it's useful to avoid certain conceits that can dog what is called new materiality.

Physicalism: To be material does not merely mean made of steel or silicon. However, the notion of materiality may usefully highlight some characteristics of physical matter, such as being subject to degeneration, irreversible processes, mortality, thermodynamics, and phase. (To do this robustly requires a careful generalization of physics such as Rene Thom's re-reading of Aristotle's Physics in the second part of *Semiophysics*[16], in which Thom develops a generalized notion of the potential versus the actual. But this exceeds the scope of our paper.)

Physiologism: Just as being material is not just to be made of metal or water, being embodied does not necessarily reduce to measuring physiological data from human bodies. In a related way, being vital or autopoietic does not devolve to hacking dishes of neurons, or other types of cells, or of higher order complexes, such as individual organisms or collections of organisms (*biologism*).

Naive notions of experience: The very term,"embodied interaction" encodes dualisms which design theory could usefully analyze and perhaps sidestep. When does experience *not* involve your body? Why must interaction be "inter"? Making relations (the arcs in a diagram) the primitive unit of analysis entails the question of what are their end points, which may be a confusing question (ungrammatical in Wittgenstein's sense). Why must there formally always be two terms to a relation? More fundamentally, such a view of relation (vs. field, for example) entails compact entities like "agents."

We suggest that an extended notion of materiality (looking to Deleuze, Barad, Simondon, and [14]), coupled with a span of technical practice that includes electrical engineering, mechanical engineering, and condensed matter physics, together with emerging models of material computation, would remove certain design problems, and point to a way to design humanely for dense built environments inhabited by arbitrary associations of people doing arbitrary things. In particular, we suggest that (1) matter can sometimes be a computational substrate, and (2) refined design and disciplined practice are possible as demonstrated by the domain of computational sound concerted with expressive corporeal movement. Such approaches may be conceptually cleaner for the theory of dense responsive environments, and practically simplify their design and engineering.

More General Material Computation
The arguments for non-standard computation such as material computation, or natural computing hinge on the depth, speed, robustness, cheapness, energy-efficiency, and density of ordinary matter. But we believe that simply imposing digital models onto material substrates, whether biological or not, is not the way to go. As S. Stepney has

observed: "[Computation using biological substrates such as DNA or proteins] is interesting and productive, but does it tell us anything deeper about computation? I would submit not. There are two main reasons for this. Firstly, the applications chosen are usually classical and digital, and not naturally suited to the analogue substrates. Secondly, and more profoundly, the biological substrate is extremely complex and complicated, having evolved over billions of years to exploit specific properties. In some sense, biological substrate is as far (or further!) removed from a primitive substrate as are our own designed abstract digital computational media" ([15], 1159). Also, in a chapter describing computing with liquids hosting reaction-diffusion processes, Adamatzky and Costello write: "So far, most known experimental prototypes of reaction-diffusion processors exploit the interaction of wave fronts in a geometrically constrained chemical medium. The computation is based on a stationary architecture of the medium's inhomogeneities. Constrained by stationary wires and gates, reaction-diffusion chemical universal processors provide little computational novelty and no dynamical reconfiguration ability because they simply imitate the architectures of conventional silicon computing devices. To appreciate in full the inherent massive-parallelism of thin-layer chemical media and to free the chemical processors from the imposed limitations of fixed computing architectures, an unconventional paradigm of architecture-less, or collision-based, computing has been adopted. An architecture-based, or stationary, computation implies that a logical circuit is embedded into the system in such a manner that all elements of the circuit are represented by the system's stationary states. The architecture is static. If there is any kind of artificial or natural compartmentalization, the medium is classified as an architecture-based computing device. Personal computers, living neural networks, cells, and networks of chemical reactors are typical examples of architecture-based computers." ([1], 1915).

Generality of Material Computation

Let's compare the claimed generality of materially embedded acoustic convolution computations with the claim that modern digital CPU's are "general purpose." Are we talking about the same sort of generality? How is this related to claims of Universality of Computation as explored by Turing and others? We first have to clarify a common confusion that it was the invention of the stored-program in digital computers that gave them generality of application. Digital stored programs provide a high level of precision and repeatability but the question of generality is contingent on what the computational components among which the stored program mediates data-flows. Analog computers and our acoustical computer store their programs in a spatial, non-digital form which we would admit is not as precise as a digital representation because, for instance, all the parameter stored are temperature dependent. A rather important practical advantage is that pianos and rooms tend to outlive digital systems so the parameter storage of the mechanical systems has a longer potential lifetime.

If we look carefully at the history of digital computer systems architectures we see regular shifts in the kinds of processing components reflecting the changing application domains of computers. Early digital computers, the DEC PDP-8 for example, had no multiplication units – multiplication was achieved by repeated addition. As applications requiring computations expressed in terms of linear algebra have expanded the number and performance of multiplication hardware components has increased. The GPU, DSP, array processors all reflect different choices of processing units to reflect the expected requirements of their specific application domains. Therefore, even in so-called "general purpose" computers, material choices in the implementations strongly influence what specifically is computed.

Designing material computation

So, how could we design some material computation systems? One account that describes the architecture uses the narrative fiction of a stimulus response processing loop (Figure 6).

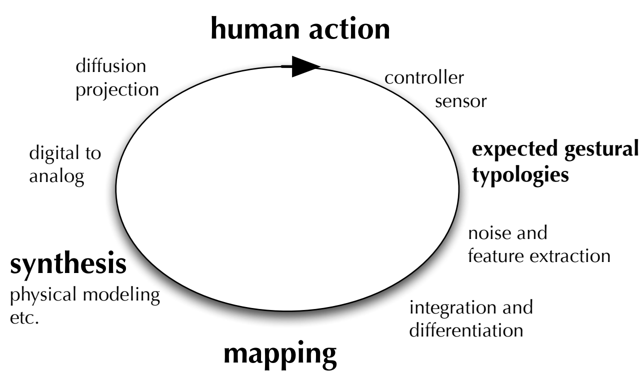

Figure 6: Conventional stimulus response processing loop.

We can see a problem with design based on the concept of a stimulus response loop. In "event-loop" programs, the design logic focusses attention on one discrete user action at a discrete time, which triggers a cascade of computer actions in response. The two agents in this design fiction, computer system and user, wait for each other at what we'll call the meso scale of a human act, paradigmatically that of making a selection among a small, discrete set of choices.

However in realtime systems like our time-based computational media environments, the flow of processing happens *continuously*, and as far as the human is concerned, concurrently with his or her continuous gesture. There is no turn taking. One symptom of applying a turn-taking approach to the design of a sound-processing application with live audio is feedback. This is an elementary "mistake" that novice sound designer/programmers quickly learn to avoid. But it reveals a deep and persistent conceit in design logic inherited from the event-loop, turn-taking conversational paradigm.

But at what, for the sake of argument, we will call a macro scale of activity, "system" designers conceive of computers as mediating humans communicating with other humans.

This raises three deep conceptual problems: (1) locally unidimensional narrative structure, (2) locus of computation, and (3) formal separation of functionality. Firstly, narrating user experience in ordinary language necessarily inherits a locally unidimensional structure from the very syntax of verbal language. For lack of space, we refer to B. Rotman[11] for an extensive critique. Our point here is that the full thickness and boundlessly open set of experiences of a responsive environment cannot be adequately modeled by any small finite number of experiential "trajectories through" that environment. Secondly, where computation "happens" is not as obvious as it may seem. (Nor is the locus of human thought any more obvious. As Wittgenstein asked in the *Philosophical Investigations*, "The chair is thinking to itself: . . . . . WHERE? In one of its parts? Or outside its body; in the air around it? Or not anywhere at all? But then what is the difference between this chair's saying something to

Figure 7: Pine-cone plus contact microphone as sensor and convolver. N. Navab, TML 2012.

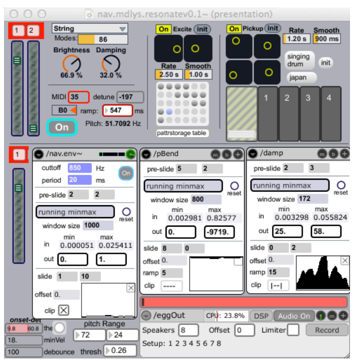

Figure 8: Max/MSP instruments paired with acoustic material. N. Navab, TML 2012.

itself and another one's doing so, next to it? – But then how is it with man: where does he say things to himself? How does it come about that this question seems senseless; and that no specification of a place is necessary except just that this man is saying something to himself?" ([18], 361)) A growing literature in the fields of material computing point to the non-digital processes of computation that happen in physical materials that do not follow the architecture or logic of a finite state machine. We emphasize here that by material computing we do *not* refer to isomorphic embeddings of FSM logic or digital computing architecures into some biological or physical substrate. Thirdly, in Simondonian terms, the formal separation of a technical object's functions into components, each of which fulfills the function independently of the other components, is an abstraction of how machines actually work in their physical, material operation. In his work in the philosophy of technology based on the history of recent technology, Gilbert Simondon considered in detail the co-evolution of technical objects and technical know-how of their communities of maker-users. We can see a historically continuous process of concretization in which some separate functions become jointly fulfilled as some of their components come to be designed and manufactured as one physical component. Separating the design of human interaction as a "symbolic" communication problem from the design of the plastic material – e.g. the heft, grip, bulkiness, stretchiness, or persistence of the physical materials encountered by human in the course of a computationally modulated event – is an abstracting separation that we claim introduces as many problems as it may solve.

Implications for Designers

So if everything happens concurrently and densely from the point of view of the human, it helps to have ready at hand some design metaphors adequate for manipulating computational media and instruments of expression that have a richness analogous to that of musical instruments and organized sound. In designing responsive media environments, we often compare our computational media to how analog media are articulated.(Figure 7, Figure 8)

In closing, let us draw attention to a set of issues that we designers of "human-matter interaction," faced with technologies of material computation, may consider. We can artfully and judiciously use analog together with digital materials. But this will demand a shift in attitude about computation that takes into account qualities extending material qualities like weight, elasticity, endurance (e.g. battery life), brittleness, stiffness, and so forth. This can include found technologies like a piano, or no-tech (like an eggplant[9]). We need to sidestep seriality, and sequential processing thinking, or multi-sequential, graph-analytic thinking, toward thinking spatially or topologically. By topology we do not intend the relatively trivial sense of graphs, but general point set topology.[13]

We close this paper with an open question: If we accept that the material medium manipulated by a human is a site of (analog) computation, and that consequently its physical qualities which can be modulated by contemporary production techniques are part of the human-computer interaction designer's responsibility, then a deep challenge opens up: What sorts of observational, instrumental, or experimental techniques, and what sorts of conceptual optics do HCI researchers and designers need in order to understand a user's experience in such material manipulations? What sorts of modes of articulation can HCI develop that would be adequate to such material qualities, not only macroscopic social qualities say of communication acts (time, speaker, geographic location, social class, etc.), but also micro-gestural or physical qualities (e.g. elasticity, material memory, heat capacity, friability, resistivity, etc.) that deeply condition the user experience?

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References

[1] Adamatzky, A., and Costello, B. D. L. *Reaction-Diffusion Computing*. Springer-Verlag, Berlin, 2012, ch. 56, 1898–1920.

[2] Barad, K. M. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Duke University Press, Durham, 2007.

[3] Battenberg, E., Freed, A., and Wessel, D. Advances in the parallelization of music and audio applications. In *International Computer Music Conference (ICMC)* (2010).

[4] Donarumma, M. Xth sense, 2013. http://marcodonnarumma.com/works/xth-sense/.

[5] Gauthier, D., Bromley, M., Sinyor, E., Berzowska, J., and Sha, X. W. CIDZIY (WYSIWYG), 2012. http://vimeo.com/tml/wysiwygclick.

[6] IRCAM. Modalys finite element modeling system, 2012. http://forumnet.ircam.fr/product/modalys/?lang=en.

[7] Latour, B. *We Have Never Been Modern*. Harvard University Press, Cambridge, Mass., 1993.

[8] Navab, N., Delapierre, J., Chong, T., and Montanaro, M. Tabletap, 2012-2013. http://vimeo.com/tml/tabletap.

[9] Navab, N., Delapierre, J., Chong, T., Montanaro, M., and Hendrik, J. Tabletap study, 2012. http://vimeo.com/tml/eggplant.

[10] Poletti, M. A. Active acoustic systems for the control of room acoustics. In *Proc. International Symposium on Room Acoustics* (2010), 1–10.

[11] Rotman, B. *Becoming Beside Ourselves: The Alphabet, Ghosts, and Distributed Human Being*. Duke University Press, Durham, 2008.

[12] Sha, X. W. *Poetics of Performative Space*. Human-computer interaction series. Springer, London, 2008, 549–566.

[13] Sha, X. W. Topology and morphogenesis. *Theory, Culture & Society 29*, 4/5 Topologies of Multiplicity, ed. Celia Lury (2012), 220–246.

[14] Sha, X. W. *Poiesis, Enchantment, and Topological Matter*. MIT Press, Cambridge, MA, 2013 (forthcoming).

[15] Stepney, S. The neglected pillar of material computation. *Physica D 237* (2008), 1157–1164.

[16] Thom, R. *Semio Physics: A Sketch*, 3 ed. Addison Wesley Publishing Company, 1990.

[17] Wessel, D., Avizienis, R., Freed, A., and Wright, M. A force sensitive multi-touch array supporting multiple 2-d musical control structures. In *New Interfaces for Musical Expression* (2007).

[18] Wittgenstein, L. *Philosophical Investigations, Third Edition*. New York: MacMillan, 2002 ()1958. tr. G.E.M. Anscombe.