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The making of performativity in designing [with] smart material composites

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The Making of Performativity in Designing [with] Smart Material Composites

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ABSTRACT

As the material becomes active in disclosing the fullness of its capabilities, the boundaries between human and nonhuman performances are destabilized in productive practices that take their departure from materials. This paper illuminates the embodied crafting of action possibilities in material-driven design (MDD) practices with electroluminescent materials. The paper describes and discusses aspects of the making process of electroluminescent materials in which matter, structure, form, and computation are manipulated to deliberately *disrupt* the affordance of the material, with the goal to explore unanticipated action possibilities and materialize the performative qualities of the sample. In light of this account, the paper concludes by urging the HCI community to performatively *rupture* the material, so to be able to act upon it as if it was always unfinished or underdeveloped. This, it is shown, can help open up the design space of smart material composites and reveal their latent affordances.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

Material-driven design; computational composites; smart materials; electroluminescent materials; affordance; performative qualities; performativity.

INTRODUCTION

Discussions about the unrealized capabilities of materials in the design of computational artifacts, and the experiences, performances and practices they contribute to generate, has steadily gained attention in the HCI community [67, 7, 65]. Giaccardi and Karana [20] have recently highlighted the importance for designers to consider the performative qualities elicited in embodied interaction with materials, in order to capitalize on the material's active role in the shaping of performances and practices.

Because of their dynamic properties, smart materials push the envelop of embodied and performative approaches to materials. In this space, the HCI community has explored their potential for giving physical expression to computational artifacts [65] and for diffusing computation into the fabric of everyday artifacts [9]. This work has contributed design strategies that take physical materials' properties as an entry point to harness computational expressiveness [64]. To account for the material's active role in the unfolding of action possibilities, hands-on approaches are privileged over representational approaches [63, 12]. Representational design approaches, such as geometry-based CAD modeling and visual collage, focus predominantly on what has to be produced rather than on how human and nonhuman formations are enacted or performed. These approaches that favour thinking over making or at best *"making through thinking"* [30] has led to a *"kink"* between the world and the designer's idea of it [8, 30], and are being increasingly questioned in HCI design practice.

The active involvement of designers at the material level becomes particularly critical when investigating new materials that are developed by scientists [57]. Thermochromic dyes, shape-memory alloy, piezoelectric films, electroactive polymers and electroluminescent materials are only a few examples of an emerging group of materials, called smart materials. While some of these (highly) engineered materials are available on the market, many are still in early stages of development. What gathers these various types of materials under a same group is their dynamic qualities in response to specific external stimuli (e.g., changes in temperature). These materials are often developed to stretch the notion of technical performance to the nano- and micro-scale of materials and surfaces.

A growing number of HCI researchers have begun to work with smart materials [12, 48, 19], mostly to get a better sense of the blending design space at the convergence of physical and digital materials. In these cases, the focus is on the 'making' of smart material composites, rather than adopting them adhoc in the late stages of concept development. The importance of 'making' in supporting designerly processes of understanding is greatly emphasized in the design literature [30, 47, 60, 63]. Practitioners like Coelho [12] often rely on craft techniques to explore and harness the potentials of smart materials. Löwgren

goes further by describing his relationship with the material during the design process as *"palpating"* the material [44], a process in which he brings forth the corporeal component of what Schön characterizes as *"reflective conversation"* [56].

However, the advantage (but also the challenge) of working directly with smart materials is that the entanglement of physical and computational properties is not engineered upfront and can be purposefully made by the designer (e.g., [57]). Their various 'becoming' [7] hints at the importance of understanding their underdeveloped capabilities, and how these can be revealed over time and in response to their context of use: that is, their performative qualities [20].

In the pursue of acquiring practical understandings of the (micro-scale) variables at play in the performative characterization of smart materials, present theorizations of performativity remain confined to either the designer's body (i.e., how the designer engages bodily with the material) or the artifact (i.e., how human performances unfolds at use time, once the artifact is made). This work instead aims to shed light on how designers may reveal unanticipated action possibilities in smart material composites, which we refer here to as 'the making of performativity.' To this end, we present a series of material-driven design (MDD) explorations with electroluminescent materials aimed to create electroluminescent material samples with novel action possibilities. The described explorations concern aspects of the making process of electroluminescent materials in which matter, structure, form, and computation are manipulated to deliberately disrupt the affordance of the material, in order to explore action possibilities and materialize the performative qualities of the sample. By examining these explorations, the paper introduces the idea of *disruption of affordance* as a design strategy for working with smart material composites, considered as always unfinished or underdeveloped. The paper concludes by promoting a *performative rupturing* of smart material composites, which may open up a broader design space and reveal latent affordances.

RELATED WORK

Smart Material Composites
Smart materials refer to a wide range of materials that share a common feature: their one or more properties might be significantly altered in response to specific stimulus. Smart materials have been approached from different stances in HCI research, including their role in realizing 'organic user interfaces' [13] and 'computational composites' [65]. Organic user interfaces specifically focus on smart materials and their intrinsic capability to respond. Based on this intrinsic capability, researchers of organic user interfaces explore how smart materials could transform the common-place flat shape of display devices, and, more generally, allow granularity between computational devices and physical material elements [13]. Other HCI researchers have adopted instead the broader definition of computational composites [65]. These are made of different physical and digital materials that are necessary for the final 'composition' to perform the way it does. Accordingly, they can exist in a number of states (e.g., colors, shapes, or positions), with the transition between different states being controlled or computed.

The notions of organic user interfaces and computational composites emphasize, respectively, a specific application context of these material composites (i.e., as user interfaces) and specific aspects of them (i.e., to reveal the properties of computation). With 'smart material composites' (SMC), we de-emphasize such frames of reference and instead refer to the underdeveloped state of smart material compositions which enables and drives creative processes with them. Seeing the composite as under-developed implies that there is a range of technical and experiential qualities that designers need to keep an open mind about. Like all becoming materials [7], composites of smart materials have dynamic qualities that unfold over time and in response to the context of use. This type of plasticity renders the performativity of SMC's particularly interesting as an entry point for designing (with) them.

Featuring inherently dynamic qualities, SMC's enable seamless diffusion of computation into formable, flexible, and stretchable material substrates [13, 65]. Dealing with them, thus, requires a departure from established methods of encasing hard electronics in material membranes (most of our surrounded interactive artifacts). The dynamic and adaptive behavior of smart materials challenges prevalent assumptions about material conditions in design of artifacts [1]. For many materials, making and manufacturing processes have been greatly protocolized, and designers hardly question the early commitments informed by representational access to the material and its design space. However, this trend is slowly changing towards viewing making and manufacturing as *"a service station for the designer to gather knowledge"* [23]. In order to realize what is truly possible with SMC's, researchers have emphasized the need to *"move away from an outcome or result driven design process"* towards an interest in understanding those technologies, through 'experimental engineering' [64, p. 197]. This is at odds with having *"a specific purpose in mind"*, implying a prioritization of intention and/or vision (i.e. top-down approach) when making such composites [65].

Among the approaches suggested for expanding ways of working with SMC's are improvised making, tinkering, and bricolage with existing technologies [64]. The need for hands-on experiences with the technology has been acknowledged in understanding, exploring, and sharing the expressive potential and the dynamic qualities of digital and hybrid technologies [59, 63]. Coelho's experimentation with conductive yarns and shape memory alloy wires follows a similar line of work, amplifying the suitability of craft techniques in realizing new technical and aesthetic possibilities at the intersection of smart materials and computation [12]. [19] has also shown in their work on ephemeral paper interfaces that manual fabrication becomes a critical part of exploring novel and unprecedented aesthetic qualities and expressions. The crafted SMC's in both works blur the boundaries between 'soft' and 'hard' materials in a different processes than just form-giving. These and similar attempts to use materials as an entry point for design practice represent a radical shift in HCI from application design (driven by task completion) to open-ended engagement with the materiality of present technologies [34].

Material-Driven Design Practices

As discussed, materials and their inherent properties can be a fundamental point of departure for discovering and exploring new functional possibilities as well as for designing distinct experiences or shaping desired practices. Over the last decades, the field of interactive arts has creatively stretched the use of technological components and materials (e.g., the work of Loop.ph with electroluminescent wires). A design project that takes the material as an entry point can be motivated by personal curiosity or fascination for a specific material, or commissioned by scientists or an external firm [43].

However, as design projects with a large variety of emerging materials from smart materials [50] to bio-based materials [38, 24] are becoming widespread in the field, design scholars have emphasized the need for a deliberate approach to the exploration and capitalization of materials' potential. Referred to as MDD [36], the approach pushes beyond the materials' current states of development, whether already developed and marketed, or still underdeveloped. The MDD practices challenge the assumption that design is to re-render *"what has already come to pass in the past"* [29], i.e., materials as given, finished and to-be-applied, and instead take materials as open, unfinished and to-be-designed.

What is distinct and deliberate about MDD practices is that they consider design variables that extend beyond product features such as texture and shape, to include, for example, micro-scale structure or direction of yarns or fibers in a composite, so that the material becomes something that needs to be designed (or redesigned) as well. It is this very rupturing of 'materials as finished' and a sensitivity to *"flows and transformations of materials as against state of matter"* [28, p. 210] that opens up a space for both the designer and the material to re-relate in combinations other than what has so far been thought possible.

By shifting designers' attention to what materials offer in direct experimentation [27], MDD practices approach 'making' as a way to unfold the material's capabilities in very-fine grained fashion. The capabilities are not characterized only in engineering and technical terms but also in relation to material experiences, i.e., *"experiential characterization"* [36]. The sensitivity for the qualities and actions elicited by the material in interaction [20] equips the designer with broad understanding of the capabilities.

The MDD practices foreground processual and performative understanding of the material in terms of what they do when you work with them and practically experience them [29]. This paper leverages on such understanding of smart material composites, facilitated through MDD practices, and explores the finer-grained entry points in creating experiential qualities, at performative level. It specifies certain phenomena and strategies that surfaced in navigating the performative possibilities, i.e., the design space in relation to performative characterization of these composites.

Notions of Performativity in HCI Design Practice

Performativity is a multivalent concept used within diverse fields. The idea of performativity initially was conceptualized as linguistic in nature, referring to *"the power of language to effect change in the world"* as opposed to *"describe the world"* [3]. It later expanded to consider the embodied and expressive character of human and nonhuman actions and engagements (or performances), always *"located at the creative, improvisatory edge of practice in the moment it is carried out"* [52, p. 199], and as such always specific and different from each and every other performance [51].

In the broad field of design, attention to performativity contributes to understandings of the ways in which artifacts are imagined, made and experienced, emphasizing that how the artifact looks like matters as much as how the material performs technically and experientially–that is, how it affects our perceptions and experiences [39].

In designing buildings, for example, attention to performativity calls for approaches that *"predates the post occupancy design considerations"* and equips the building with *"the potential to adjust itself to foreseen and unforeseen external contingencies"* [35, 41]. In the design of textiles, it may concern elasticity of the material construct of the garment, beyond its pure geometry, so that it can be open to change and alteration by the human body [53]. In product design, attention to performativity has spurred objects designed to disrupt a product expected experience or function, so to require unique performances and counteract prescribed behaviors and dominant routines [46].

In HCI, Spence [58] identifies four applications of the concept of performativity. These are in relation to: (a) the capability of things (e.g., words or artifacts) to act on the world; (b) an emphasis on processes and events (rather than the single object or result); (c) a focus on people's active engagement with the world; and (d) theatrical performance.

Contributions in HCI to understanding and applying performativity in relation to people's bodily engagements and theatrical performance is vast and substantial. It goes from foundational work on technology as situated [18] and as 'lived and felt' [45], to work that more specifically considers the interaction with a computer as a theatrical performance to be orchestrated [6], to projects that use performativity to emphasize the physically embodied nature of human interactions and what that means for designers [31, 32, 42], in particular their *"free-flow, non-directed conversation"* with design materials [26]. Embodied ideation methods, including role-playing and body-storming, have paid special attention to the corporeal aspects of imagining yourself in the minds and bodies of people carrying out practices [68, 21, 40], on the premise that *"by acting before understanding, we approach the possibility of learning in our bones"* [54, p. 51]. It is the line of HCI work concerned with bodily conversations with the design material (e.g., [26]) and how design can shape human and nonhuman performances (or capability to perform, more specifically in our case), which this paper contributes to.

More specifically, the paper relates to craft-oriented works in HCI that emphasize the role of pragmatic skillful engagement in supporting forms of knowing through an immersive sensory experience of the material at hand [15, 47]. HCI papers describing craft-oriented practices with traditional materials

include leather [62], hand-blown glass [55], and paper (e.g., [10]).

Similar to these studies, [37] illustrate a designer's journey in foregrounding the performative qualities of a range of materials. The design process is focused on the familiar practice of 'tuning the radio' to explore alternative and possibly more expressive performances for tuning (e.g., *kneading*). Here different materials and their unique qualities were considered in their performative character rather than as form-giving substances. However, in these early explorations of the performative qualities of materials, the bodily aspect of the performance is addressed from the perspective of the user only. In this paper instead, we are interested in teasing out the perspective of the designer in her making practice, and the strategies that have been put in place 'before understanding' and developing a vision for how the material should be infused in products. In doing so, the paper shifts the focus from selecting materials for their known performative qualities to an investigation of what the material may offer in response to the designer's skillful, bodily engagement in an open-ended design situation, in which the material is approached as 'underdeveloped.'

DESIGN EXPLORATIONS OF ELECTROLUMINESCENT MATERIALS

Electroluminescent materials are smart materials that emit light in response to changes in a strong electric field. They have been recently used for prototyping customized thin-film displays, because of the rapid and inexpensive fabrication techniques such as screen printing and conducive inkjet printing made available to non-experts [48]. These fabrication techniques enable luminescent materials to be easily crafted through tinkering with the layered structure of electroluminescent composites and their main constituting elements. These components include two electrodes (at least one of which must be transparent to let the light escape), phosphor, dielectric insulator, and substrate. The choice of electroluminescent materials as a case for our research is motivated by the EU project, Light.Touch.Matters. The project proposed collaborative development of smart material composites, by involving designers in the early processes of developing composites of thin-film luminescent materials and piezoelectric polymers. These underdeveloped pressure and deformation sensing luminescent composites could, as proposed, unlock novel experiences and applications, particularly in relation to their unique performative qualities. To identify the design space with these underdeveloped composites, we initiated several MDD projects, e.g., departing from unprocessed electroluminescent materials.

In this paper, we present four explorations from different MDD projects carried out by industrial/product design students at Delft University of Technology. These explorations are selected from five material-driven design projects. Three of these explorations were group projects conducted for the Materials for Design elective course; two were part of master's graduation projects. The elective course was approximately nine weeks, and graduation projects lasted from five to six months. All students were given the same design assignment
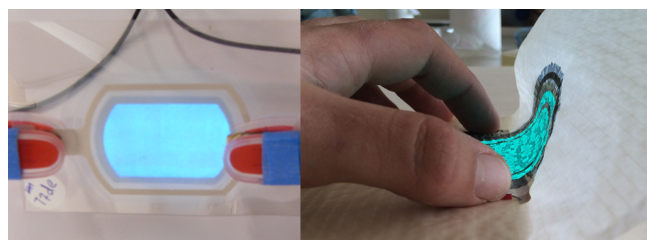

Figure 1. Two different layering sequences were used for bottom-emitting electroluminescent sample (left) and top-emitting electroluminescent sample (right).

to create product applications with the electroluminescent materials. They were instructed to follow the step-wise method of Material-Driven Design [36] which prioritizes materials understanding through tinkering and making, and promotes designing for materials experience.

Wondering 'how designers explore the performative qualities of electroluminescent materials departing from an underdeveloped state', our investigations focus specifically on the material making of the design students. The designers were initially acquainted with the 'materials experience framework' [20] and were offered an introductory workshop on the basics of electroluminescent material printing. The first author closely observed and made notes of their processes on a daily basis through direct supervision. The designers also were asked to document their process through written explanation, photographs and videos of their experiments and samples. By triangulating data from the first author's notes that were taken during these processes and data from the designers' own diaries (textual annotations, pictures, and physical materials samples), we reconstructed how each final electroluminescent sample has come into being. These served as input for the analysis of the design variables/phenomena at stake and their relations to the actions and qualities evoked by the created samples.

The reconstructed explorations were, accordingly, clustered in relation to the four variables/phenomena of 'matter', 'structure', 'form' and 'computation'. These concepts not only are largely used in materials science and design models [2, 66] and material-driven HCI research [65, 33, 17], but also were referred to (implicitly or explicitly) by the students. Anchoring the analysis and discussion to these concepts we were able to reach beyond the limits of our specific material case (electroluminescent materials) and to draw inferences that are relevant to a wider range of smart material composites. Interestingly, a converging strategy was identified in their making of performativity that is elaborated in the following section.

Making Electroluminescent Material Samples

In order to make an operational electroluminescent sample, the designers were instructed to print and cure (in the oven) three layers of materials on an indium tin oxide (ITO) coated polymer sheet in sequence. First, the phosphor paste was screen printed and cured in the oven and then the same procedure was repeated for the dielectric paste and, finally, for the silver paste. The electroluminescent sample made through this process is referred to as *bottom-emitting* sample, since light
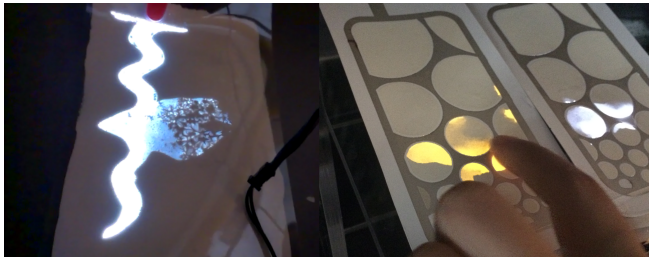
Figure 2. Using water as a replacement for the printed conductor in the bottom-emitting (left) and top-emitting (right) samples.
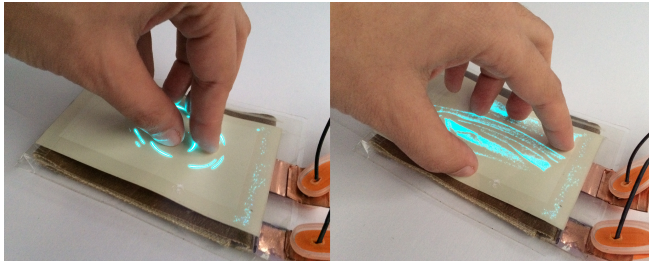

Figure 3. Using different conductive materials in between the separated structure.

Figure 4. The gradient effect achieved by altering the form of the printed top-conductor.

Figure 5. Tinkering process with the phosphor powder (left) and Silly-Putty (right).

exits from the rear side of the substrate sheet (Figure 1, left). Several *top-emitting* samples were also made, using variety of non-conductive substrates, such as paper and textiles (Figure 1, right). For fabricating those samples, the printing sequence had to be altered (silver, dielectric and phosphor) and a forth ingredient, the transparent carbon-based ink (i.e., PEDOT), had to be added on top. The samples were then connected to a powered DC-AC converter through dedicated connection points and, in case of no defect, lit up.

Besides the knowledge of the layering sequence and the ingredients and know-how of screen printing in making operational electroluminescent samples, all the designers were equipped with a higher level understanding of the electroluminescent basic working principles. For instance, in either top or bottom emitting sample, the phosphor paste must be enclosed between two electrodes or at least one electrode must be transparent. The underdeveloped state of the electroluminescent materials, when accompanied by the conceptual and practical support, enabled them to explore the relationship of matter, structure, form, and computation for creating an expanded set of (performative) qualities.

Design exploration #1: Matter
In an exploration series, the designers followed the layering sequence presented in [19] to create samples that require water to illuminate. The realization that the solid electrodes can be partially replaced with liquid conductors motivated new ways of interacting with electroluminescent materials. As shown in [19], water can be *sprayed* (e.g., using a syringe) or *splashed* using hands. In addition to water, the designer experimented with a water-based gooey substance (i.e., Silly Putty) on both bottom- and top-emitting electroluminescent samples and explored the action possibilities of incorporating different matters. Since electroluminescent requires relatively high voltage, it is not safe to simultaneously touch the top and bottom
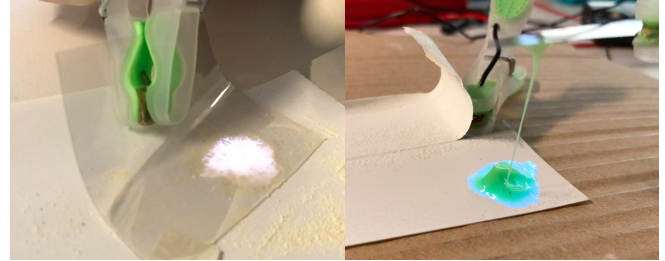
electrodes. Isolating the bottom conductor from skin contact, the designer created safe-to-touch samples that elicited playful interactions such as *sweeping* and *brushing* with fingers (Figure 2, right). In another trial of this exploration series, the designer made a bottom-emitting sample that was placed over a smear of Silly Putty and water (Figure 2, left). This sample elicited very different range of actions, including *pressing*, *stroking*, and *poking*. Viscosity of the Silly Putty and its sticky and bouncy qualities were key in encouraging those actions.

Design exploration #2: Structure
In another exploration series to make active samples, the designer separated the two electrodes. The possibility was accidentally discovered by [19], when they used an ITO coated polymer on an unfinished electroluminescent sample (which was basically missing one electrode). The structural intervention resulted in two separate sheets that do not emit light unless assembled and pressed against each. The two separate sheet allowed the light output to be varied in pattern, corresponding to the conductivity and contact area of the conductive materials placed in between them (Figure 3). The designer harnessed the qualities of conductive materials, including textiles (e.g., to wrinkle) and rubber (e.g., to bounce back) to stimulate variety
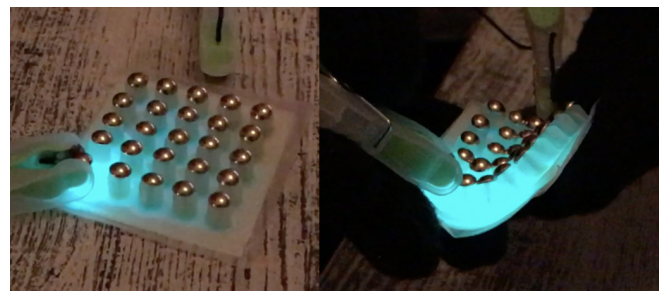

Figure 6. The electroluminescent sample with multiple bulgy contact points.
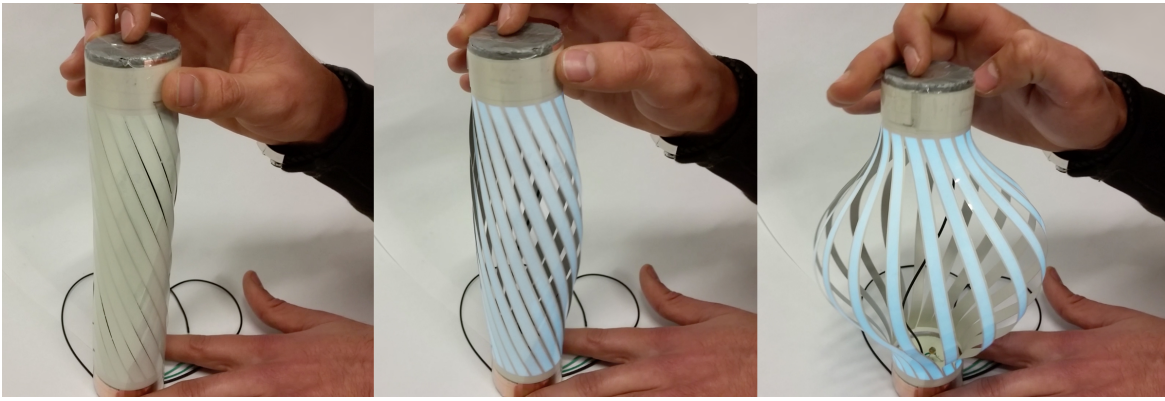
Figure 7. Computationally corresponding action with electroluminescent light intensity.

of actions such as *rubbing* and *pressing with the palm*. In the interplay between structure and the interactive/experiential qualities, the sample is both operational and flexible/adaptable, inviting the designer to further explore the relationship of material, body, and light.

Design exploration #3: Form
The next exploration began with a discovery that length of the top electrode can be a variable in designing with electroluminescent materials. The ratio of length to area determines electrical resistance of each point along the printed line, and, by playing with the resistance, a gradient effect can be created. The designer, accordingly, prepared a serpentine pattern for printing the top electrode (i.e., PEDOT) on a thick paper substrate. Using multiple connection points, the light gradient could be moved along the printed trace, as illustrated in Figure 4. To access the middle parts with the connection clips, the substrate was cut, leading to an accordion form, which also allowed for *stretching* and *contracting* actions. Inspired by such stretchable form, the idea to incorporate additional contact points at the edges of the cuts was also envisaged. With such modification, possibly, the gradient light could grow and shrink corresponding to the action.

In another project, the designers take the idea of corresponding the light spatial movement with people's action to a new level. They began with a series of experimentation with (cured) phosphor powder, to see if it can light up in between two ITO sheets (one insulated with layer of dielectric). However, except for hardly visible sparks not much of light could be produced by this recipe. They continued the experimentation by sprinkling water on the powder and the uncured phosphor paste, which in both cases resulted in visible light output (Figure 5, left). Seeing that liquid-form phosphor performs better, the idea of using powder phosphor was abandoned. Similar to the exploration #1, the designers printed the phosphor layer on the insulated ITO sheet and explored with Silly Putty. The possibility of having the connection point distant from the unfinished printed sheet was experienced during their tinkering with Silly Putty (Figure 5, right). Having multiple Silly Putty lumps on a single sheet (that basically leveled the connection points) let the designers light the phosphor underneath individually or collectively, depending on the positioning of the loose powered ITO sheet. Understanding how the height of

the lumps unlocked new action possibilities, they created a sample that combined the idea of multiple connections and the structural separation (exploration #2). By making an array of small bumps with metal caps on a sheet of silicon (Figure 6), the designers conditioned activation of the phosphor in each bump to making contact with the adjacent ones. The design requires people to *bend*, *squeeze*, and *knead* the silicon sample to spread the light.

Design exploration #4: Computation
Besides inspecting how matter, structure, and form of the electroluminescent materials contribute to creating novel performances, the designers also re-examined the possibilities of manipulating the electrical connections and control unit. Creating a range of cuts (inspired by Japanese art of Kirigami), that allow the 2D surface to become 3D objects, the designers followed a more classic approach to exploring the action possibilities. The performable structures, however, did not provide any response unless an external sensing component was incorporated. With no structural alteration and relying merely on a cutting technique (form), an intermediate object (not sample, nor a product) [5] was created. As illustrated in Figure 7, the object could deform between a closed cylindrical and an open vase-like shape. The designers realized that such deformation can control entry of the surrounding light into the cylinder. Thus, the electroluminescent light output could be conditioned by people's action (e.g., *twisting with a gentle inward press*) by means of incorporating a light sensor inside the cylinder and modifying the electroluminescent driver electronics.

THE MAKING OF PERFORMATIVITY IN MATERIAL-DRIVEN DESIGN PRACTICES
Skillful engagement with electroluminescent materials enabled designers to get a feel for action possibilities of the material that were unknown and unrealized in the early stages of the process. Designers' performances were key in perceiving and materializing the affordances of electroluminescent materials. Studying this making process enables to explain how such performative potential was actualized. The cases used to illustrate the process pinpoint and identify variations of what we believe is an overarching *disruption* strategy in characterizing and mobilizing performativity.

Figure 8. Thick Cutlery Set (left) and Chained Fork (right) by Katherina Kamprani. (https://www.theuncomfortable.com/).

Figure 9. Paper Torch by Nendo (http://www.nendo.jp/en/works/paper-torch/).

Approaching electroluminescent materials through a rupture of their components destabilizes conventional boundaries between human and nonhuman performances, and displaces the common designer-technology relations. *It is through this material-driven displacement that a space opens up for the designer and the electroluminescent material to perform and relate in combinations other than what has been initially thought possible.* This departure from common designer-technology relations relies on a performative understanding of the composite as underdeveloped.

Disruption of Affordance as Design Strategy
The term disruption has been increasingly used over the last years mainly in relation to design thinking in business innovation [14, 11]. Often, disruption of the known and existing is needed for change to take place. Design is a practice particularly apt to make change happen. Disruption in this case refers to the problematizing attitude of the designer along the process of making and conceptualizing, in the urge to push boundaries.

At the product level, pushing boundaries by means of disruption is often the result of a disruption of the function conventionally attributed to well-known objects (e.g., dishware). For example, [46] has designed a series of *"performative objects"* meant to be forcefully social. By breaking the *"plan for action"* embodied in the product, the designer fundamentally disrupts patterns of perception and preconception. From this series, 'Social Cups' are designed to shape people's interaction with each other by means of a deliberate functional disruption. Five round-bottom cups are connected by a mechanism that allows them to stand upright. When at least three cups are connected, they form a stable unit. As the function of standing is disrupted if more cups are detached, people are encouraged to socially interact with each other in a mindful way. As a consequence of this functional disruption and the actions put in place by people to compensate for the disruption, people perform with the cups in an unconventional way, which in Niedderer's work is meant to promote sociability. Other examples of functional disruption can be found in the product series called 'The Uncomfortable' (see Figure 8), designed by Athens-based designer Katherina Kamprani. Being deformed (e.g., a watering can), too thick (e.g., thick cutlery), not sturdy enough (e.g., chain fork), these products incorporate various strategies to break the affordances necessary to perform the conventional function of *watering the plant* or *eating*. In this series function is disrupted without offering a clear means of compensation or an alternative plan for action [46]. They are
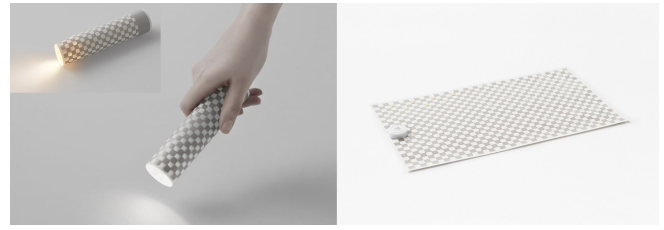
intentionally dis-functional. However, in both Niedderer's and Kamprani's work, the expectation to perform and the norm of efficient functionality are equally challenged. While both sets of objects maintain visual and semiotic references to the original product categories (champagne glasses, cutlery), at the pragmatic level they disrupt the *expected affordances* of those categories. A similar approach in HCI design practice is found for example in [49].

When it comes to the material level, disruption is rather a more fine-grained rupture aimed to actualize *unexpected affordances*. Imagine that we have a rigid composite sheet developed originally for certain structural performance. The heterogeneity of the composite, in making, allows for a range of samples that are fully rigid, fully flexible, or both qualities at once (e.g., rigid from one direction, flexible from another). After being fabricated, however, the flexible sample and the patterned sample enable new action possibilities that were not afforded readily by the rigid composite. In MDD practices, materials are often processed and treated to prompt new and unanticipated qualities, beyond established boundaries (e.g., [61]). These boundaries can be our expectations for materials to perform in certain ways and/or a norm of efficient functionality [46]. An example that gets close to challenging those boundaries is 'Paper Torch' by Nendo (Figure 9). The flat surface may not maintain visual and semiotic references to a torch, but it affords rolling so that it can be gripped in hand the way a typical torch is handled. By varying the path length of each LED, corresponded to how tight the paper is rolled, brighter or dimmer lighting can be achieved. Moreover, due to the characteristic of the LEDs, the light color can switch between warm orange and while color, as the paper is rolled inside out. Here, perhaps, the *ambiguity of affordances* and an intentional resourcefulness of Paper Torch are accounted for its adaptation in different use situations and the unfolding of new performances.

In the electroluminescent cases described in this paper, we noticed similar diversions from existing recipes that can be framed as various manifestations of affordace creation through disruption. Borrowing Niedderer's logic, we may say that changes in matter, structure, form, and computation disrupt the light-giving 'function' of the electroluminescent materials that was initially afforded by the switch. Performativity is thus achieved through deliberate disruptions of this obvious plan for action and by introducing other means to compensate for it. Anchoring to design variables of matter, structure, form, and computation, designers managed to variously disrupt the efficacy of switching On/Off action and materialized new ac-

tion possibilities involving people's corporeal interaction with the luminescent material.

In exploration #1 and #3 the state of the conductor is variously altered (liquid, solid, gel) to diversify action possibilities. By taking the state of matter as an entry point [17] and replacing the solid conductor with liquid or gel conductors, the designer breaks the static interaction pattern and enables creative patterns of action to unfold. In exploration #2, the loose structure enables a wide range of actions from adding different conductive materials in between the substrates to modulate the contact area, by stroking and pressing the modified composite to reveal the patterned light. In both explorations, the electroluminescent driver as well as the connection points stay intact and unchanged.

On the contrary, in exploration #3, the designers increase the control states between solid-surface illumination and dynamic patterns by increasing the connection points, facilitated by the specific form of the sample. These connection points, basically, intervene into how the electroluminescent driver and the composite structure interface. By channeling stimuli (electric current) through more connection points, an originally single-contact electroluminescent composite is transformed into a multi-contact sample. In other words, the designers made a matrix of electroluminescent patches that were individually controlled through physical engagement with the substrate. Finally in exploration #4, the designers did not change the material structure, as both the layer sequence and the components stayed the same. Instead they hacked the electroluminescent driver and controlled the electrical stimuli based on the input from an ambient light sensor. The particular form of the object and the programmed behavior together could then influence the light output in relation to one's action.

The material samples created by the designers do not have a specific function, like a cup or a fork might have. Rather, the expected light-giving quality of electroluminescent materials is disrupted through structural and non-structural interventions, with deliberation to open up new action possibilities. In this way, the samples can give light in ways that move past the conventional switching of an On/Off button. Because the novel performances, afforded by the new action possibilities, unfolded in the making process cannot be easily 'restored' in the context of use, designers will need to think of how to invite people to splash water or move the gradient light. In all the described cases, after creating the material sample, the designers were asked to explore which conditions and situations might help facilitate the performances encountered by the designer in the making process. For instance, inspired by the gradient quality of light output and the possibility of spatially moving it across the printed pattern, the designers came up with the idea of a 'discovery' book for children. As shown in Figure 10, the solid print of the top electrode conceals the hidden visual pattern that can be revealed by means of moving the torch (electrical connection) over the page. The torch provides a symbolic cue to hint how the content of the book might be accessed. Without active browsing using the torch, the content of the page remains invisible. In this example, the deliberate disruption of the book function (i.e., providing visual content)
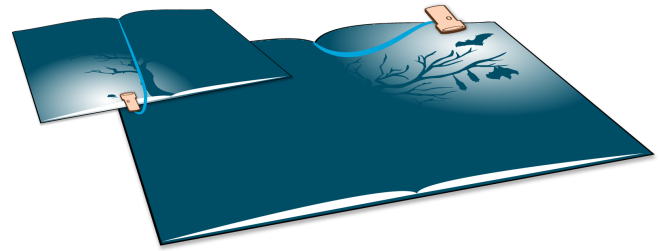

Figure 10. The children book concept, inspired by the gradient sample.

and resulting curiosity to see the content of the page encourage desired performances in a specific context of use.

Understanding the Material as Underdeveloped

When designing (with) smart material composites, being able to bodily engage and collaborate with the material to elicit unexpected performances is key to encounter new capabilities and demonstrate *different faces of a material* (cf. [24]). The Material-Driven Design approach grafts onto existing creative practices (e.g., interactive arts) and materials but it also moves past practice-based material exploration and customization to create new opportunities for a broader spectrum of designers. This performative understanding of the material echoes theoretical positions that regard matter as an active participant, denying that there are representations on the one hand and, somehow, separate entities awaiting representation on the other hand (cf. [4]). The conceptual articulation of smart materials as underdeveloped composites is critical to unpack the ways in which designers might methodologically bring about the performative potential of a smart material by means of variations, hacks or disruptions of the electroluminescent material's matter, structure, form, and mechanisms of computation. In this perspective, materials are understood and acted upon as unfinished or underdeveloped entities, which we have referred to in this paper as 'the making of performativity'.

To explain how the designers enacted the performativity of electroluminescent materials, both *properties* and *function* seem to be insufficient concepts. The former qualifies an existing material sample (answering what it is), while the latter concerns its contextual purpose (answering what it is for). The relational concept of *affordance* [22] perhaps can provide designers with a more inclusive and useful approach–as in Gibson's original definition, an affordance is just *"a material disposition"* [25] where both properties and function are underspecified.

While the making of affordance (e.g., portability) in design can be driven by having a clear function in mind (e.g., serving food), MDD practices take a rather *bottom-up* understanding of affordance that is anchored to the material. In tinkering with an underdeveloped material whose affordances can still be manipulated, the way in which the designers act upon the material may become the medium for materializing affordances (cf. [16]). For instance, as discussed in exploration #3, the electroluminescent cardboard unfolded new possibilities for action and expression once practically cut to reach to the middle part of the cardboard.

Initial hypotheses in the making of composite might be useful when designers have sufficient understanding of the range of technical and experiential qualities of the composition, in relation to the envisioned context of use. For instance, in the explorations with electroluminescent materials, designers were able to make assumptions based on prior knowledge of physics law (e.g., the possibility of gradient light due to the inverse relation between resistance and current). Even in that case, later in the process of making the children book, the whole page lit up and the actual prototype did not work as envisioned (see Figure 10). While a technical explanation is that the large printed area has comparably small resistance to create the gradient effect, additional experimentation and making iterations were necessary. As Ingold points out,

> Thinking does have the habit of running ahead of making and it does. There is to which we are not just feeling our way forward but in which our actions are being pulled in front. Our imagination runs a head of what we do. And yet when we are working with materials there is a limit to how fast we can move. Materials have their own way. they held us back momentarily in check with slow movement of working with materials [29].

Compared to amateurish tinkering, the skillful making informed by both technical and practical knowledge is a clear advantage of MDD practices that promote a performative understanding and engagement with the material as always 'unfinished.' In such practices, the rupturing of the material to new capabilities can be considered as a form of *affordance-making*: *a making process in which both the designer and the material perform in response to the skillful exploration of not-yet actualized affordances*.

CONCLUSION

In this paper, we have presented and discussed a number of material-driven design (MDD) explorations which take their departure from an underdeveloped smart material composite, specifically an electroluminescent material composite. These explorations are focused on the creation of electroluminescent material samples with novel action possibilities and are facilitated by the designer's skillful engagement with the electroluminescent material. In describing the making processes, we have articulated how bodily manipulations of matter, structure, form, and computation can facilitate the emergence of certain performances. Examining the explorations from the perspective of what we refer to as the 'making of performativity' in MDD practices, the paper introduces the idea of *disruption of affordance* as a design strategy for working with smart material composites. We conclude by promoting how such conceptual articulation of smart materials as underdeveloped composites may unpack new ways of bringing about the performative potential of a smart material and revealing its latent affordances. In the MDD approach, as proposed, materials are understood and acted upon as always unfinished or underdeveloped. This offers HCI design practice with smart material composites a better leveraging of the dynamic properties of such materials, and potentially more dynamic responses and performances by the products in which these materials may be infused.

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