Designing with an Underdeveloped Computational Composite for Materials Experience

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Abstract

In response to the urge for multidisciplinary development of computational composites, designers and material scientists are increasingly involved in collaborative projects to valorize these technology-push materials in the early stages of their development. To further develop the computational composites, material scientists need designer's inputs regarding the physical properties and temporal behavior of the composite, as embodying an application in a context of use. Effective communication of material knowledge and design knowledge between the two disciplines (material science and design) has proven to be challenging due to their different perspectives on materials. Designing appropriate product concepts requires understanding of composite's unique characteristics and creating aspired value closely linked to those characteristics. Our design case shows that designing for materials experience can provide a useful framework to organize the design activities around understanding the technical and experiential characteristics of underdeveloped computational composites. Collecting and making tangible samples, outlining and simulating possible physical and temporal behavior and discussing them with material scientists and users improved designer's understanding of the underdeveloped computational composite. Our study points out the need for clarification of possible aspired values in designing with computational composites and discussions on those, prior to determining the design/development path. Further, it underscores the multifaceted role of prototypes in resolving uncertainty associated with material knowledge and a preferred design path and mobilizing design actions, that entails further investigation.

Keywords

design process; computational composites; materials experience; design-driven innovation; smart materials

Recent advances in material engineering and manufacturing techniques, and miniaturization of electrical components have given rise to a large number of technologically viable as well as large-scale producible material compositions. So-called 'computational composites' (in short CCs) (Vallgårda & Redström, 2007) are possible assemblages of smart materials with embedded electronics that are able to convert particular forms of energy reversibly (e.g., to/from electrical energy). They can be programmed to dynamically change their physical features, such as color and texture, in response to external stimuli (e.g., touch, temperature, etc.).

A large number of future CCs are still in the early stages of their development (i.e., underdeveloped; Fig 1), meaning that their components are rather experimental and not yet integrated in materials of applications. Recently, there have been systematic efforts to produce CCs made of smart materials in collaborative projects between designers and material scientists (e.g., Light-Touch-Matters (http://www.light-touch-matters-project.eu/), Project Solar-Design (http://www.solar-design.eu/project)). The underlying goal of early collaborations and consultations with designers is to guide the development of smart material composites according to both experiential and functional advantages (Miadownik, 2007; Wilkes, Wongsriruksa, Howes, Gamester, Witchel, Conreen, Laughlin, & Miodownik, in press; Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015). Communicating the potential of new technology, exploring and demonstrating applications for new technology are among variety of ways that designers can benefit co-development of new technological materials (Nathan et al., 2012). Understanding unique characteristics of the composite (both technical and experiential) and creating aspired value (e.g., certain experience) closely linked to those characteristics are critical steps in designing appropriate and meaningful applications (Karana et al., 2015).

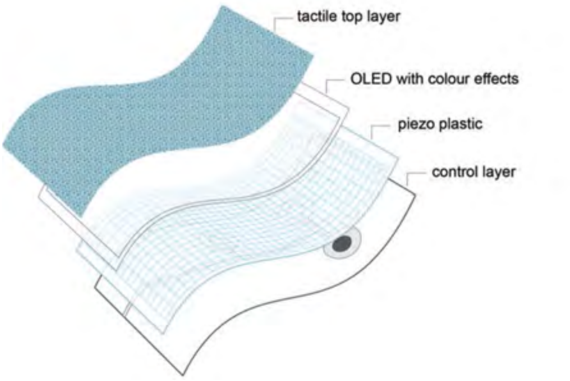

Fig 1. Schematic representation of an underdeveloped CC, Light.Touch.Matters (source: Miodownik and Tempelman, 2014)

Regardless of how CCs are labeled, as physical/digital materials or technologies, designing with them is phenomonologically similar to other material or technology-driven situations, with a difference that early in their development process CCs are hardly available to be directly experienced and tinkered with. So the questions raised are: how can designers explore CC's potential and design with it based on material information provided by material scientists? What strategies can designers rely on to improve their understanding of the CC and its unique characteristics? And what design activities or tools can support them through the process of understanding and designing?

In an earlier study, we suggested the logical equation of 'what' +'how' leads to 'why' as a basis to analyze the design situations starting from an underdeveloped CC (Barati, Karana, & Hekkert, 2015). Our three cases showed that designers relied on 'framing' and 'analogical reasoning' to bridge between the CC's properties (e.g., producing electrical current when deformed) and an aspired value. Analyzing the CC in terms of its functional and experiential qualities supported designers in building such bridges. Adopting the model of product impact (Fokkinga, Hekkert, Desmet, & Özcan, 2014), we explained how the three levels of property, user-product interaction, and overall effect encompass the designers' activities concerning the completion of the equation.

In this paper, we present a six-month journey of a Master's graduation project departing from an underdeveloped CC, Light.Touch.Matters (LTM materials), and finishing with a demonstrative application. We look into the design activities she carried out for bridging between and across the levels and determining the aspired value, and discuss the tools and strategies she relied upon. Our insights on her process help us identify areas that need further in-depth research.

Challenges of Designing with Computational Composites

Designing with CCs in collaborative projects imposes multidisciplinary challenges as well methodological challenges (Redstörm, 2005). Coming from very different backgrounds, designers and scientist have different perspectives on materials, properties and technical limitations, and use different language to communicate. Particularly in the early stages of development, designer's understanding of what the technology is and is capable of is mainly through the material science channel. Such understanding is possibly limited to material's main technical characteristics, functional principles, existing processing/manufacturing techniques and applications. In order to design for materials experience, designer's understanding of CC should encompass not only *what it is* and *what it does,* but also *what it expresses to people, what it elicits,* and *what it makes people do* (Karana et al., 2015). In other words, designers need to make sense of the CC information both as a design material (which needs to be shaped/integrated into a product) and as experienced in use (supporting/hindering certain actions and values).

Methodological challenges of designing with a CC are concerned with the digital-physical nature of CCs and their dual citizenship in embodiment and function of the application (Wiberg & Robles, 2010; Redstörm, 2005). In addition and in relation to the static physicality, CCs also characterize certain temporal behaviors that need to be defined. Designing with CCs is, therefore, not only a matter of giving them physical form, but also envisioning their temporal characteristics as situated in the social, cultural and behavioral context of use (Rosner, Ikemiya, Kim, & Koch, 2013)—within a 'situational whole' (Karana, 2009). Over the past decade, many design researchers have invested a great deal of effort in exploring affordances and expression possibilities of programmable materials (for a review see Wiberg, 2014). However, horizontal material explorations, reported in many of material-related studies in the field of interaction design lack what Wiberg (2014) calls 'the matter of purpose', i.e., value and meaning creation as the ultimate aim of design.

Recently, Wiberg (2014) proposed a methodology for material-centered interaction design research that emphasizes a back and forth thinking between 'materials' (i.e., material properties and character) and 'wholeness' (i.e., way in which the material is approached from the perspective of the user, and appraised within a composition). Through designing material surface, particularly texture and by elaborating on aesthetic details, designers organize the material properties into applications, and communicate certain qualities and values (Wiberg, 2014). Iterative cycles of making material samples and testing with users allow designers to explore material's experiential qualities (Karana et al., 2015) and verify their success in communicating the intended qualities and values. Tinkering with the material is also encouraged to obtain practical knowledge on its main technical properties, limitations and possible manufacturing processes (Karana et al., 2015). In designing with CCs, designers need additional technical competences such as programming and working with electronic component such as sensors and actuators to embody the temporal characteristics (Bergström et al., 2010; Vallgårda & Sokoler, 2010).

From Underdeveloped Computational Composites to Aspired Values

Any purposeful design process aims to close the logical equation of 'what' +'how' leads to 'value' (Dorst, 2011) and the situation of designing with an underdeveloped CC is no exception (Barati et al., 2015). In an open technology-driven design brief, the starting point and the only constraint is the technology itself (i.e., a fraction of 'what', in this case properties of CCs) and designers have freedom to designate virtually any aspired value as long as the proposed design exploits the unique characteristics of the technology. But where does designer's intended aspired value come from? Is an underdeveloped CC a neutral object or does it invite certain ways of dealing with it (Ihdle, 1990)? In order to design meaningful applications, looking exclusively at either the human or technological side would not suffice, instead the designer require consideration of the complex relations that the technology makes with other artifacts or the context of its use (Jung & Stolterman, 2012). Designing with a technology to create value involves three types of investigations, as discussed by Friedman et al. (2013): technical, conceptual, and empirical investigations. Technical investigations aim for understanding the technology in the light of its 'value-suitabilitie' (i.e., the range of activities and values a technology supports or hinders). To discuss and assess an aspired value of an application the central constructs of 'what values' and 'whose values' should be first conceptualized (i.e., conceptual investigations). Empirical investigations comprise surveys, observations, and experimental studies that help designers study the human context in which the technical artifact is (or will be) situated.

In case of CCs, the communicated properties, characteristics etc. are the only given inputs. As a result sooner or later designers reason from them (or link to them) to the two unknowns of the equation, namely 'how' and 'why'. In order to be able to design with a technology, designers need to interact with it and make sense of it (Orlikowski & Gash; 1994). In this sense-making process, they develop particular assumptions, expectations, and knowledge of the technology, which then serve to shape subsequent actions toward it (Orlikowski & Gash; 1994). In our earlier studies, we realized that design students adopted frames of reference in absence of the actual material, for example an activity like CPR, to explore CC value-suitabilities and to complete the logical equation (Barati et al., 2015). Established activities such as Yoga and boxing, encompass the 'how' and the 'why', and make designer's life much easier in coping with uncertainties regarding CC value-suitabilities. We also observed that a frame of reference could be a theme, which is not associated with a definitive context, such as "way finding in the dark" or even a metaphor such as "parasitic". The important feature is that it helps a designer to build a hypothesis which brings the properties of materials forward: IF this combination of properties are seen from this particular lens THEN they may elicit such aspired value and applicability. In the case presented in this paper, we encouraged the student to design for materials experience through exploring and reflecting on the CC's experiential qualities at sensorial, affective, interpretive and performative levels (Giaccardi & Karana, 2015).

A Case: Interactive Cape Jacket

Our case was defined in connection to a EU project, the Light.Touch.Matters, which brings together designers and material scientists for the goal of design-driven material innovation (Verganti, 2009). The underlying goal of design-driven material innovation is to explore potentials of the technology in opening up new experiences and to further develop the composite according to the design requirement. The LTM materials are composites of two main components of flexible OLED and Piezo electric polymer. The LTM materials feature some main characteristics due to their thin and flexible structure and their pressure and position sensitivity and surface lighting. Since the composite is still in the early stages of its development, it can be merely communicated through description of its components and main characteristics and limitations (provided by material scientists).

In a 6-month graduation project, a Master's design student was asked to (1) explore and communicate unique characteristics of the LTM material and (2) embody the LTM material in a product concept that stands out from its categorical benchmark due to a creative use of the identified unique characteristics.

In order to map the designer's journey from the introduced LTM material to an interactive cape jacket concept (Fig 2), we use the mapping tool we developed earlier in Barati et al. (2015) (Fig 3). The mapping tool consists of three main levels: property level, interaction level and overall effect level which provide a useful landscape of design activities with the aim of navigating design possibilities of an underdeveloped CC. Design activities at property level correspond to 'what' a material/ or future product and their properties are (i.e., descriptive). Design activities at the interaction level correspond to 'how' a material and its properties afford certain forms and functions, how they gratify senses, evoke meanings, elicit emotions and facilitate unique actions/performances (i.e. *materials experience*; Karana et al., 2008; Giaccardi & Karana, 2015). Design activities at the overall effect level encompass any other explorations and investigations regarding the purpose of the material/product (why) and the context of use (where and when).

In addition, the mapping tool supports capturing how various frames of references and eventually design intent facilitate bridges between the property level and the other three levels (dashed line in Fig 3). The connection between the levels is thus used to discuss the aspired value in relation to what ultimately the designed application intends to offer, including value in changing the appearance and adding new functions, value in changing experiences of existing products, and value in changing the purpose for which the existing product are used or in unfolding unforeseen practices. It is important to note that changing the appearance/function, for example, could be a means for reaching to an intended experience or changing the product purpose. The model try to capture to what extent the designer is aware of these moves and influences them in the design intent.

Fig 2. The final concept and prototype

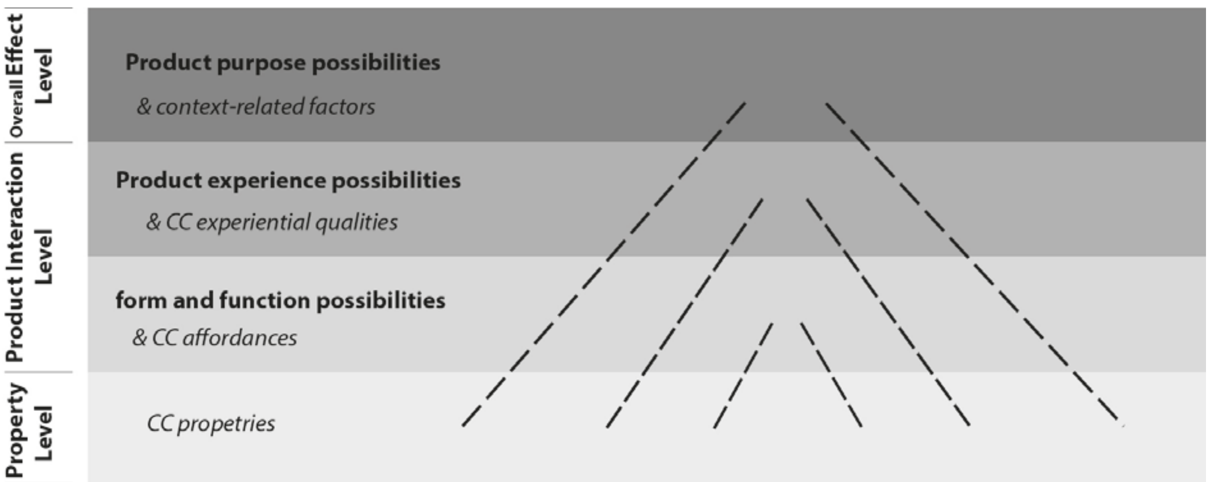

Fig 3. Mapping tool (source: Barati et al., 2015)

Fig 4 illustrates the sequence of designer's activities in connection to the levels presented in the mapping tool. In the following paragraphs, we first report on the main design activities, including mapping the properties; exploring the promising application areas; hands-on material exploration and simulation; materials experience investigation; vision creation, and iterative concept development. While all these activities supported the designer to approach the design assignment systematically, some activities were more critical in addressing the challenges of designing with the LTM materials as underdeveloped CC. We explain the necessity of those activities in material understanding and characterizing, when dealing with information, rather than an actual material.

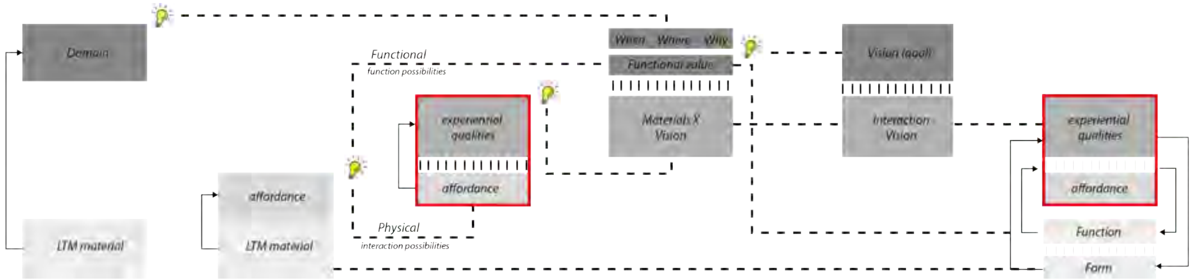

Fig 4. Sequence of designer's activities according to the levels of the mapping tool

Mapping the properties

The designer started the journey by mapping the properties of the two main components of the LTM materials and their overall characteristics according to the information inquired from a material expert. She developed pictograms of the properties and a video showing the main components emphasizing their particular properties (e.g. water resistant) (Fig 5) to map and communicate the material information.

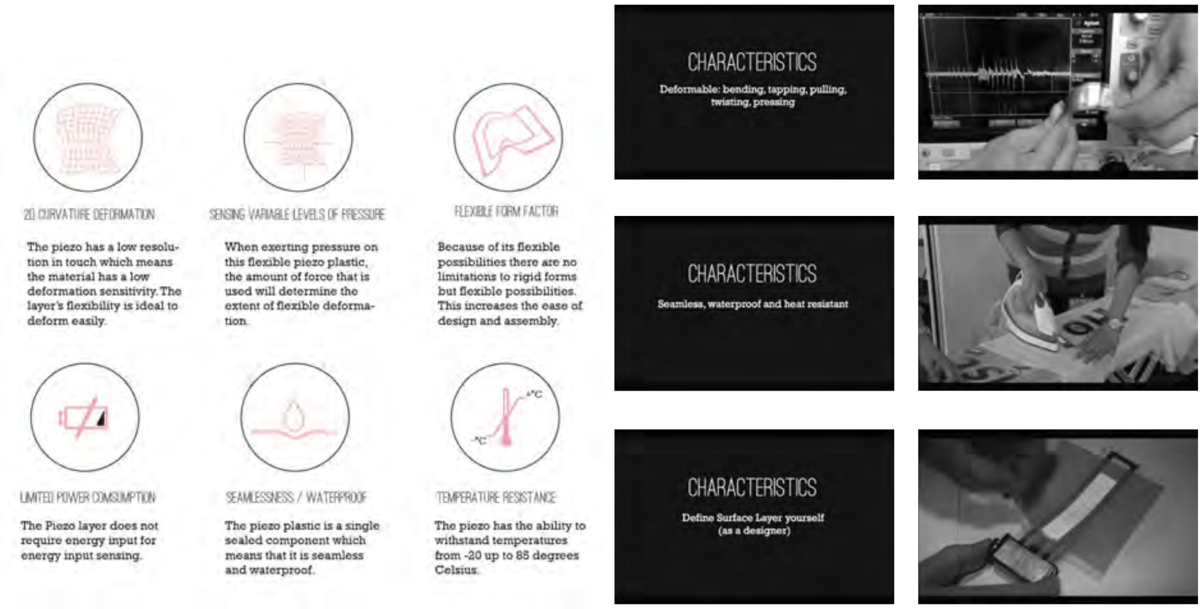

Fig 5. Examples of the pictograms (left), screenshots of the video (right)

Exploring the promising application areas

In a generative session, she invited 5 other design students and designers to identify the promising domains of application based on the provided information. She then cross-related the identified areas to the pictograms and ranking the application areas according to the number of properties that could come into play (Fig 6). The generative session, discussions and reflections on the application areas in relation to the mapped properties helped the designer realize the landscape of competing values (e.g., autonomy vs. security). Such thoughtful consideration of how people might be personally/socially impacted by a technological design involving the LTM material, are the initial steps towards conceptualizing specific values (e.g., conceptual investigations; Friedman et al., 2002). In Fig 4, the designer's first move between the levels is shown using an arrow from mapping the properties to the domains/context of application. By this move, the designer reached out for existing product categories, trends, activities, themes and domains (e.g., rehabilitation) to reflect on the overall effects and purpose of the LTM material in composition.

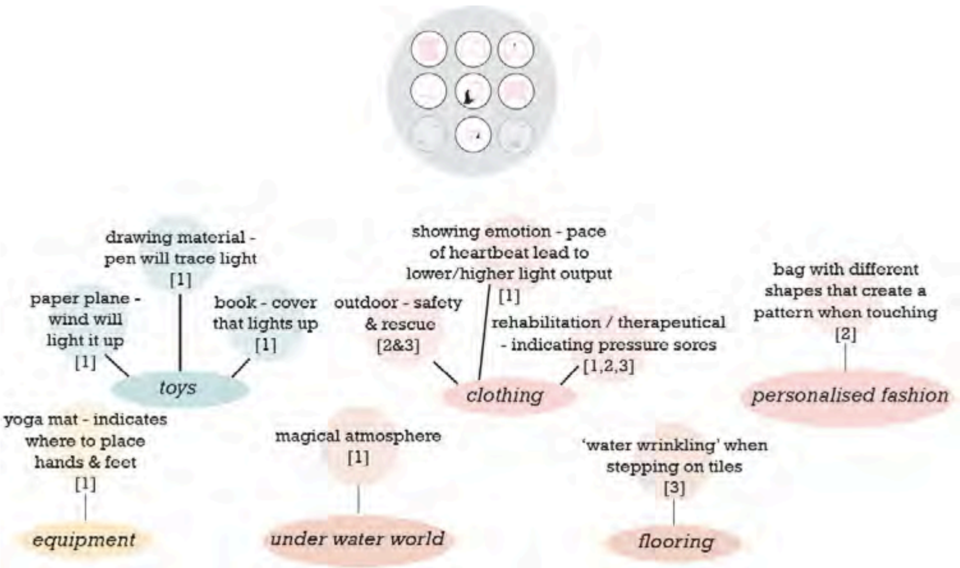

Fig 6. Mapping possible connections between the properties and application areas

At the end of the generative session, the participants were asked to describe their experience of the assignment and discuss the role of pictogram and video in understanding the LTM material. According to the discussions, it is concluded that:

(1) Designers experienced high level of uncertainty regarding what exactly the technology is in terms of feel and experience. They believed that having no material sample hinder an understanding of the LTM material that can be operationalized and readily translated to what can be done with it.

(2) The video, compared to the pictograms, was more successful in sparking a tangible manifestation of the LTM material, however, designers could not transcend literal translations of what they saw in the video.

She deliberately decided to postpone any context-related fixations in the early stages of design process since they could narrow down the design possibilities up front. Instead, she focused again on understanding the LTM material and helped herself (and other designers) understand it in terms of what could be done with it (i.e., affordances) and what experiences it could elicit (i.e., experiential qualities). She hoped that by gaining insights on how the material actively operates, a cohesive design goal, encapsulating the desired impact, the experience and interactions, could be formulated.

Simulating the LTM material and exploring form and interactions

Designer's next activity towards understanding what can be done with the LTM material was to simulate it according to the given specifications, namely the thickness and the radius of flexibility. She made a small tangible library (Fig 7) exploring various textures, forms and printed light patterns (in connection to printability of OLED) and tried to connect the physical aspects of the LTM material to the possible forms and actions they afford (both the actions and how they are performed, i.e. performative qualities; Giaccardi & Karana; 2015). As indicated with an arrow in Fig 4, her hands-on approach enabled a move from material descriptive properties to navigating form and action possibilities of the LTM materials. It was also a takeaway for the designer toward further exploring the experiential qualities that those actions might elicit. The collection of samples formed in different ways not only gave a tangible manifestation to myriads of properties, but also facilitated a more factual and detailed communication between the designer and the material expert. As a result, a more elaborated understanding of the LTM interaction possibilities in connection to the properties and its functional principle was developed.

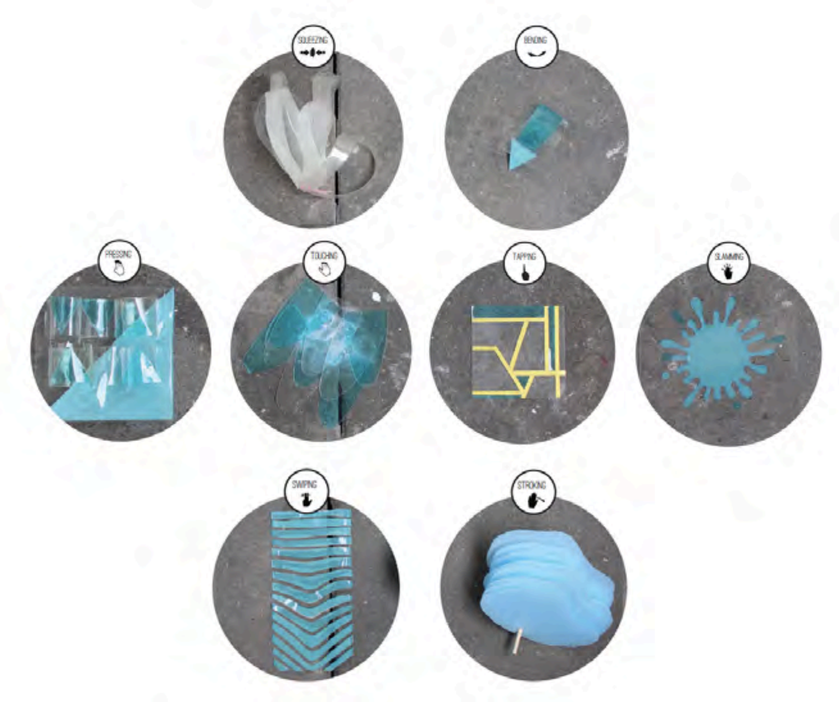

Fig 7. Exploring textures, forms and printed light patterns in tangible samples

Investigating the experiential qualities

Although her understanding of form possibilities with the LTM material had improved considerably, as a result of her hands-on explorations and discussions with the expert, to be able to design she needed to understand how the LTM material and its sensorial properties would be experienced. Karana et al. (2015) emphasize the importance of such understanding and investigating the interrelationships between experiential qualities and the formal properties of the material. Formal properties of a CC include the physical form as well as the temporal form (i.e., the pattern of the state changes that the controller will produce). The designer's next activity was concerned with an understanding of the negotiation between the two form elements (i.e. physical and temporal) in relation to the possible/ promising experiential qualities.

She created a matrix of actions (e.g. stroking, squeezing) and temporal behaviors of light output (e.g., dimming, flashing, pulsating) corresponding to the functional principle of the LTM material (Fig 8). In an online questionnaire, she asked 20 participants (male and female between 24 and 65 years old) to choose the two ‘intuitive’ combinations and describe aesthetic qualities, meanings and emotions the combinations elicit (e.g., ‘creating powerful rhythm’, ‘feeling alive’ were associated to squeezing/pulsating). Result of the study showed that input/output couplings could readily signal to a broad range of functional values (e.g., light as illumination vs. light as carriage of information) and emotional experiences (e.g., relaxing and reassuring in stressful situations). Investigating the associated experiential qualities offered understanding of how the LTM physical and functional affordances may support or hinder certain experiences (and values). Such understandings when combined with the values identified in connection to the domains, worked as a compass towards certain applications.

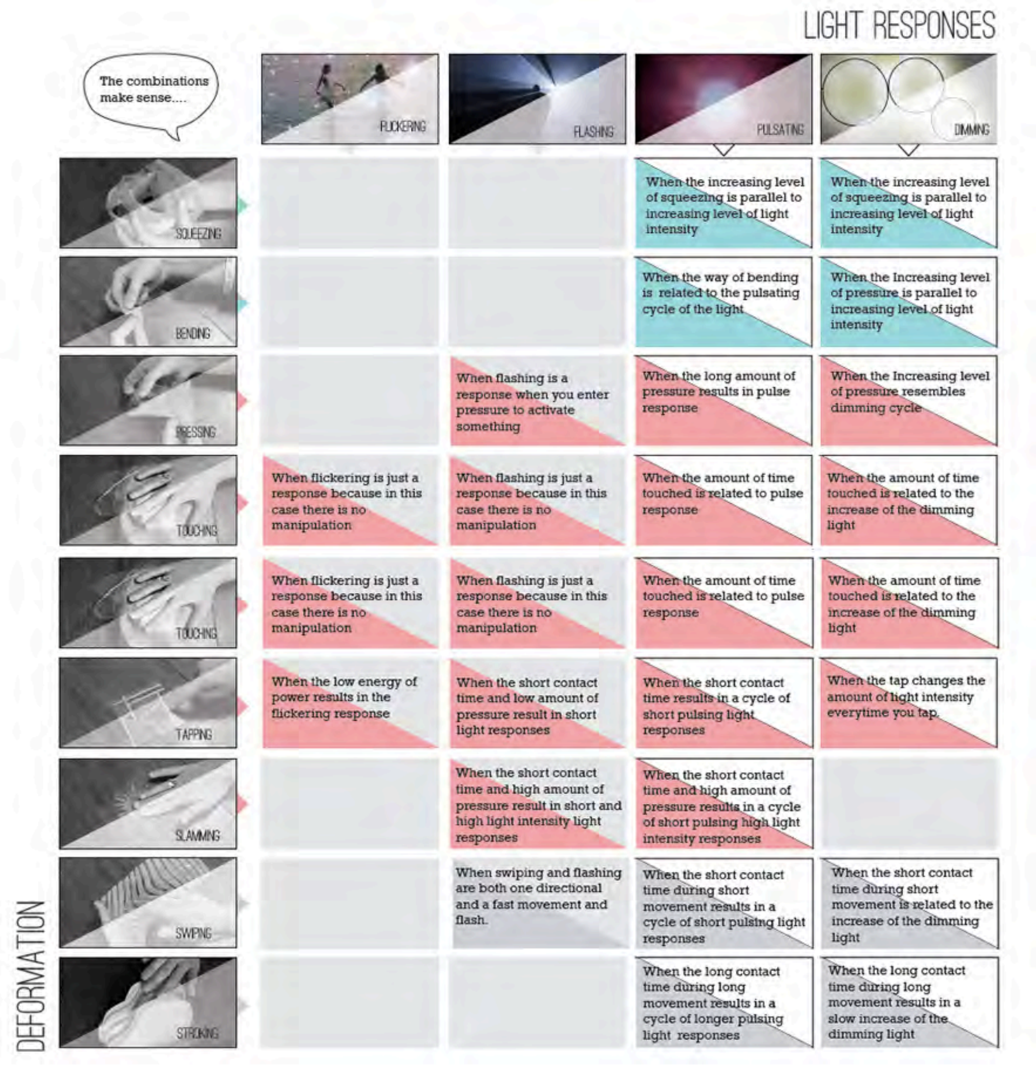

Fig 8. Matrix of actions as input and temporal behaviors of light output

Creating an inclusive vision

All her explorations and investigations provided means to move from property level to affordances and experiential qualities and eventually shaped her understanding of the LTM material and its potentials. In order to bring the various findings under a cohesive intentional whole and to have a clear guide for making further design decisions, she articulated the design intention through a two-level ‘vision statement’ (Hekkert & van Dijk, 2011). In her vision statement (Fig 9), she specified why people would find her to-be-designed application valuable and meaningful by elaborating on the use purpose, context and qualities of interaction. By further analyzing the promising domains of application and functional values of light, the designer elaborated on when, where and why the unique technical properties and experiential qualities of a material may come forward (Karana et al., 2015). Fig 4 depicts how designer’s move between the levels are fused and intersected, to enable the designer form an inclusive design goal (using dashed-lines and lamps).

DESIGN GOAL

‘ I want people in unclear weather conditions to communicate their presence to the people around them for extra safety and visibility.’

INTERACTION VISION

‘ The interaction with the material’s tactile and visual possibilities should be dynamic and mystifying. It should feel like expressing oneself when on the move, but at the same time ensuring personal safety. ’

Fig 9. Designer’s vision statement including the design goal and interactions

Iterative concept development

In an iterative making/testing process, she elaborated on the physical and interactive aspects of a cape jacket for outdoor activities, focusing on the texture and light expression. In an experimental study, she showed multiple material samples and 8 texture probes (a ribbed, a woven, a flowing, a facetted, an irregular, a smudged, a wrinkled and a studded texture) to 5 participants and tested which ones could evoke the intended qualities of ‘intuitive’, ‘alive’ and ‘dynamic’ (Fig 10). By playing with the frequency, power and rhythm of light feedback, through programing, she finalized the LTM temporal expression corresponding to the intended interaction qualities.

Fig 10. Experimental texture test (left), programing the light feedback on the shoulder piece and sleeve (right)

Incorporating the LTM material in a wearable jacket made a good use of LTM unique characteristics including waterproofness, flexibility, portability and thinness. Similar to other multifunctional jackets, the concept features an additional functionality to provide visibility (due to OLED bright surface light). What makes the concept different from other existing jackets is the possibility to personalize the light patterns in relation to users' pressure inputs. Particular attention to texture and appearance of the jacket intends to encourage certain performances and actions to activate the sensing Piezo electric layer. But it does not stop there. The concept benefits from the LTM's programmability to allow users personalize the light output beyond a basic function of keeping them safe and making them visible. It unlocks unpredicted practices (e.g., new ways of communicating street/privacy intrusions) leveraging on the sensorial, affective, interpretive, and performative qualities of LTM material. Although the concept has the potential of intending and reaching such overall impacts beyond product experience (Fokkinga et al., 2014), to get there from what it currently is, more iterations of user testing and modifying will be needed.

Discussion

The process presented in this article provided further insights about the situation of designing with underdeveloped CCs. The structured approach highlighted the important components and activities, the designer incorporated to bridge between the given properties and a purposeful application. Our observations and analysis of the design process showed that the uncertainty rising from immaturity of the technology is a challenge and hindrance in designing appropriate application (Shrivastava & Schneider, 1984). However, simultaneously, such uncertainty brings about a unique opportunity for designers to challenge the dominant 'technological framings' (Orlikowski & Gash, 1994)—i.e., dominant conceptions of technology value-suitabilities and already-existing meanings. It gives designer a scape from conceptual limitations induced by an established body of knowledge, and a chance to reinterpret proper meanings and functions of a *becoming* material (Bergström et al., 2010; Sengers & Gaver, 2006). To advance the benefits of uncertainty in collaborative material development, designing for materials experience provides a flexible framework focusing on the understanding of technical and experiential characteristics.

One area that needs clarifications is the quality of applications in terms of value. Designing for materials experience although helped with the CC's understanding in connection to other materials, users and the context of use did not indicate what aspired value to designate as the ultimate design goal. Conceptual investigations on which aspired values are preferred for development of a particular CC and reflecting on them (between the stakeholders) help to explicate what is expected from a proposed application and how it is assessed.

Looking at the product concepts proposed in this paper and our earlier study (Barati et al., 2015), namely an interactive CPR trainer, Yoga mat, punching bag and finally an interactive cape jacket, it is clear that they posit very different 'raison d'etre' (reason for existence), even though they all exploit LTM's technical characteristics. What interests us is the manifold role of the LTM material in embodying these concepts, contributing to or improving their utility, shaping user-product experiences, unfolding unseen and unforeseen practices, and even touching upon ethical issues (saving human lives). These roles are consequences of a set of decisions made throughout design process, including design motivation and inspiration as well as rationale drawn by the functional principle of the LTM material, its characteristics and limitations. Jung and Stolterman (2012) suggest that quality of designs can be discussed based on (1) how aesthetic and functional potential of the technology are illustrated, (2) how meaningful a design intention is from social and cultural perspectives, and (3) how design references are properly surveyed, selected, and applied. Looking into the relationship between materials, their properties and practices developed around the products (made of those materials), Giaccardi and Karana (2015) elaborated on the role of materials experience in shaping our (everyday) practices. Accordingly, the quality of designs might be also discussed with respect to the role of CC's experiential characteristics in unfolding unseen and unforeseen practices.

It is suggested that designer's naïve perspective with respect to every technical details of a technology allows them to see new applications (Dunne & Raby, 2014). Our observation shows that this proposition is true if the designer is keen on attuning her conception of the CC's technical properties and functional principle to what material scientists take for granted about it. Gathering material samples and prototyping in the process of designing with the LTM served both as a way of understanding the given properties and a means of communication (Henderson, 1991). Without such physical representations, it would have been very difficult to verify designer's conception of the LTM material and its aesthetic and functional potential. Our observation confirms that physical probes and prototypes made along the process are viewed as 'boundary objects' (Star & Griesemer, 1989) to resolve uncertainty associated with material knowledge and a preferred design path (Mark, Lyytinen, & Bergman, 2007). Boundary objects are defined as "objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star & Griesemer, 1989, p. 393). But what features of a physical probe/ prototype make it an effective boundary object to facilitate communication across designers, material scientists and users (i.e., participatory design)? What features of it contribute to the understanding of a particular CC (e.g., inspirational bits; Sundström et al., 2012) and inspire design ideas? In our next study, we will elaborate on these questions.

Conclusion

This paper presented a design case study with an underdeveloped computational composite. Explaining the methodological and communication challenges of designing in the context of material co-development, we showed an approach to tackle the challenges along the design process. The approach particularly focused on qualifying the properties in relation to actions, emotions, associations and performances and investigating the user's experience patterns. Designing for materials experience provides a flexible framework to organize the design activities around understanding the technical and experiential characteristics of an underdeveloped CC. However, conceptual investigations concerning the aspired value should be taken place and discussed prior to determining the design/development path. Making physical probes and prototypes helped with understanding the CC and mobilizing further design actions while those intermediate prototypes can be used to communicate, discuss and transform material and design knowledge. The multifaceted role of prototypes in addressing/resolving uncertainty associated with material knowledge and a preferred design path should be further investigated.

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