Conceptualizations of the Materiality of Digital Artifacts and their Implications for Sustainable Interaction Design

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Abstract

In this essay, we report on our survey of the design and HCI literature and other sources we have conducted in order to create an inventory of notions of digital materials past, present and future. We provide some thoughtful speculations and implications for design of digital artifacts with focus on emerging materials based on this survey. Our inventory includes state-of-art technologies and art and design projects covering the topics of organic user interfaces, smart materials, transitive materials, and so forth, as well as theoretical perspectives on materials in interaction design (Blevis, 2007; Löwgren and Stolterman, 2004). We construct design implications to include specific application scenarios of new material and interface technologies based on speculations for each theme of material perception that we uncover in our survey. These include (i) reducing the use of disposable materials—*how to reduce material consumption as personal lifestyles,* (ii) creating mechanisms of innovative, appropriate interaction—*how to reduce energy consumption by means of the use of digital artifacts constructed with new display technologies,* (iii) fostering ownership of sharable resources—*how to promote the feeling of ownership or security in sharing public resources,* (iv) updating things through the use of new materials—*how to renew old objects by adding new technologies instead of replacing them with new ones,* and (v) using materiality for engagement and expression—*how to promote peoples' attachment to artifacts by means of preserving sentiments and histories in the qualities of materials as a critical motivation for sustainable behaviour.* We provide specific examples that reflect on how such themes can foster sustainable design practice with new material and interface technologies by expanding the perception and understanding of the materiality of digital artifacts.

Keywords

design; material; materiality; digital artifacts; sustainable interaction.

As digital technology continues its rapid pace of development and pervades everyday life more and more, it exhibits increasing material effects both in terms of an augmented selection of materials in design practice and material consumption in use. Previous theoretical perspectives in the area of HCI and interaction design have suggested ways to promote sustainable interaction design along a number of dimensions, notably by emphasizing the need to promote renewal and reuse over the invention and disposal of digital artifacts with focus on the material effects of software technology (Blevis, 2007). Very recently, there has been a shift in focus from design for mitigating unsustainable behaviors that lead to climate change to design for adaptation to the likely effects of climate change (Blevis & Blevis, 2010). Sustainability concerns are part of the origins of our interest in digital materiality—nonetheless, our present writing concerns digital materiality directly in all contexts, including a world where resources have become more precious. We introduce the term *resource-conserving interaction design* to stand for both possibilities—a focus on sustainable behaviors and a focus on adapting to changing global conditions.

We are confronting new challenges and opportunities in interaction design especially with the introduction and advancement of new material and interface technologies such as tangible/organic user interfaces (Holman and Vertegaal, 2008), computational composite (Vallgårda and Redstrom, 2007), and transitive materials (Coelho et al., 2009). These new technologies blur the boundaries between hardware and software elements of digital artifacts, transforming the notion of materiality in interaction design. These new technologies require new conceptualization of materiality both in terms of how to use new materials in shaping an interactive object and how to predict its material effects in use. Specifically, as materials of traditional design have significance in determining the range of function, durability or cost of a product (Ashby & Johnson, 2002; Doordan, 2003), new material and interface technologies can also transform the way we design and use digital artifacts with new product ecosystems. For example, the invention of electronic papers might transform the user experience of reading books with new device interfaces as well as the process of purchasing books by eliminating the distribution of physical materials. Another possible example is programmable fashion—forms of clothing that can be updated for style by software means. The scenario of programmable fashion poses a question of how the fashion industry can adapt as the capability of updating styles of clothing becomes available by means of software programming. What is needed is a more developed conceptualization of what we mean by materiality in the context of digital technology. Such a conceptualization can support a better understanding of design potential of new material and interface technologies and appropriate strategies in design practices. Operating under an hypothesis that these technologies could contribute to supporting and promoting sustainable behaviors by transforming the way we use and value digital artifacts, our goal is to explore diverse dimensions of materiality in the context of resource-conserving interaction design.

Based on this background motivation, the present study first introduces a theoretical foundation regarding materials of digital artifacts to understand how materials of interaction design are increasingly different from those of traditional product design. Next, we provide a survey of recent trends of material and interface technologies from art and design projects, based on which the conceptual dimensions of materiality are explored in terms of perception and use of digital artifacts. Finally, we delineate design implications and possible research opportunities in relation to the explored dimensions of materiality of digital artifacts.

Materials of Digital Artifacts

Material is an essential element of design. Specifically, material selection—based on the understanding of physical properties of a variety of materials—is critical in forming aesthetic and functional qualities of an object in design practice (Lefteri, 2007). Moreover, unique symbolic meanings of a certain material based on its social or economic values—as in jewellery or garments—are also something designers need to consider beyond functional qualities of a design. Through the lens of materials, design can be considered as a process of creating meaning with proper materials and applying them to appropriate contexts based on exploratory practice with them. How to choose the right tools and methods to manipulate materials has always been a major issue of design practice. Moreover, materials are not just a given to be incorporated in the designer's calculation, but are a part of design problems (Doordan, 2003). Invention of a new material sometimes brings design innovations and changes our experiences with objects, as seen in many examples such as plastics in modern design (Monem, 2008). Likewise, the advent of new materials in the modern era often poses a new design problem—both in terms of operationalizing new manufacturing process for them (Vallgårda, 2009) and envisioning their social and cultural impact in use—rather than providing a simple solution for what design opportunity is considered.

Recently, designers of digital artifacts are facing a particular challenge regarding design material due to its complex composition of physical and digital qualities. Especially with respect to the software aspect of interaction design materials, Löwgren and Stolterman (2004) described digital technology as *material without qualities,* indicating its unlimited yet undefined design potentials—both aesthetic and functional qualities that designers could realize with digital technology. In other words, the design of digital artifacts is largely open, leaving designers with significant power to shape a future and also with corresponding responsibility. Especially, with advancement of tangible and physical computing interfaces, digital technology may be more seamlessly weaved into physical materials, and thus digital devices may be designed in many forms for a variety of purposes in everyday life beyond work-related tasks in office environments. Initiated by the notion of tangible bits (Ishii and Ullmer, 1997), there have been many studies exploring new applications of physical computing interfaces from product to architecture—as in studies of computational composite (Vallgårda, 2007) and transitive materials (Coelho et al., 2009), to name a few. Starting from the approaches for technical implementation, now the focus of research on tangible and physical computing has moved to design potential of new forms and interactive behaviors of computational objects. For example, Holman and Vertegaal (2008), in the context of human-computer interaction research, envisioned new, organic forms of computer devices by emphasizing three developments in computer technology, namely (i) advances in touch input technologies, (ii) flexible displays, and (iii) Kinetic Organic Interfaces. Brownell (2006), from the perspective of industrial design, highlighted transformational and interface aspects of design materials with enhanced functionality. Likewise, as computational technology is more physically materialized, it holds the potential not only to change forms of computer devices, but also to transform the way we interact with static objects and environments into computational activities. In our present writing, such physicality and forms of digital technology are considered to be main issues of new design materials of digital artifacts. Specifically we question how the development of tangible and physical interface technology can influence on the relationships between people and objects. In particular, we focus on the nature of material impact in use of digital materials that change the way in which people value enduring relationships with objects constructed in part from digital materials.

Materiality of Digital Artifacts

The increasing physicality of computational technology has brought challenges of complex design materials. They call for expanding conceptual dimensions of materiality of digital artifacts in order to predict how digital artifacts designed with new materials can transform user experience as well as social and material ecology. For example, these new materials can provide users with rich sensory experiences (Djajadiningrat, 2004), leading to more attachment to an object and achieving ensoulment or heirloom status of an object (Blevis and Stolterman, 2007). Specifically in terms of sustainability of digital artifacts, Blevis (2007) describes a designerly ethos to promote renewal and reuse over the invention and disposal of digital artifacts as a matter of promoting sustainable or resource-concerning behaviors with focus on the material effects of software technology. This notion has been advanced by investigating critical design qualities of digital artifacts that are loved and ensouled, and thus consequently contribute to sustainable relationship with users (Odom, Pierce, Blevis and Stolterman, 2009). While these approaches are analytical based on design theories and philosophy of material objects, there are also exploratory approaches for new design methods and processes with digital technology by considering social and material impact of design. For example, Bonanni, Parkes, and Ishii (2008) suggest the notion of *future craft* with examples of new design process and examples to more conscientiously include users in the design process through personalized digital materialization. Moreover, by tracking and visualizing material flows in manufacturing and distributing process, digital enhancement of material objects can promote more active sustainable behaviors in producing and purchasing industrial goods (Sterling, 2005; Bonanni et al., 2010).

Broadly speaking, new design materials or manufacturing processes associated with materials can transform the way we design, use, and relate to material objects. In this vein, the conceptualization of materiality of digital artifacts could serve as a lens to strategize design with digital technology considering its material effects in use. We categorized five themes that are related to material effects of digital technology—*disposability, energy consumption, sharability, reconfigurability, and expressive engagement*—by speculating on specific examples from art and design projects.

Disposability: reducing the use of disposable materials

Disposability is one of the most frequently discussed material effects of digital devices. As software technology quickly develops, disposability of digital artifacts is increasing; no matter how durable a device might be, it is easily discarded if its software is out-dated in terms of processing speed or data storage capacity (Blevis, 2007). Interaction designers tend to less care about outside (i.e. shapes, materials) than inside (i.e. software, contents) in designing digital artifacts (Critical Friends of Technology, 2003).

Moreover, digital device tends to be considered as an instance of similar types of other devices—as easily replicable as software programs. For example, BIC phone, a disposable mobile phone was introduced in 2008 with a pre-charged battery and a SIM (Subscriber Identity Module) card so that people can immediately use it by purchasing without a phone contract (Figure 1). This unit actually costs cheaper and is more easily replaceable than most contract-based phones. However, the convenience of prompt availability entails increasing disposability of hardware materials. The company had to deal with this issue by coming up with a recycling program where people can ship the phone back to them when they finished with it. Commodification of digital devices, in many cases, fosters disposability of materials by facilitating manufacturing and disposal process. As material consumption and disposal is closely related to lifestyle issues—specifically how people either embrace social concerns or act with conformity—a conscientious design strategy considering recycling materials need to be considered in close relation to social and cultural as well as economic values of digital artifacts.

While recycling is one strategy for increasing disposability, another possible design opportunity is to deeply appreciate material qualities and craft authentic values of a device. Magnhild Disington, a Norwegian fabric designer, offers an interesting perspective on the design of digital artifacts through her project of furry objects (Figure 2). Applying natural materials like wood, leather and fur to portable electronic devices, she designed unique character and sensory experiences, which can create a greater emotional value within the physical product. This approach questions whether the use of authentic materials in design of digital artifacts can be a solution for reducing disposability of digital devices by endowing them with unique values that cannot be replicated by similar other devices as in fashion design (Svendsen, 2006). Although this may not be the solution for increasing disposability of digital artifacts, it does expand design possibilities in terms of diversified material selection of digital artifacts toward sustainability.

Figure 1 BIC phone © BIC
(Retrieved from www.bic-phone.fr)

Figure 2 Furry Objects © 2009 Magnhild Disington
(Retrieved from http://www.magnhilddisington.com)

Energy consumption: creating mechanisms of innovative, appropriate interaction

More and more, digital devices emphasize the non-physical materials over the physical ones—the physical form factor of devices like the iPhone and iPad reduce the physical materials to their simplicity, for example. Notwithstanding, many visions of digital technology—represented by the notion of calm technology and ubiquitous computing environment (Weiser & Brown, 1995)—require more energy consumption for continuous data sensing and capturing, prompt access, and ambient displays.

Considering, for example, the iPhone compared to an older bar type Nokia phone, much more interactivity depends on the use of the display in a manner, which consumes more power than the traditional phone (Figure 3). At the same time, versatile features and access to abundant information enabled by iPhone prompts more use of it in varying contexts compared to simple features of making phone calls or sending texts of older phones. Of course, these advanced information applications has made our life more convenient. However, in some sense, this technology or business oriented development—as opposite to value-sensitive design approach (Friedman, 1996)—has created additional human needs, resulting in more energy consumption.

Figure 3 Bar-Type Phone with Small Screen vs. iPhone with Touch Screen

There have been many studies to use ‘visualization’ of energy consumption as a part of user experience to persuade user behaviors to reduce energy consumption in daily life as enumerated in (Pierce, Odom, and Blevis, 2008; Pierce and Roedl, 2008). However, more fundamentally, research on more energy-efficient display technology is in demand with increasing display-centered digital artifacts such as e-papers or OLED (Organic Light Emitting Diode) lighting applications. With the development of organic user interfaces (Holman and Vertegaal, 2008), it is a promising design direction to develop alternative solutions for information display by exploring symbiotic use of natural material properties and their computational enhancement. There are some projects exploring energy-generating interactions that use physical engagement as source of power. For example, Villar and Hodges (2010) developed an interaction-powered rotary input device that sources its power from the physical effort required to operate it. When turned, its circuit provides a temporary power source for an embedded device, and doubles as a sensor that provides information about the direction and rate of input. Such design exploration with new forms and mechanisms of interaction can provide alternative solutions to current display-oriented digital devices by diversifying design opportunities of digital devices.

Sharability: fostering ownership of sharable resources

The development of network technology has enabled ubiquitous data access through online data storage or applications such as google documents, dropboxes, and Cloud computing. Cloud computing is Internet-based computing, whereby shared resources, software and information are provided to computers and other devices on-demand.

In spite of this convenience of data access, some people are uncomfortable working with online documents, without the comfort of knowing that the data resides on their own devices. This sentiment of ownership of actually “having” or “keeping” a digital material in the same manner as physical one may be one of the important issues in relation to feelings of privacy or security as well. In this vein, the vision of Cloud computing provides interesting design questions on how ubiquitous access to data can transform the conceptualization of ownership of a digital device by separating its software contents and physical interfaces.

This vision may help reduce material consumption by enabling public sharing of physical interfaces and display to access personal data. On the other hand, advanced networking technology like Cloud computing might actually foster more instances of physical interface that could be easily acquired and thrown away. In any case, the vision of the new network technology can influence how people own or share physical devices, and design can contribute to shaping a sustainable model to access ubiquitous data considering the aspects of privacy and security as well as sharability of material resources.

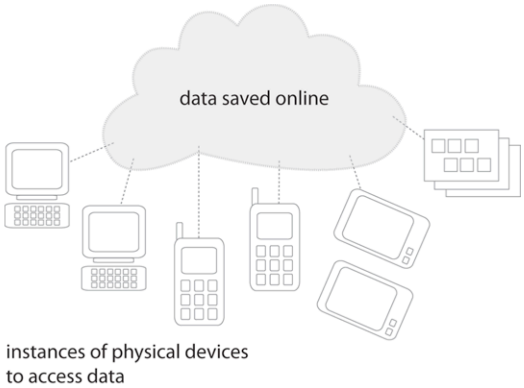

Figure 4 Ubiquitous Data Access

Reconfigurability: updating things through the use of new materials

As digital devices often work in connection with other devices, interaction designers now need to consider ecological aspects of a digital device (i.e., compatibility with other devices, upgradability to newer versions) beyond its own functional and aesthetic qualities. From an ecological perspective, it is critical to support reconfiguration of individual digital devices so that they can flexibly adapt to each individuals as a whole system.

However, in many cases, it is still not easy to customize or update physical and hardware aspects of a digital device compared to its software upgrade. This often leads people to have multiple devices with redundant features because subtle differences in physical forms and hardware aspects of each device—i.e., different screen sizes of a desktop computer, a laptop, or a smart phone—exhibit varying contextual affordances in use although technical features of these devices are basically similar with each other (Wortham, 2010). Moreover, digital devices easily become old-fashioned by losing their technical compatibility (not working in connection) or aesthetic commonality (not looking up-to-date) with other newer devices (Jung, et al., 2008). From the perspective of sustainability, it is a waste of resources that properly functioning digital artifacts are increasingly disposed or just left not used.

New design approaches for supporting flexible reconfiguration need to be considered, especially in terms of physical and hardware aspects of digital devices. Advanced material and interface technologies can provide new design solutions, for example, by modularizing software/hardware parts that can be assembled for different purposes of use, by adding new features to an old device for functional enhancement, or by transforming shapes of an artifact for aesthetic refreshment. For example, modu Ltd. introduces a mobile ecosystem where people can choose a new phone as often as they like, constantly taking different forms, functions and designs in a way to satisfy changing user needs, preferences and styles (modu Ltd., 2008). Another interesting example is the concept of transforming fashion by Hussein Chalayan that experiments potential of new technologies applied to fashion design either for functional or aesthetic purposes (Figure 5). In the Flat Futures project, Miquel Mora explored application scenarios of digital paper (Figure 6). With the concept of *objects wearing technology* in forms of interactive, dynamic digital paper, he envisions new ways to add or modify technical features with materials that are easy to handle.

Likewise, the advanced physical computational technology can envision new design scenarios of “programming hardware like software”, by transforming physical forms flexibly according to different contexts or purposes of use. With this potential, designers can more actively materialize ecological aspects of digital devices by blurring lines between objects.

Figure 5 Transforming Fashion © 2007 Hussein Chalayan
(Retrieved from http://www.husseinchalayan.com)

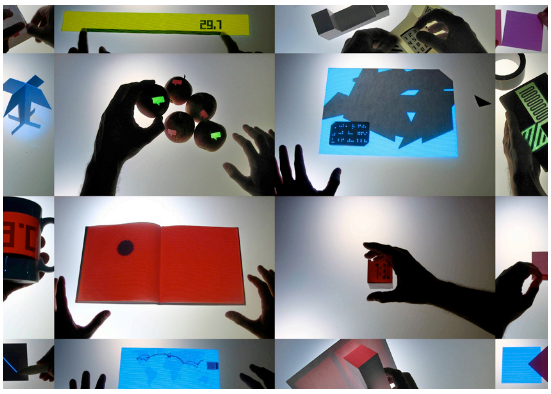

Figure 6 Flat Futures: Exploring Digital Paper © 2007 Miquel Mora
(Retrieved from http://www.flatfutures.com)

Expressive engagement: using materiality for user engagement and expression

Touch screen interfaces, blurring the boundary between interface and information, have brought many benefits in terms of simple and intuitive interaction from direct manipulation as well as portability by merging physical and digital elements of a device. However, aesthetic qualities of form or tactile feeling have been relatively less considered in the design of digital artifacts, although people are very sensitive at perceiving subtle differences of such qualities.

Tactile properties of an object, affording rich sensory experiences and bodily engagement, can serve as an essential motivation for users to interact with and to feel attachment to an object. Upon the increasing priority of efficiency or functionality of digital devices, interaction designers need to more seriously consider how the corresponding trend of simple and minimal design will influence the relationship between user and device and what qualities of interaction will be lost or gained from such design beside function-oriented simplicity. For example, the concept of e-paper devices has many benefits to reduce the amount of paper consumption, but sensibility of physical books is still left as critical design challenges to overcome for popular use of digital paper.

With increasing design potential of physical computational technology, tactile/sensory qualities can be further explored in a way to build intimate and affective relationship between user and object. Physical properties of materials—how they invite user engagement or how they reflect the history of use (Figure 7)—can provide meaningful insights to interaction design, especially to explore diverse form properties of computational materials. Such design exploration with new computational materials can eventually contribute to increasing the feeling of attachment to an object by empowering users to more actively expressing their emotional conditions or personal identities through of an interactive object (Ahde, 2007; Webb, 2005).

Figure 7 Physical Materials Inviting User Engagement or Reflecting History of Use (from left to right: soft cushion, worn keyboard letters, and message board)

Implications for Sustainable Interaction Design

As briefly introduced above, the materiality of digital artifacts is becoming more complicated due to its dynamic computational properties. As if traditional product design underlines the understanding of physical qualities of materials, the conceptual dimensions of material effects of digital technology could help designers calculate functional and aesthetic qualities of a digital artifact as empirical design knowledge. Considering interaction design material as a composition of both technical artifacts and social systems, we attempted to strategize design with new digital materials—particularly physical computational materials—speculating on their material effects in sustainable use of digital artifacts. In particular, our interests include, but are not limited to, questions on how tangible or physical computing interfaces would transform the relationship between user and digital artifacts from longitudinal and socio-ecological perspectives, how they could achieve or would lose certain design qualities compared to the interaction with non-digital artifacts, and how designers could strategize design with physically enhanced computational technology to promote sustainable interaction.

Based on the review of specific examples and design scenarios, we have described five themes of material effects of digital artifacts—*disposability, energy consumption, sharability, reconfigurability,* and *expressive engagement.* These themes are not mutually exclusive but closely related to each other. Each of the themes suggests a corresponding design implications and research directions in the service of sustainable interaction design and resource-conserving interaction design—specifically (i) reducing the use of disposable materials: *how to reduce material consumption as personal lifestyles,* (ii) creating mechanisms of innovative, appropriate interaction: *how to reduce energy consumption by means of the use of digital artifacts constructed with new display technologies,* (iii) fostering ownership of sharable resources: *how to promote the feeling of ownership or security in sharing public resources,* (iv) updating things through the use of new materials: *how to renew old objects by adding new technologies instead of replacing them with new ones,* and (v) using materiality for engagement and expression: *how to promote peoples' attachment to artifacts by means of preserving sentiments and histories in the qualities of materials as a critical motivation for sustainable behavior.*

The themes and implications in this essay are to explore design and research opportunities regarding sustainable interaction design with digital materials by questioning and speculating on the material effects of computational technology, instead of offering prescriptive solutions for sustainable interaction design. Further investigation for each theme needs to be followed for practical application of the implications described above.

Conclusion

In this essay, we introduced a theoretical foundation regarding materials of digital artifacts by comparing them to materials in traditional product design. Our survey of recent material and interface technologies described specific art and design examples in order to conceptualize the emerging material qualities of digital artifacts in terms of their material effects in use. As an overall observation based on this survey, we found that there is a need for interaction design and HCI research to pay more attention to the ongoing rapid and dynamic development of new physical materials. It is clear that these new materials bring potentials for new forms of interaction design where the physical is merged and blended with the digital.

The qualities of digital materials—including *disposability, energy consumption, sharability, reconfigurability, and experiential qualities (expressive engagement)*—suggest that there exist corresponding design implications for sustainable interaction. Application of these implications to interaction design practice requires more research from different disciplines, but the lens of materials helped us have a broader view of how to design with digital technology considering its material effects in terms of sustainable interaction. We argue that the future of sustainable interaction design is partly to be found in the exploration and examination of new materials with the aim to find new approaches suitable for resource-conserving interaction design.

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