Exploring 'Immaterials': *Mediating Design's Invisible Materials*

Timo Arnall

Oslo School of Architecture & Design, Oslo, Norway

This article explores the related issues of invisibility and material in interaction design, and argues that there is a need to consider 'immaterials' as a frame to explore and mediate invisible technological systems. Contemporary visions of technological development often focus on invisibility and 'seamlessness' in interface technologies, while the methods of building knowledge about designing with these technologies or issues of agency and control over these invisible interfaces are overlooked. I approach this in two related ways. First, I investigate the context of invisible interfaces and the issues of immateriality in computing, and argue for a renewed investigation of materials in interaction design. Second, I present an exploratory design research enquiry in which an invisible interface technology called Radio Frequency Identification (RFID) was discursively revealed. Drawing on these foundations, I show how design approaches can create new material knowledge by making technical exploration apparent through visualisation, photography, animation, and filmmaking. Overall, this enquiry illustrates a communicative, mediational design research practice that I call discursive design, that constructs language, new narratives, and communicative material that may translate between complex technical subjects and broader audiences and discourses.

Keywords **–** RFID, Design Material, Communication, Interaction Design, Discursive Design, Ubiquitous Computing.

Relevance to Design Practice **–** This study is based on interaction design practice, and offers approaches for exploring and communicating design materials that are applicable both in design practice and research.

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Introduction

This article emerged from five years of design practice and research in a project called *Touch* that investigated a technology called Radio Frequency Identification (RFID) through exploratory interaction and product design approaches. The project involved a team of trans-disciplinary designers, technologists and researchers.

RFID was chosen as the subject of the research because it sits at a confluence of multiple contexts, practices, and discourses. The technology is already widely used for ticketing, access control, security, and payment. The diversity of RFID tags from London, Seoul, Helsinki, Berlin, and Oslo can be seen in Figure 1. If you have a travel card, library card, or work in a large office, it's likely you have an RFID tag in your pocket or purse right now. In industrial and marketing perspectives, RFID seems ripe with new opportunities for 'frictionless' transactions, and the control and monitoring of objects and flows (Fleisch & Dierkes, 2003). However, as we shall see, the technology is also heavily contested by those who are concerned by the effects of such systems on privacy, and by popular media that embellishes technical possibilities and implications for dramatic effect.

Technically, an RFID system consists of a *reader* that induces a current into the antenna of a small, cheap, battery-less *tag*, establishing a wireless connection and transferring a small amount of data. RFID tags contain data, such as a unique identifying number, so they can allow objects to be identified at a distance. Both RFID tags and readers can be embedded invisibly in objects, products, fabrics or beneath physical surfaces.

Figure 1. Various RFID tags collected by the author.

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***Corresponding Author:** timo.arnall@aho.no

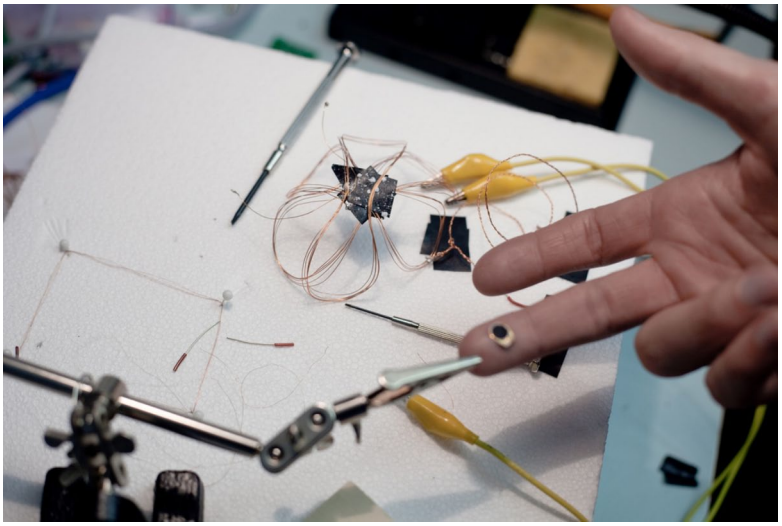

Figure 2. Exploring the technical material of RFID: an RFID tag is being taken apart on this workbench in our design studio. The looped wire antenna as well as the tiny memory chip resting on the finger are shown.

This invisibility is a desirable yet problematic quality of RFID systems. RFID is popular in Human Computer Interaction (HCI), interaction design, and ubiquitous computing research, where it can be used to make cheap, robust, and invisible interfaces out of ordinary, everyday objects. However, these qualities also make the technology deeply unpopular to groups concerned about the privacy implications of unknown, invisible tracking of personal information (Albrecht & McIntyre, 2005). In this way RFID is a microcosm of a larger debate about 'invisible computing,' where the "most profound technologies are those that disappear" (Weiser, 1991, p. 1), but where the questions of agency, control, and trust in these invisible interfaces are yet to be resolved (Ratto, 2007).

The *Touch* project was an opportunity for the team as designers and researchers to participate, negotiate, and intervene in matters of concern to the team, and to support the ongoing discussion of emerging RFID technology. By drawing on our assembled knowledge of approaches and techniques, from diverse disciplines such as animation, filmmaking, electronics, industrial, interaction, graphic design, and communication design, we were able to explore and articulate new perspectives on RFID. This ranged from explorations of technical components (such as the deconstruction of RFID tags shown in Figure 2), to designing products and prototypes using RFID interfaces, to creating visualisations, animations, and films about the material phenomena of RFID interactions. Through these dynamics of making and reflection, we revealed previously hidden aspects of the technology, and articulated these perspectives through creative, communicative, and narrative means. This mixture of methods and outcomes supported important discussions of RFID both in and beyond the disciplinary boundaries of engineering and interaction design.

Timo Arnall is a designer, filmmaker and researcher working with interactive products and services. He has been making films, designing products, and researching emerging technologies for 15 years. Much of his work has been about understanding, developing and explaining interface technology through films. Arnall is presently creative director at BERG. Prior to joining BERG, Arnall led an international research project investigating emerging wireless technologies through design at the Oslo School of Architecture & Design.

Outline and Key Questions

In contrast to many other design research projects that focus on the use, function, or application of technologies, or on the qualities and meanings of designed objects, this research instead argues for discursive approaches that focus on materials and mediations in design. It is through both analysis of design and computing literature, and through the *Touch* project's photographic, visual, animated, and filmic explorations, that this article builds knowledge about how technology may be mediated and revealed as a design material. I present and discuss the approaches we took to generating and communicating new perspectives on RFID, through visualisations that were empirically grounded in material phenomena rather than based in speculation or marketing mythology. I refer throughout to the artefacts generated in the *Touch* project, which is one of very few design research projects that has explored RFID technology as a material for interaction design.

The following main questions are addressed:

- How might a designer explore an invisible interface technology like RFID in order to have reflective conversations with it as a design material?
- How can material and mediational approaches contribute towards shared knowledge of RFID, both in design and as a means of discussion across disciplines?

In Section 1 I situate design as a sociocultural practice that is concerned with culture, critical approaches, and with engaging the technocultural imagination. I consider the often opposed issues of invisibility and materiality that are beginning to be addressed as part of a 'material turn' across many disciplines,

including computing and design. This is followed by a discussion of the term 'immaterials,' the language the *Touch* project team invented to discuss new kinds of interaction design materials. These framings reveal the relationships between invisibility and materials in design.

In Sections 2 and 3 I present a series of design and research approaches that explore, discuss, and communicate the material phenomena of RFID interactions. These projects demonstrate how visual material was created using technical probes, animation, and filmmaking processes. They also show mediational strategies, such as the use of documentary formats, online film, and weblog writing to communicate and discuss our work to broad audiences.

In Sections 4 and 5 I reflect on the ways in which these explorations have revealed new material perspectives on RFID, and the ways in which they have been shared, discussed, and developed by others. These explorations of material are related back to the discursive approaches to design materials, showing how materials and mediation are at the generative heart of our interaction design research and practice.

This text is partly a visual essay, illustrated with photographs and films from our design processes that attempt to convey the richness of our communicative approaches. It is also layered to adopt and address these multiple perspectives of interaction, visual, sociocultural, and discursive design.

1. Framings

In this section I explore some framings of design, technology, and material from related theoretical backgrounds and disciplines. Previously our research into RFID centred on the design of short-range RFID as conceptual material (Nordby, 2010), and design experiments and filmic mediations to make apparent the qualities of emerging wireless technologies (Arnall & Martinussen, 2010; Morrison & Arnall, 2011; Morrison, Arnall, Knutsen, Martinussen, & Nordby, 2011). In this section I take this further, drawing on a range of research from within HCI and ubiquitous computing as a backdrop to a more communication design oriented approach and analysis. I connect the very different domains of socio-cultural perspectives on design, design materials, and the issues of seamlessness and invisibility in computing. These themes are necessarily interlinked here to be able to frame the exploratory enquiry in section 2.

A Socio-cultural Perspective on Interaction Design

Socio-cultural design practices and research can be traced back to the 1960s and 70s with Archigram and Superstudio (Lang & Menking, 2003; Emilio, 1972) that engaged in critiques of dominant thinking and modes of representation in architecture. More recently, Anthony Dunne and Fiona Raby have popularised the term 'critical design' that challenged the assumptions, preconditions, and givens in technological systems (Dunne & Raby, 2007). Critical design "rejects how things are now as being the only possibility, it provides a critique of the prevailing situation through designs that embody alternative social, cultural, technical or economic values" (Dunne & Raby, 2001, p. 58). Variations on this approach have been developed, including critical practice (Mazé & Redström, 2007), reflective design (Sengers, Boehner, David, & Kaye, 2005), and design fiction (Kinsley, 2010) where speculation and proposition about potential futures are realised through objects and everyday products. While these perspectives are valuable, and many have been taken up in this study, the aspects of critical design drawn from critical theory offer "little insight about how to make things" and emphasise "the meanings and effects of cultural artifacts over their creation." (Bardzell, Bardzell, Forlizzi, Zimmerman, & Antanitis, 2012, p. 290). In this way critical design focuses its analysis on finished artefacts and their sociocultural implications, and rarely develops knowledge about the design, research, and communicative processes behind them.

In response to these limitations in critical framings, I situate my research in what I call *discursive design* (Arnall & Martinussen, 2011; Morrison et al., 2011) that investigates the "relations between the mediational and the technical, and that connects communication, context, and culture." (Morrison & Arnall, 2011, p. 2). Discursive design explores the dialogical, dynamic, and exploratory character of design practice that does not necessarily hold the designed artefact as its central theme. It opens up for the tentative, generative exploration in other aspects of design, such as reflection on experimental methods, on revealing design materials, or on investigations of design or visual culture that are revealed through visualisations.

I relate closely to Anne Balsamo's notion of design as a technocultural practice of knowledge production, where design develops literacies around "how technologies are built, how they are implemented, how they are reproduced, and how they affect cultural arrangements" (Balsamo, 2005, p. 3). This perspective situates design and technological development as intrinsically interwoven with issues of culture, in a practice that Balsamo described as 'technocultural innovation' (Balsamo, 2011, p. 6). She pointed out that the common understandings of innovation (particularly in the popular business press) focus "almost exclusively on its technical dimension, and that people are surprised by the fact that technological innovations have cultural consequences" (ibid, p. 4).

Balsamo has described the role of design in technocultural innovation as the performance of two practices: 1) the exercise of the *technological imagination*, and 2) the work of cultural reproduction. Exercising the technological imagination is a process where the cultures and materiality of the world are engaged and reworked, "creating the conditions for future world-making" (ibid, p. 6). In *technological reproduction*, a concept that resonates with Bolter and Grusin's 'remediation' (Bolter & Grusin, 2000), technological innovation replicates previous elements such as "codes, standards, forms of knowledge, and conventions" where:

> Designers serve as cultural mediators by translating among languages, materials and people [...] through the practices of designing, cultural beliefs are materially reproduced, identities are established, and social relations are codified. Culture is both a resource for, and an outcome of, the designing process. (Balsamo, 2011)

From these perspectives it is possible for interaction designers and researchers to situate technology in developmental and cultural contexts of design and use (Bratteteig Wagner, Morrison, Stuedahl, & Mörtberg, 2010; Suchman, 1987). Unlike critical design, that emphasises designed objects in exhibition and gallery settings (Bowen, 2009, p. 91; Mattern, 2012), discursive design emphasises the developmental, generative, mediational aspects of design practice, and research.

The Problem of Invisible Computing

It is important at this point to acknowledge the power of computing in design today. Computing is increasingly central and visible in the popular imagination, it is highly "present, visible, and branded" (Bell & Dourish, 2007, p. 142). Computing is now truly 'post-disciplinary,' central to, and re-articulated through the rhetorics of culture, economics, and politics. However, contemporary visions of technological development increasingly focus on invisibility and 'seamlessness.'

Invisibility is now often framed as both an inevitable and desirable quality of interface technology. This can be seen in the discourses of ubiquitous or pervasive computing, in Human Computer Interaction (HCI), and in some parts of interaction design. For example, Norman (1998) proposed the 'invisible computer' as the model for the future of computing, while Ishii argued for "seamless interfaces between atoms and bits" (Ishii & Ullmer, 1997, p. 1), and Spool (2009) wanted interfaces to be "experienced and not seen." The concept of invisibility in the Heideggerien sense is already widely used in HCI (Dourish, 2004, p. 109), that once a tool becomes familiar to us, it becomes invisible in use as a kind of extension of our hand. The tool itself does not become invisible although we no longer see it. In ubiquitous computing, Weiser (1994) restated this distinction as something being 'effectively' invisible versus 'literally' invisible. The invisibility of infrastructures and technologies has become a theme within architecture and urban planning (Polyak, 2010; Shields, 2002), and within HCI (Bell & Dourish, 2007; Hincapié-Ramos, Tabard, & Bardram, 2010). In sociology, Thrift provided an account of "how it is that environments of which we are a part gradually come to be accepted as the only way to be because, each and every day, they show up more or less as expected" (Dourish, 2004, p. 212).

In interaction design the concept of 'invisible design' has become increasingly common, under such headlines as "good design is invisible" (Reichenstein, 2012). To Van Campenhout, Frens, Overbeeke, Standaert, & Peremans (2013) digital objects are now "dematerialised" in the "shift from matter to information." Meanwhile Apple popularised the idea of seamlessness across devices and invisibility as a central technocultural theme by opening their commercial for the iPad 3 with the line "We believe that technology is at its very best when it's invisible" (Apple, 2012). The modernist approach to hiding technological infrastructure under clean, architectural lines can be clearly traced through to contemporary technology such as the smooth surfaces of Apple's iOS products that bears little relation to the technical infrastructures below. As Folkmann (2012) said: "the hidden operation of the microchip in the digital age has led to 'black box' design with object surfaces that only hint at the function of the object" (p. 137).

The discussion of digital systems since the 1960s has emphasised the immateriality of the digital through rhetorics of abstraction and liberation from physical constraint (Negroponte, 1995). This dematerialisation has been enabled and driven by the increasingly invisible phenomena of technology: wireless communication, tiny embedded microprocessors, 'cloud' computing, data structures, protocols, and abstractions of code. Computing increasingly operates in the unseen networks and data-centres of the Internet (Blum, 2012). It operates underneath shells of plastic, glass, and aluminium that sit in our wallets and pockets, and it is embedded into the appliances and infrastructures of homes and cities. Complexity is necessarily hidden away, modularised, and abstracted to enable the development of systems such as the Internet or a smartphone.

However, the concept of immaterial, invisible technology is now so widespread as to become problematic. It has blinded us to our material reality in which all digital systems are inherently composed of and constrained by physical phenomena. They have distinct physical qualities that define how they perform and function in opening up for or constraining interactional possibility. As Blanchette (2011) put it, technologies are still "suffused through and through with the constraints of their materiality" (p. 2). The fundamental phenomena of radio waves, of processing circuits, electrical power, and connectivity still present themselves, particularly during the definition, design, and testing of a product, or when a technology in use fails.

As Hjelm (2001), Chalmers (2003), and Ratto (2007) have pointed out, the contemporary rhetorics of seamlessness and invisibility intentionally hide the phenomena and materiality of technology. They attempt to smooth over the natural edges, seams, and transitions that constitute all technical systems. In doing so they entail a loss of understanding and agency for both designers and users of computing. A lack of understanding leads to uncertainty, unhelpful mythology or folk-theories, and lavish dramatisation in popular media (Poole, Le Dantec, Eagan, & Edwards, 2008) that hinders our ability to design or use technical systems, and clouds the critique of technological developments. In particular, the invisibility of RFID systems has complicated the adoption, development, and understanding of the technology, with uncertainties, assumptions, controversy, and fear, such as the 'Spychips' debate (Albrecht & McIntyre, 2005).

The (Design) Material Turn

In contrast to the immaterial discourses in computing, a 'material turn' has recently emerged across many disciplines where research has adopted an "intensified interest in 'thingness' and materiality" (Svabo, 2007, n.p.). This renewed attention to materiality has ranged from a 'new materialism' in philosophy (van der Tuin & Dolphijn, 2012), to geography (Whatmore, 2006), to informatics (Blanchette, 2011), to architecture (Hill, 2006; Thomas, 2006), to management research (Leonardi, 2010; Orlikowski, 2010; Svabo, 2007), to design research (Blevis, Lim,

& Stolterman, 2006; Karana & Hekkert, 2010; Storni, 2006; Van Kesteren, Stappers, & De Bruijn, 2007), and to interaction design (Fernaeus & Sundström, 2012; Jung & Stolterman, 2011; Redström, 2005; Robles & Wiberg, 2010; Van Campenhout et al., 2013). However, despite this renewed attention to materiality, the relationships between designers and their materials, and the ways in which materials shape and constrain the design process is still overlooked in much design research.

In their important, yet now historical, treatise on 'The material of invention,' Manzini and Cau (1989) suggested that designed objects are an embodiment of what is both thinkable and possible, where objects are:

> situated at an intersection of lines of development of thought (models, cultural structures, forms of knowledge) with lines of technological development (availability of materials, transformation techniques, forecasting and control systems). (p. 17)

In this view, both the cultural and material are generative resources that a designer builds knowledge about through practice. Another material-oriented perspective is Schön's (1992) characterisation of designing as a "reflective conversation with the materials of a design situation" (p. 3), in which designers interact with their intermediate design representations and these materials 'talk back' to the designer. In this view, design materials are the sketches, diagrams, models, visualisations, and prototypes that the designer can shape, reflect upon, and reshape. Further, in industrial design there has been great historical emphasis on a high degree of material knowledge in the processes of invention, such as actual production materials, e.g. plastic, metal, and wood.

To address the centrality of material understanding in industrial and product design, formalised methods of material testing have been developed. Industrial designers are familiar with instruments that can measure the "properties of materials and components using tension, compression, flexure, fatigue, impact, torsion, and hardness tests" (Instron, 2012, n.p.). This kind of testing involves the materials being unpacked, pulled apart, broken, reconstructed, and reshaped to build knowledge about the opportunities and constraints they may embody. Outside of practice however there is still "no common systematic approach for supporting designers in involving these [material] concerns into their selection processes" (Karana, 2010, p. 273).

In interaction design too, studies of material are relatively rare, as most research focuses on interfaces in use, on usability, and application. In interaction design our 'intermediate representations'—to take Schön's term—may be diagrams, information architectures, sketches of user interface elements, or mockups of screens. However, our materials also include hardware components such as screens, buttons, RFID readers, and Wifi modules that can be explored through 'hardware sketches' using prototyping platforms such as Processing or Arduino (see Figure 3). Here the most developed understandings of interaction design materials come not from research but from interaction design education, from weblogs, through online forums, and handbooks such as Tom Igoe's 'Making Things Talk' (2011). Knowledge is shared through snippets of code, modular *Processing* sketches, and through sharing knowledge of protocols, microprocessors, and the cataloguing of components by companies such as the website Sparkfun.com that offer both technical knowledge and the supply of the hardware itself.

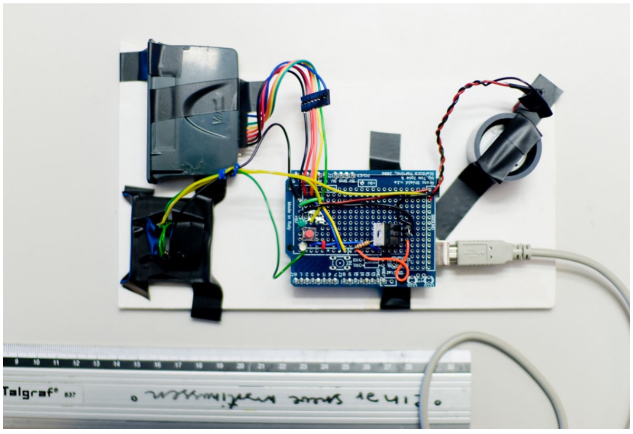

Figure 3. An early 'hardware sketch' of 'Sniff' the interactive dog, shown in section 2 below, made with an Arduino and various electronic components.

Interaction design studies that have engaged with material have largely focused on software, attempting to account for the perceived intangible, immaterial nature, and behaviour of code (Jung & Stolterman, 2011; Vallgårda & Redström, 2007). Hallnäs and Redström (2006) found that in interaction design "the material we 'use' is in many ways abstract and we tend to think of it not as material, but as expression neutral technology" (p. 216). The potential to "trivialize the role of technological choices required to actually cater for a good user centered design" has been identified in HCI (Fernaeus & Sundström, 2012, p. 486), where technical choices were often overlooked and engineering problems attributed to human error. Nordby (2011) found that it is "difficult to find frameworks that show how to analyse technology so as to present it as a material specifically oriented toward industrial and interaction design," and suggests that we need to develop 'conceptual materials' that are "created to support designers' conceptualisations of new artefacts" (p. 12). Supporting this, Fernaeus and Sundström (2012) found that there is a need to develop "methods for material exploration," and means to communicate these "material properties and possibilities" in interaction design (p. 494).

Drawing upon many of the discourses on the material, in particular actor network theory, Storni (2006) provided an account of the ways in which material and non-human objects manifest in design practices and processes through theories of object-centred sociality (Knorr-Cetina, 1997) and material agency (Pickering, 2001). He showed how design practice involves "material manipulations, transformations and constructions which produce a final object with a stable shape" (Storni, 2006 p. 25). In this perspective, design is a practice that deals with material problems, that are mediated semiotically and materially through tools and technology through "chains of visual and material artifacts" (ibid, p. 93).

The Immaterials of Interaction Design

As we have seen above, there are two connected but contradictory issues in interaction design: the move towards invisible computing and at the same time a renewed need to understand computation and interaction as composed with and of materials. How might designers come to accept that interaction design materials may be both immaterial and a material at once? What kind of language and framing do we require for that to be possible?

While there are instances where invisible phenomena have been taken up in HCI and ubiquitous computing, here research is mostly related to user-problems and usability issues. As Nordby (2011, p. 68) pointed out, this research analyses technology through application and use rather than analysing or generating knowledge about design materials. For instance Reeves Pridmore, Crabtree, Green, Benford, and O'Malley (2006) explored the spatial characteristics of sensors in relation to user-understanding; Ailisto, Korhonen, Plomp, Pohjanheimo, and Strömmer (2003) created comparisons of physical sensing methods in mobile phone applications; and Gorlenko and Merrick (2003) looked at the usability issues with invisible wireless connections. Additionally, instead of opening up the material nature of technologies, ubiquitous computing research often considers interface technologies as smoothly and invisibly embedded into our environments and tasks, where materiality and technical constraint are smoothed over and downplayed, as described by Chalmers and Galiani (2004). These seamless visions are particularly unhelpful when attempting to understand the materiality of ubiquitous computing, where they celebrate the invisibility of technology, rather than making its material qualities legible and understandable.

In the *Touch* project we coined the term 'immaterials' to describe this duality. It is a playful reshaping of 'immaterial' into the plural, not just 'the immaterial' in general, but a defined and knowable set of 'immaterials' or 'an immaterial.' The word embodies both the idea that something could be invisible and yet have form or qualities that are shapeable and understandable. Immaterials is a pragmatic framing of the literally and effectively invisible phenomena that should be accounted for in interaction design. In our initial thoughts, presented at a conference on creativity in London, we proposed that *radio*, *data*, *sociality,* and *time* might be some initial material phenomena that interaction design could take up (Jones, 2009). This was a provocation to stimulate discussion and further thinking, and a call for others to take up and investigate or extend the issues.

How does the term immaterials differ from other ways of describing invisibility? First, immaterials is not about the invisible effects or implications of designed objects or materials. It is not about the intangible practices, meanings, histories or personal narratives behind designed objects that have already been the subject of design research (Frers, 2012; Karana 2010; Kouhia, 2012; Piper, 2012).[1] It is also not about the invisible social or cultural implications of designed objects as described by Folkmann (2012). Unlike the discourses around invisible design, the term immaterials does not seek to make the results of design processes invisible or to make interfaces disappear.

In inventing and using the term immaterials, we sought to provoke and build understanding around the compositional character of invisible design materials themselves. It is more closely aligned with Mori's perspective on materials in architecture, in which she presents immaterial phenomena such as light, smell, and sound alongside other physical materials (Mori, 2002). It also echoes other attempts to redefine material away from physical matter, towards an adjective or dictionary definitions of 'practical instantiation,' and 'significance,' or by emphasising its performativity where it may provide "capabilities that afford or constrain action" (Leonardi, 2010, n.p.).[2]

By putting emphasis on the concept of immaterials we called for investigation, exploration, and communication of technical and interactional phenomena, for the opening up of black-boxes. In engineering a 'black box' is a device whose implementation is opaque, that can only be interrogated by its inputs and outputs without any knowledge of its internal workings. This metaphor was adopted by Latour (1987) to describe the way that the complexity of systems are 'fenced off' to make work and organisation possible. These black boxes embody the complex history and body of knowledge that engineers and developers have created, but much of it is invisible, undocumented, tacit, implicit, and optimised towards certain kinds of behaviours, functions or applications. We cannot see this complexity by simply using its inputs and outputs, and documentation such as specifications, instructions or data-sheets necessarily obscures, simplifies, and abstracts away much of this knowledge. As interaction designers we are often presented with literal black boxes such as the RFID reader in Figure 4. In the next section I describe and analyse a set of design projects that attempted to gain material understanding of this literally invisible technology.

2. Design and Research Approaches

Mixed Design Methods

This study takes up the conversation that designers can have with RFID technology, a conversation with technical design material at many levels, mixing technical, cultural, and design knowledges. This is a process that involves engaging with the technicalities of RFID, material exploration, technological reproduction, and (re) mediation. In these modes, we generate new knowledge through experiments, invention, and design practice, and in the process make material from what was previously invisible.

Methodologically, this entailed a research by design activity, an inquiry that contains both goals and means[3]. This process involves a practical theory of knowledge: knowledge creation as a way of acting, and developmental, reflective experimental enquiries[4] as suggested by Dewey (1933). "In real-world practice, problems do not present themselves to the practitioner as givens. They must be constructed from the materials of problematic situations which are puzzling, troubling, and uncertain" (Schön, 1983, pp. 39-40). The arguments are made through a generative and reflexive research by design activity (Sevaldson, 2010) that works through a series of designed artefacts, probes, and visualisations,

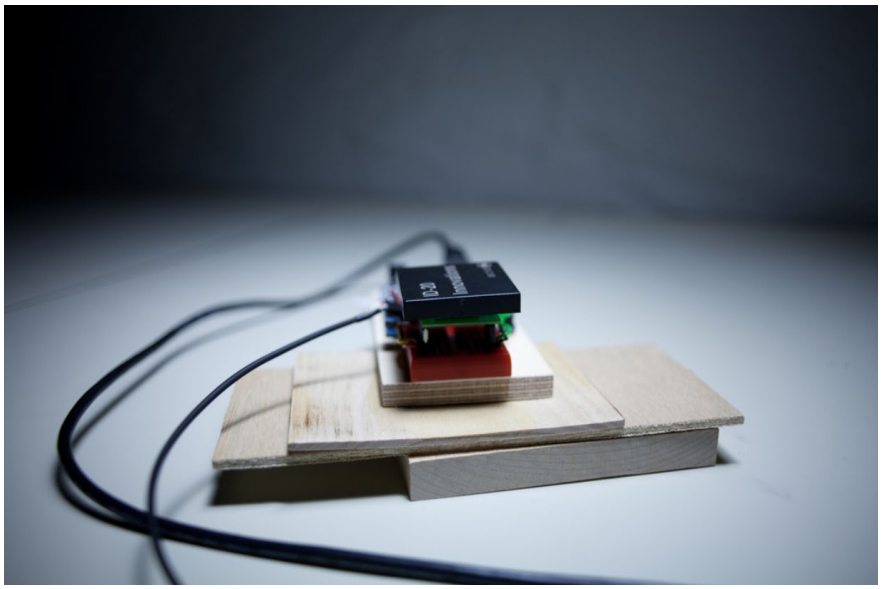

Figure 4. The 'black box' of RFID. The black square in the centre of this image is an 'Innovations ID-20' RFID reader connected through various prototyping components to an *Arduino* microcontroller.

with emphasis on the knowledge generated from design processes as well as the designed artefacts themselves (Fallman, 2003). These experimental processes present suggestions rather than empirical insights, they can "illustrate and show the direction of a proposed program, methods, new design materials" or "highlight hidden problems, forgotten issues, open up new perspectives, ask the new questions, define and present basic concepts" (Hallnäs & Redström, 2006, p. 135). This intertwined making and reflecting is an abductive process that allows us to build knowledge through invention, making, and reflection on objects and visualisations.

The *Touch* project (2006) involved a core group of trans-disciplinary designers and researchers working at the Oslo School of Architecture and Design and a design studio in London called BERG. It was run as a design studio project, involving core members, partnering companies, and masters students in workshops, sketching, experimental making, and conversation. The research began by engaging in the dominant technocultural imaginations of RFID, from industrial visions to popular media understandings. This involved investigations of the social, cultural, and communicative discourses and representations around RFID such as their visual branding (see Figure 1), instructional design, and explanation. The outcomes of these investigations were expressed as a set of fourteen design briefs that were used to guide our subsequent research. The following sections offer an account of a chain of explorations and mediations of RFID interaction itself.

Designing Communicative Prototypes

The first design explorations in the *Touch* project were investigations of playful products that were conducted to build knowledge of RFID as a technology that could be included in our product and interaction design practices.

The products and prototypes we developed were a toy car that followed instructions from wireless tags scattered across the floor, an exhibition for children that used a table of objects to control character animations, described in Nordby (2010), a toy dog (Figure 5) that sniffed for tags embedded in the world (Johansson, 2009), and a wooden bowl (Figure 6) that acted as a TV remote control, playing back content from objects that were placed inside it (Arnall & Martinussen, 2010). Each of these prototypes were developed with attention to physical materials such as wood and fabric, with product design languages that spoke to Scandinavian design history, and interfaces that prioritised non-screen-based direct manipulation and tangible feedback. Through these kinds of design developments we wanted to show that RFID had compositional potential as part of product and interaction design approaches.

These product prototypes served two purposes. First, it was a reflexive, conversational, developmental process for us as designers, through hands-on experimentation with the opportunities and constraints of RFID interaction. We developed specific, tacit understandings of how the RFID reader modules in Figure 7 responded to various RFID tags, and how the signals travelled through wood, fabric, and metal. This material knowledge defined the kinds of interactions and gestures that could be designed, whether interactions would trigger casually at a long distance, or whether tags would require deliberate and careful placement. Second, they provided stable objects around which to discuss alternative perspectives on RFID technology. They positioned RFID as a decidedly seamful, direct manipulation interface technology that could be used for playful, self-contained interactions. This challenged the dominant themes of invisibility and seamlessness in ubiquitous computing. In this way these design projects were more akin to critical design in their use of designed objects to challenge the dominant themes of technological development.

Figure 5. The toy dog 'Sniff'. Sniff has an RFID reader in his nose, and when he encounters RFID tagged objects, various sounds and haptic feedback are triggered.

Figure 6. An image of the 'Skål' or 'Bowl' prototype. A wooden bowl contains an RFID reader and sits in the middle of a number of a number of smaller objects that contain RFID tags. When these objects are placed in the bowl they trigger media playback on a connected television.

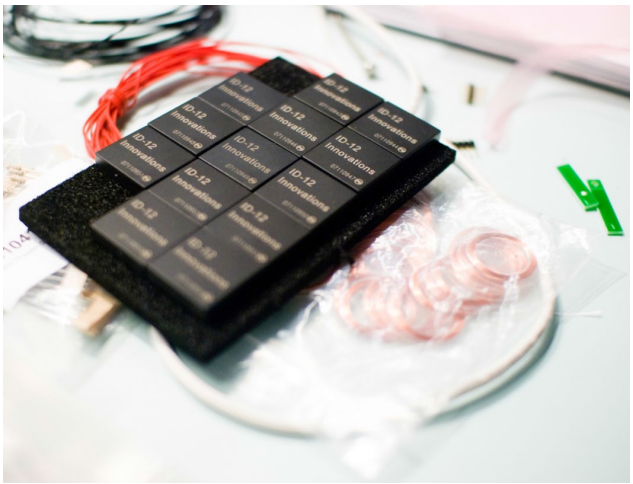

Figure 7. A package of 'Innovations ID-12' RFID modules as they arrive from the manufacturer.

Exploring RFID as Design Material

As a result of designing the prototypes above, we developed a hands-on, tacit, embodied literacy about RFID as a design material. We developed a literacy with the RFID readers depicted in Figure 5; their hardware and software interfaces, timings, protocols, standards, and specifications. Although there are material characteristics to many of these properties, here I concentrate on the literal invisibility of the technology, and the physical and spatial qualities of RFID's radio field.

Rosol (2010) found that the "expectations of RFID's ability to form an augmented digital space are in fact bound simply to its capacity to transmit data via radio signals" (p. 39). RFID's invisible 'wirelessness,' to draw on Mackenzie's (2008) term, is thus its central characteristic. In his work on 'hertzian space' Dunne pointed out that "All electronic products are hybrids of radiation and matter [...] radio space is actual and physical, even though our senses detect only a tiny part of it." (Dunne, 2005, p. 101). Radio fields have spatial characteristics that are defined by many things including the design of the antennae, frequency of the radio waves, power, and their propagation through physical materials. Radio is such a complex phenomena that the practice of antenna design is often referred to as a 'black art' in engineering communities (Huang & Boyle, 2008, p. 216).

In our design process we met the central problem of using novel technology in interaction design; the material qualities of RFID are complex, invisible, and badly documented. The readers in Figure 5 come with 'data sheets;' product descriptions that offer little more than theoretical limits to give us any indication of the physical characteristics of the radio field. In our research, Nordby noted that "the available information concerning SR-RFID in relation to industrial and interaction design is limited and often oriented toward finished solutions rather than exposing potentials for designing" (p. v). Thus to design with this 'immaterial' we had to explore its invisible technological phenomena, we needed to design our own empirical experiments, what we call material exploration to discover how it worked as physical design material.

Revealing RFID

To discursively reveal RFID as a design material required multiple experiments and approaches. How could we translate the knowledge we had built in our product experiments above into explanatory visual and narrative artefacts that we could reflect upon and that could be accessible, inspirational, and generative for other designers? We needed to find means to represent the invisible phenomena of RFID as a spatial and physical material.

Revealing the Invisible through Light Painting

Light-painting is a creative image-making technique familiar to many artists, filmmakers, and designers. It is a fundamentally photographic technique for creating images of light moving over time, using long-exposure to 'paint' motion into the photographic image. The technique has been explored by many artists and photographers including Étienne-Jules Marey, Man Ray, Picasso,

Jack Delano, Andreas Feininger and Eric Staller[5]. In 1914 Frank and Lillian Gilbreth used light-painting techniques to study and improve the practices of bricklayers and factory-line workers, photographing their movements with lightbulbs attached to their hands. As described by Price (1989), this was an important time and motion study in the development of the industrial era.

The visualisation in Figure 8 shows a cross-section through the three-dimensional physical space in which an RFID tag and a reader can interact with each other. We created this image by designing a probe with an LED attached to an RFID tag, that would flash every time an RFID reader sensed it. By carefully moving this reader while taking a long-exposure photograph we could paint an outline of the 'readable volume' of the system. By moving the probe by small amounts and painting multiple images we could produce animations that revealed further dynamic and three-dimensional qualities of RFID interactions as seen in the film 'Immaterials: Ghost in the Field.'

This visualisation technique shows empirical evidence of the physical phenomena of RFID interactions[6]. This interaction is dependent on the power of the reader, the size and shape of both the reader and the tag's antennae, the type of RFID system, and the materials in the surrounding environment, to name just a few variables. These complex interactions would be difficult to visualise in other ways, for example in software simulation, for example see Han (2010).

This process of revealing staged both individual and collaborative conversations about the phenomena of RFID, developing and challenging our understanding of RFID interactions. For instance, before seeing these images and animations we had no knowledge that the 'side lobes,' the small bubbles on the left and right of the reader, played such an important part of RFID interaction. With an RFID reader embedded below a flat surface, the size of the 'readable area' could be changed from just a few mm up to a circle of 10 cm in diameter through small adjustments to the position of the reader. By seeing RFID interactions as physical 'immaterials' we could adjust and control its material relationships, to significantly alter the interactional experience of RFID interfaces. This reflexive knowledge building, and the resulting extension of our material understanding allowed for more nuanced discussion and design approaches to RFID interfaces. The visualisations also changed the perception of RFID technology in our collaborative teaching and lecturing, abstract discussions of privacy and ubiquity were transformed into materially grounded discussions of the fields and interactions based in this material evidence.

Mediational Strategies

These visualisations were carefully constructed graphically, drawing on extensive reflection on and remediation of existing visual culture and practice. The use of a flashing, rather than constant, light created dotted or dashed lines which have traditionally been used to represent invisible boundaries or hidden features in mapping and instructional design. We designed the visual expression to relate closely to other popular media tropes such as the green[7] cascades of digital information in The *Matrix* (Silver, 1999), and of the popular comic book technique called Kirby Crackle, which uses clustered dots to depict energy or invisible forces (Harry, 2011). It remediated and reproduced these visual features to articulate this new technological phenomena alongside familiar cultural meanings. Through this combination of the familiar and the unknown, the visualisations resonated broadly into news media and exhibitions such as MoMA (Figure 9).

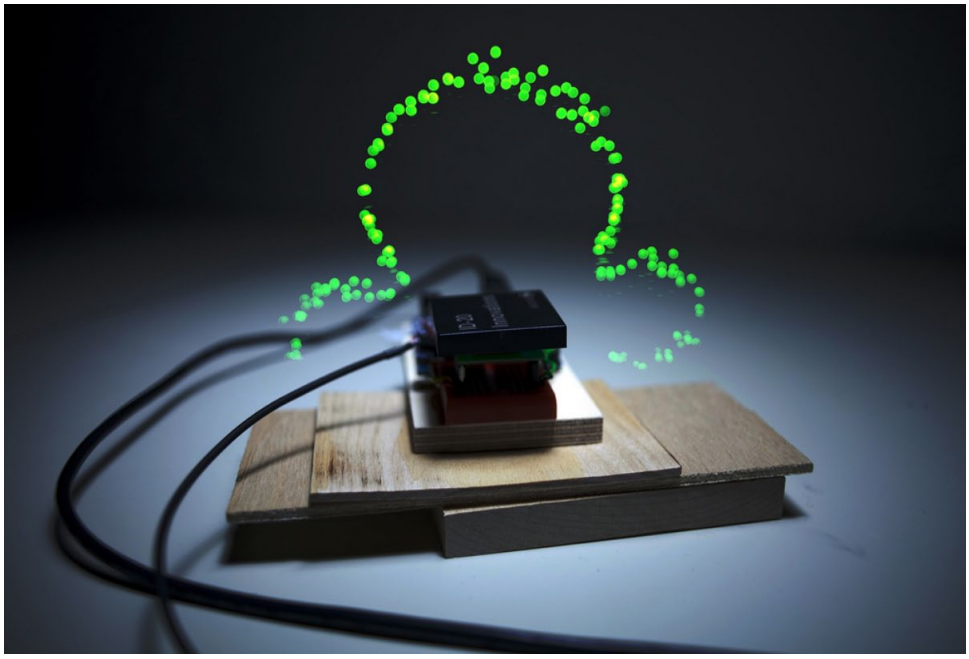

Figure 8. A still from Immaterials: Ghost in the Field. A light painting of the interactions between an RFID reader and a tag. Watch the full film here: http://vimeo.com/7022707

Figure 9. Immaterials:
Ghost in the Field in the MoMA 'Talk to Me' catalogue.

The visualisation required further translation and explanation through the development and production of documentary film that described the issues of invisibility in RFID, demonstrated the techniques, and expanded on the meanings of the visualisations. Light painting is a fairly obscure technique that can easily be interpreted as an optical phenomena visible to the human eye, rather than the long-exposure camera, so it requires explanation. The film was scripted to describe the visualisations through motion graphics and edited explanatory sequences with interview 'talking heads' in a way that used familiar documentary conventions to help explain and demonstrate the complex subject and visual material.

Alongside the visualisations, the work also provided an opportunity to inscribe new language about design materials in other ways. Communicating this research was the moment in which we had to invent a vocabulary to describe our 'immaterials' approach. Discursively, immaterials was important to us as a community of designers and technologists, where we needed to refer to immaterial phenomena in discussions with clients, in research proposals, and in talks and lectures. The term immaterials provided a common framing in which to debate, discuss, and develop our understanding of specific interaction design materials, outside of and in opposition to other discourses around invisibility or seamlessness.

Discussion

The interlinked practices of material exploration and mediation demonstrated above exemplify one approach in which interaction design research may participate in a material and cultural conversation about technological development. Below I reflect on these practices and their interaction design and sociocultural contexts.

Material Exploration

As outlined in Section 1, there are few existing approaches to developing shared understandings of materials in interaction design. If we accept that interaction design, like other design disciplines, has material concerns, then means of exploring and mediating knowledge of its materials are essential for the development of the discipline.

Broadly, material exploration is a means of generating knowledge about the materials of a design situation so that we can have a conversation with and about them. Analytically, as Storni argued, material explorations acknowledge the importance of non-human and material objects in the design process, where they "let new possibilities and entities 'pop up' and start taking part in the gathering" (Storni, 2006, p. 355). Material explorations are a means for revealing the agencies of interface technologies, that through reflective conversation in design, may open up for material manipulations, constructions, and transformations.

The processes outlined above showed how the revealing of RFID interaction through visual approaches led to new understandings of the technology as a spatial, manipulable, gestural phenomena. As shown in the section 'discursive outcomes' below, many others have taken up this approach to other interactions, phenomena, and technologies. Additionally, material exploration has been widely used and extended in our design practices, not just in this case of RFID, but also for large datasets and algorithms. When we look at material exploration and mediation together, they offer one approach to Fernaeus and Sundström's (2012) call for material exploration and communication methods in interaction design.

Mediating Immaterials

Inherent in our material explorations of RFID are approaches that are communicative and mediational. The design work in these studies deliberately assembles heterogeneous visual and narrative means, drawn from other disciplines such as photography, animation, comics, and cinema. This combination and entanglement of many different techniques into a communicative whole is an approach that trans-disciplinary design teams (such as the *Touch* project) can achieve through bringing together knowledge of many different techniques, tools, and methods. The intention of this approach to communication is that the films then circulate widely amongst different audiences, and across disciplinary boundaries, as artefacts that generate discussion, responses, and further exploration. So we need means to account for and analyse the complex ways in which these explorations work as communicative objects.

Historically, photography and film have played transformative and stabilising roles in product design, architecture, science, and technology (Kirby, 2010). Photographers have been closely related to the development of architectural movements, for example Julius Schulman's defining images of modernism (Rosa, 2008). The Eames were early pioneers in the use of film to communicate design work, not just using film to document their designs, but designing and inventing in the medium, using film as a tool (Neault, 2008). More recently films have become the popular cultural objects around which design is mediated and discussed (Apple, 2012; Design onscreen, n.d.; Hustwit, 2009).

In interaction design, film has become a tool for exploration and mediation. The ambiguous nature of film language can engage users in discussions about speculative products (Briggs et al., 2012). Documentary film can play a part of exploratory and inspirational user research (Raijmakers, 2007). Stop-motion animation can be a prototyping tool for tangible interfaces (Bonanni & Ishii, 2009), and 'virtual video prototypes' can engage users in fictional and speculative designed objects (Halskov & Nielsen, 2006).

The development of digital filmmaking tools and online video has meant that film production and distribution is well within reach of small design teams and research projects, allowing for much broader audiences to be included in conversations about design and materials. The use of online video supported the construction of shared understandings of RFID across constellations of design and technology communities. Allowing the Immaterials film to be embedded[8] in news sites, social networks, and weblogs meant that it could be used in many ways: to illustrate articles or arguments about RFID, as a part of collections of films on technology, or as a news story in its own right (Figure 10). Each time the images were copied or the film was embedded, they carried the concept of immaterials to new communities, provoking new discussions.

Figure 10. Immaterials projects written up in Weave magazine (DE).

In our attempt to translate this highly specialised and relatively obscure technology into a more accessible object, we reproduced some of the conventions of traditional documentary filmmaking such as the layering of authoritative, interview voice over the visualisations. This explanatory structure means the films are persuasive, with some of the effortless and everyday qualities of television. In this way the knowledge they mediate may be somewhat veiled by their surface: the need to condense information into accessible forms does indeed obscure some of the complexity of the subject. The compression and abstraction of knowledge into filmic form opens up for broader discussion across wider communities of interest, but also closes down certain aspects of in-depth conversation in others. Indeed, the film's approach alienated some technologists and engineers who dismissed the empirical aspects of the approach and treated the visualisation as either obvious or self-evident. In its attempts at accessibility there are views, explanations, and perspectives that are excluded.

There is also a tension in the differences between the photographic and the animated visualisations. The animated visualisations show RFID fields as relatively unstable and fluid phenomena that morph and change depending on their physical relationships. However when shown as a single image, the field is shown as a literally stable, static object. As in science (Carusi, 2012), design research will need to develop an epistemology that can account for the persuasiveness and trust imbued into different kinds of visual evidence that may represent only partial perspectives.

Discursive Outcomes

While the main focus of this article is on the mediational approaches for exploring and communicating immaterials, there is also a need to acknowledge the variety of responses and discussions from people who have been motivated to participate, extend, and even to take up some of these investigations into their own work. It is instructive to reflect, briefly, on four ways in which others have engaged with the subject and approaches presented in the Immaterials film.

As discussion of RFID as material. A summary of responses to the film revealed discussion from designers, journalists, privacy advocates, radio engineers, and science fiction authors. This diverse audience added many new perspectives to the work, such as the relation to historical explorations of electricity such as those of Tesla, thoughts on privacy implications, and to the use of these techniques to explain other technologies. In particular the film enacted a move in discussions away from abstract concepts and folk-mythologies of RFID towards engaging with the evidence of material phenomena. For instance, technology critic Adam Greenfield wrote:

> Rather than asserting "an RFID" as some eternal given, something that will produce the same linear, determinate effect each and every time it is deployed, Immaterials reminds us that the choice of material, shape, size, direction, orientation and power rating of the components involved have distinct consequences for the uses to which those components can be put.[9]

These discussions took serious account of the concept of RFID as a material, and took up the generative potential of the material for further development of application, use and critique.

As a symbol for RFID technology. The image shown in Figure 8 has been used as a symbol for RFID technology (see Figure 11), replacing other common representations such as an RFID tag or a generic commercial symbol. For instance, the image is used as the icon for the RFID group on Quora, a popular Silicon Valley-based discussion site. A Google image search for 'RFID field' also shows the image being used widely across the web. While the image may be more descriptive of RFID interaction than a more generic image, here it may be problematic that the

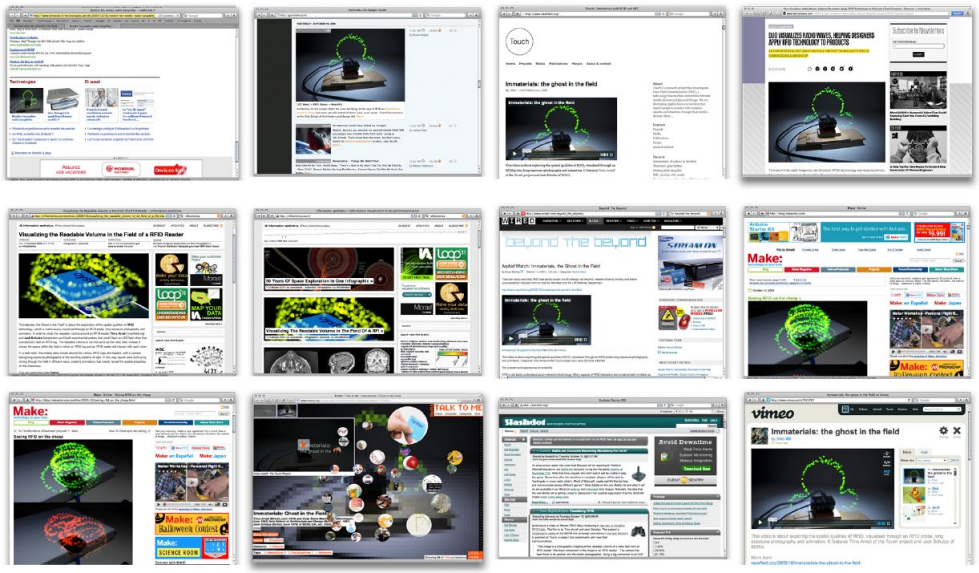

Figure 11. Immaterials: Ghost in the field imagery embedded across the web in news sites, weblogs, and gallery sites[10].

image (unlike the animated visualisations) can be accepted as a stable, unproblematic artefact, in some respects a new 'black box.' Although there is clearly potential in providing a new symbol for RFID, in losing the relationship between the symbol and the visualisation approach, it loses much of its discursive and generative agency.

As exhibition and education. Although the film was designed as a linear viewing experience, it ended up being cut up, edited and repurposed widely for gallery installations, and at workshops, in presentations, and in lectures. A silent, text-driven version of the film was exhibited at MoMA in New York (Figure 9), the London Transport Museum in London, and many other international exhibitions and galleries. As well as being adapted for an Open University programme on information technology and ubiquitous computing, the film was used in our interaction design teaching practice. The material arguments embedded in the work provided a discursive foundation for teaching the fundamentals of RFID with design students, where they helped construct material-based, inventive approaches rather than fictional or speculative accounts of the technology.

As an approach. Perhaps the most important discursive outcome is the material exploration approach. This has been taken up, used, and extended widely across many disciplines and applied to many technologies. The methods behind the visualisation were critiqued and discussed extensively at technical sites like Slashdot, where they were compared with other methods such as simulation. More significantly, the technique was extended through development of software and hardware platforms to map other wireless phenomena such as Wifi, GPS (Martinussen, 2013) and other electromagnetic fields. The BBC and Discovery Channel have both adopted our techniques as explanations of 3G and Wifi, respectively, for popular, primetime audiences. The film demonstrated that explorations of technical subjects could resonate broadly through various cultures by assembling creative approaches such as light-painting, photography, animation, and documentary. This created the conditions in which emerging technologies could be revealed and explained by many groups and communities, and for discussion by many different kinds of audiences.

These four areas show some of the ways that the project enacted conversations in different contexts with various audiences. Initially the film highlighted the otherwise hidden issues of materiality in RFID interactions, and opened up new perspectives on, and discussion around these phenomena. The film strongly advocated for an approach to material exploration that, over time, staged and formatted an abundance of other material explorations and mediations, generated by other communities and networks, in other disciplines and contexts. These networks of discussions motivated us and others to reflect on and re-engage with the material of emerging technologies, provoking further chains of investigations and debate.

Towards Discursive Design

The explorations above have exemplified one way in which designers can participate in reflexive conversations about 'immaterial' materials and the literally invisible aspects of ubiquitous computing technology. This is possible through addressing socio-cultural concerns through dialogical, material, and communicative modes of design, that requires both practical and analytical intersections in designing and reflection. This kind of discursive design builds bridges between technical and the cultural domains in interaction design and communication. It builds upon some of the traditions of critical design but focuses on generative, constructive approaches to material and

communications, the "reflexive and iterative interplay between materials, experimentation, and use" (Morrison & Arnall, 2011, p. 226). The explorations show that interaction design can build language, narratives, and communicative material that, through chains of visual and material artifacts, translate between complex technical subjects and broader audiences and discourses. The term 'immaterials' is helpful in this, giving us language to frame, discuss, and explore interaction design material, that helps us deal with the invisible-material contradiction without obscuring or mystifying underlying complexities.

As Balsamo (2011) stated, "cultivating and shaping the technological imagination is a cultural imperative of the highest order" (p. 247). Through the development of expert practices in photography, animation, filmmaking, and social media, interaction design can transform tacit, obscure, and technical knowledge into communicative, discursive material. The communicative outcomes of these processes are designed to both explain and reflect upon technical materials and our approach to understanding them. In this process we take up the culture and materiality of the world, and actively remediate it through "the development of new narratives, new myths, new rituals, new modes of expression, and new knowledges" (Balsamo, p. 237). In this kind of discursive design approach, we account for the material and mediational aspects of design that engage in the technological imagination.

Conclusions

The problematic issues of invisibility and seamlessness in interfaces have meant that the physical and material aspects of interface technologies have been overlooked in favour of treating them as 'expression neutral' or simply immaterial phenomena. The 'material turn' suggests that materials are again being accorded agency in design, and if designed objects embody what is both thinkable and possible—the intentional use of the cultural and the material—then we need a significantly stronger focus and attention to material exploration and mediation in interaction design.

I have shown that socio-cultural, discursive design approaches can argue for the agency of materials in design, and may negotiate and translate among complex technologies, materials, languages, and people to build shared knowledge about technology as material phenomena. By articulating the invisible 'immaterials' of RFID through visualisation, reproduction, and remediation of popular culture, narrative media, online video, animation, and visual design, this research has exemplified how design research can engage in developing the technocultural imagination.

By conducting explorations, creating media, and inventing language, this inquiry points towards a discursive interaction design that is not just about problem solving or solution finding, but instead about exploration, conversation, and communication. This framing of design takes up the understanding of interface technologies as important for both design practice and for wider trans-disciplinary discussion. These material mediations in discursive design are less concerned with application and use, and instead explore and communicate to inscribe new patterns and grain in our understandings of interface technologies.

Acknowledgments

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Endnotes

1. Karana (2010) found that the 'meaning' of a material changes based on "the product the material is embodied in, how we interact with it, and the context in which the interaction takes place." Here materials are analysed through their intangible and dynamic semiotic qualities, where they impart meaning and have indexical or connotative qualities.
2. Within management, communication and sociology research, Leonardi suggested that materiality has been largely ill-defined, either downplayed or treated as symbolic. Following Pinch (2008), he attempted to describe digital materials without alluding to the cultural baggage of physicality; material can instead be defined as 'practical instantiation' or 'significance.' When we "describe digital artifacts as having "material" properties, aspects, or features, we might safely say that what makes them "material" is that they provide capabilities that afford or constrain action" (Leonardi 2010).
3. Schön has defined problem setting as «a process in which, interactively, we name the things to which we will attend and frame the context in which we will attend to them» (Schön, 1983:40).
4. Dewey described a reflective process as an ‹active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends› (Dewey 1933:118)
5. For more light painting research see 'Painting with light—how it all began' by Sergey Churkin. http://lpwalliance.com/index2.php?type=publicationview&id=15
6. We could look at these visualisations as 'epistemic artefacts' (Tweney 2002): knowledge creating or knowledge carrying objects that are an intrinsic part of the exploration, discovery, and invention process.
7. There was a deliberate decision to use green LEDs in the visualisation for two reasons. One was that the green LED light is strikingly different from other common indoor colours (the same reason green is used in greenscreen special effects), it shows up in a striking way that white LED light would not. Secondly it relates strongly to digital phenomena: early green text displays and wireframe graphics, green printed circuit boards, and popular-media images of 'the digital' including The Matrix.
8. The concept of 'embedding' is central to many video sharing websites such as Youtube and Vimeo, where videos can be embedded in any HTML page by simply copying a small 'snippet' of code. This allows videos to be seen on news sites, blogs, and social media, where they can be used to illustrate arguments or shown alongside other material.

9. A writeup of Immaterials by Adam Greenfield: http://speedbird.wordpress.com/2009/10/15/on-immaterials/
10. The film was released online in October 2009, and has been played over two hundred thousand times as of July 2013.

References

1. Ailisto, H., Korhonen, I., Plomp, J., Pohjanheimo, L., & Strömmer, E. (2003). Realising physical selection for mobile devices. In A. Schmidt, S. Benford, & A. Butz (Eds.), *Proceedings of Physical Interaction Workshop on Real World User Interfaces* (pp. 38-41), New York, NY: Springer.
2. Albrecht, K., & McIntyre, L. (2005). *Spychips: How major corporations and government plan to track your every move with RFID*. Nashville, TN: Thomas Nelson.
3. Apple. (2012). *iPad 3 Commercial*. Retrieved August 3, 2012, from http://www.youtube.com/watch?v=da9q_v10ooU
4. Arnall, T., & Martinussen, E. S. (2010). Depth of field: Discursive design research through film. *Journal of FORMakademisk, 1*(3), 100-122.
5. Balsamo, A. (2005). *Taking culture seriously: Educating and inspiring the technological imagination*. Retrieved August 3, 2012, from http://goo.gl/8OlQcc
6. Balsamo, A. (2011). *Designing culture: The technological imagination at work.* Durham, UK: Duke University Press.
7. Bardzell, S., Bardzell, J., Forlizzi, J., Zimmerman, J., & Antanitis, J. (2012). Critical design and critical theory: The challenge of designing for provocation. In *Proceedings of the Designing Interactive Systems Conference* (pp. 288-297). New York, NY: ACM.
8. Bell, G. & Dourish, P. (2007). Yesterday's tomorrows: Notes on ubiquitous computing's dominant vision. *Personal Ubiquitous Computing, 11*(2), 133-143.
9. Blanchette, J. F. (2011). A material history of bits. *Journal of the American Society for Information Science and Technology, 62*(6), 1042-1057.
10. Blevis, E., Lim, Y.-K., & Stolterman, E. (2006). Regarding software as a material of design. In K. Friedman, T. Love, E. Corte-Real, & C. Rust (Eds.), *Proceedings of Design Research Society International Conference* (pp. 1-18). Lisbon, Protugal: Centro Editorial do IADE.
11. Blum, A. (2012). *Tubes: A journey to the center of the internet*. New York, NY: HarperCollins.
12. Bolter, J. D., & Grusin, R. (2000). *Remediation: Understanding new media.* Massachusetts: MIT Press.
13. Bonanni, L., & Ishii, H. (2009). Stop-motion prototyping for tangible interfaces. In N. Villar, S. Izadi, M. Fraser, & S. Benford (Eds.), *Proceedings of the 3rd International Conference on Tangible and Embedded interaction* (pp. 315-316). New York, NY: ACM.
14. Bourdieu, P. (1990). *The logic of practice.* Cambridge, UK: Polity press.
15. Bowen, S. (2009). *A critical artefact methodology: Using provocative conceptual designs to foster human-centred innovation* (Unpublished doctoral dissertation). Sheffield Hallam University, Sheffield, UK.
16. Bratteteig, T., Wagner, I., Morrison, A., Stuedahl, D., & Mörtberg, C. (2010). Research practices in digital design. In D. Stuedahl, A. Morrison, C. Mörtberg, & T. Bratteteig (Eds.), *Exploring digital design* (pp. 17-54). Vienna, Austria: Springer.
17. Briggs, P., Blythe, M., Vines, J., Lindsay, S., Dunphy, P., Nicholson, J., … Olivier, P. (2012). Invisible design: Exploring insights and ideas through ambiguous film scenarios. In *Proceedings of the Designing Interactive Systems Conference 2012* (pp. 534-543). New York, NY: ACM.
18. Carusi, A. (2012). Making the visual visible in philosophy of science. *Spontaneous Generations, 1*(6), 106-114.
19. Chalmers, M. (2003). Seamful design and ubicomp infrastructure. In J. McCarthy & J. Scott (Eds.), *Proceedings of 5th International Conference on Ubiquitous Computing.* Berlin, Germany: Springer-Verlag. Retrieved January 21, 2013, from http://www.dcs.gla.ac.uk/~matthew/papers/ubicomp2003HCISystems.pdf
20. Chalmers, M., & Galani, A. (2004). Seamful interweaving: Heterogeneity in the theory and design of interactive systems. In D. Benyon, P. Moody, D. Gruen, & (Eds.), *Proceedings of the 5th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques* (pp. 243-252). New York, NY: ACM.
21. *Design onscreen.* (n.d.). Retrieved January 21, 2013, from http://www.designonscreen.org
22. Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educational process.* Lexington, MA: Heath.
23. Dourish, P. (2004). *Where the action is: The foundations of embodied interaction.* Cambridge, MA: MIT Press
24. Dunne, A., & Raby, F. (2001). *Design noir: The secret life of electronic objects.* Vienna, Austria: Springer.
25. Dunne, A. (2005). *Hertzian tales: Electronic products, aesthetic experience, and critical design.* Cambridge, MA: The MIT Press.
26. Dunne, A., & Raby, F. (2007). *Critical design FAQ.* Retrieved August 3, 2012, from http://www.dunneandraby.co.uk/content/bydandr/13/0
27. Fallman, D. (2003). Design-oriented human-computer interaction. In C. Cockton & P. Korhonen (Eds.), *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 225-232). New York, NY: ACM.
28. Fernaeus, Y., & Sundström, P. (2012). The material move how materials matter in interaction design research. In *Proceedings of the International Conference on Designing Interactive Systems* (pp. 486-495). New York, NY: ACM.
29. Fleisch, E., & Dierkes, M. (2003). *Ubiquitous computing: Why Auto-ID is the logical next step in enterprise automation. In Auto-ID Center White Paper.* University of St. Gallen.

30. Folkmann, M. (2012). The aesthetics of immateriality in design: Smartphones as digital design artifacts. In E. R. Ramírez (Ed.), *Proceedings of the International Conference on Design and semantics of form and movement* (pp. 137-147). Wellington, New Zealand.
31. Frers, L. (2012, Sept. 26). *Making absence. Evoking materialities.* Paper presented at the the 1st Making Conference on Materiality and Knowledge, Høgskolen i Telemark, Porsgrunn, Norway.
32. Gorlenko, L., & Merrick, R. (2003). No wires attached: Usability challenges in the connected mobile world. *IBM Systems Journal, 42*(4), 640-651.
33. Hallnäs, L., & Redström, J. (2006). Interaction design: Foundations, experiments. Borås, Sweden: University College of Borås.
34. Halskov, K., & Nielsen, R. (2006). Virtual video prototyping. *Human-Computer Interaction, 21*(2), 199-233.
35. Han, C., & Wang, D. (2010). Research and application on RFID tags and antenna simulation deployment system. In *Proceeding of the 2nd IEEE International Conference on Information Management and Engineering* (pp. 373-378). Piscataway, NJ: IEEE.
36. Hill, J. (2006). *Immaterial architecture.* New York, NY: Routledge.
37. Hjelm, S. I. (2001). *Designing the invisible computer– From radio-clock to screenfridge*. Retrieved August 3, 2012, from http://smart.tii.se/smart/publications/pubs/invisibleComputer.pdf
38. Huang, Y., & Boyle, K. (2008). *Antennas: From theory to practice.* New York, NY: Wiley.
39. Hustwit, G. (Director). (2009). *Objectified.* New York, NY: Gary Hustwit.
40. Igoe, T. (2011). *Making things talk.* Sebastopol, CA: Maker Media.
41. Instron (2012). *Materials testing machines for tensile, fatigue, impact & hardness testing.* Retrieved August 3, 2012, from http://www.instron.us/wa/home/default_en.aspx
42. Ishii, H., & Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits and atoms. In S. Pemberton, (Ed.), *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 234-241). New York, NY: ACM.
43. Johansson, M. (2009). Sniff: Designing characterful interaction in a tangible toy. In P. Paolini & F. Garzotto (Eds.), *Proceedings of the 8th Interaction Design and Children* (pp. 186-189). New York, NY: ACM.
44. Jones, M. (2009). *Immaterials lecture at CAT London.* Retrieved August 3, 2012, from http://berglondon.com/talks/immaterials/
45. Hincapié-Ramos, J. D., Tabard, A., & Bardram, J. (2010). Designing for the invisible: User-centered design of infrastructure awareness systems. In O. W. Bertelsen, P. Krogh, K. Halskov, & M. G. Petersen (Eds.), *Proceedings of the 8th Conference on Designing Interactive Systems* (pp. 302-305). New York, NY: ACM.
46. Jung, H., & Stolterman, E. (2011). Form and materiality in interaction design: A new approach to HCI. In D. Tan, B. Begole, & W. A. Kellogg (Eds.), *Proceedings of the International Conference on Human Factors in Computing Systems* (pp. 399-408). New York, NY: ACM.
47. Karana, E., & Hekkert, P. (2010). User-material-product interrelationships in attributing meanings. *International Journal of Design, 4*(3), 43-52.
48. Kinsley, S. (2010). *Practising tomorrows? Ubiquitous computing and the politics of anticipation* (Unpublished doctoral dissertation). University of Bristol, Bristol, UK.
49. Kirby, D. A. (2010). *Lab coats in hollywood: Science, scientists and cinema.* Cambridge, MA: The MIT press.
50. Harry, M. (2011). *Evolution of kirby krackle.* Retrieved August 3, 2012, from http://www.kirbymuseum.org/blogs/simonandkirby/archives/3997
51. Knorr-Cetina, K. (1997). Sociality with objects: Social relations in postsocial knowledge societies. *Theory, Culture and Society, 14*(4), 1-30.
52. Kouhia, A. (2012, Spet. 26). *From materiality to immateriality: The role of crafts in mediating the encultured knowledge and personal narratives.* Paper presented at the 1st Making Conference on Materiality and Knowledge, Høgskolen i Telemark, Porsgrunn, Norway.
53. Lang, P., & Menking, W. (2003). *Superstudio: Life without objects*. Milan, Italy: Skira Editore.
54. Latour, B. (1987). *Science in action : How to follow scientists and engineers through society.* Cambridge, MA: Harvard University Press.
55. Leonardi, P. M. (2010). Digital materiality? How artifacts without matter, matter. *First Monday, 15*(6). Retrieved August 3, 2012, from http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/viewArticle/3036/2567
56. Mackenzie, A. (2008). Wirelessness as experience of transition. *The Fibreculture Journal,* (13). Retrieved August 3, 2012, from http://thirteen.fibreculturejournal.org/fcj-085-wirelessness-as-experience-of-transition/
57. Manzini, E., & Cau, P. (1989). *The material of invention: Materials and design.* Cambridge, MA: The MIT press.
58. Martinussen, E. S. (2013). Pockets and cities: Interaction design and popular imagination in the networked city. *Design and Culture, 5*(3), 289-312.
59. Mattern, S. (2012). Talk to me: Design and the communication between people and objects. *Design and Culture, 4*(3), 369-373.
60. Mazé, R., & Redström, J. (2007) Difficult forms: Critical practices of research and design. In *Proceedings of the 2nd Conference of International Association of Societies of Design Research* (pp. 2-18). Hong Kong, China: Polytechnic University School of Design.
61. Mori, T. (2002). *Immaterial/ultramaterial: Architecture design and materials.* New York, NY: George Braziller..
62. Morrison, A., & Arnall, T. (2011). Visualizations of digital interaction in daily life. *Computers and Composition, 28*(3), 224-234.

63. Morrison, A., Arnall, T., Knutsen, J., Martinussen, E. S., & Nordby, K. (2011). Towards discursive design. In N. Roozenburg, L. -L. Chen, & P. J. Stappers (Eds.), *Proceedings of the 4th Conference of International Association of Societies of Design Research* (p. 70). Delft, The Netherlands: TUDelft.
64. Emilio, A. (1972). *Italy: The new domestic landscape.* New York, NY: Museum of Modern Art.
65. Negroponte, N. (1995). *Being digital.* New York, NY: Knopf.
66. Neault, M. (2008). *The films of Charles & Ray Eames.* Retrieved August 3, 2012, from http://eamesdesigns.com/library-entry/films-of-charles-and-ray-eames/
67. Nordby, K. (2010). Conceptual designing and technology: Short-range RFID as design material. *International Journal of Design, 4*(1), 29-44.
68. Nordby, K. (2011). *Between the tag and the screen: Redesigning short-range RFID as design material* (Unpublished doctoral dissertation). Oslo School of Architecture & Design, Oslo, Norway.
69. Norman, D. A. (1998). *The invisible computer.* Cambridge, MA: MIT Press.
70. Orlikowski, W. J. (2010). The sociomateriality of organisational life: Considering technology in management research. *Cambridge Journal of Economics, 34*(1), 125-141.
71. Pickering, A. (2001). Practice and posthumanism: Social theory and a history of agency. In K. K. Cetina, T. R. Schatzki, & E. Savigny (Eds.), *The practice turn in contemporary theory* (pp. 172-183). London, UK: Routledge.
72. Piper, G. (2012, Sept. 25). *The invisible and visible in making. Reflection on personal practice.* Paper presented at the 1st Making Conference on Materiality and Knowledge, Høgskolen i Telemark, Porsgrunn, Norway.
73. Poole, E. S., Le Dantec, C. A., Eagan, J. R., & Edwards, W. K. (2008). Reflecting on the invisible: Understanding end-user perceptions of ubiquitous computing. In H. Y. Youn & *International Conference on Ubiquitous Computing* (pp. 192-201). New York, NY: ACM.
74. Price, B. (1989). Frank and Lillian Gilbreth and the manufacture and marketing of motion study, 1908-1924. In W. J. Hausman (Ed.) *Business and economic history* (Vol. 18, pp. 88-98). Fredericksburg, VA: BookCrafters.
75. Raijmakers, S. (2007). *Design documentaries: Using documentary film to inspire design* (Unpublished doctoral dissertation). Royal College of Art, London, UK.
76. Ratto, M. (2007). Ethics of seamless infrastructures: Resources and future directions. *International Review of Information Ethics, 8*(8), 21-25.
77. Redström, J. (2005). On technology as material in design. In W. Anne-Marie. (Ed.) *Design philosophy papers: Collection two* (pp. 31-42). Crows Nest, Australia: Team D/E/S.
78. Reeves, S., Pridmore, T., Crabtree, A., Green, J., Benford, S., & O'Malley, C. (2006). The spatial character of sensor technology. In J. M. Carroll, S. Bødker, & J. Coughlin (Eds.), *Proceedings of the 6th Conference on Designing Interactive Systems* (pp. 31-40). New York, NY: ACM.
79. Reichenstein, O. (2012). *Good design is invisible: An interview with iA's Oliver Reichenstein.* Retrieved August 3, 2012, from http://www.theverge.com/2012/7/24/3177332/ia-oliver-reichenstein-writer-interview-good-design-is-invisible
80. Robles, E., & Wiberg, M. (2010). Texturing the material turn in interaction design. In M. Coelho, J. Zigelbaum, H. Ishii, R. J. K. Jacob, P. Maes, T. Pederson, O. Shaer, & R. Wakkary (Eds.), *Proceeding of the 4th International Conference on Tangible, Embedded, and Embodied interaction* (pp. 137-144). New York, NY: ACM.
81. Rosa, J. (2008). *A constructed view: The architectural photography of julius shulman.* New York, NY: Rizzoli.
82. Rosol, C. (2010). From radar to reader: On the origin of REID. Aether. *The Journal of Media Geography 5*, 37-49.
83. Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York, NY: Basic Books.
84. Schön, D. A. (1992). Designing as reflective conversation with the materials of a design situation. *Knowledge-Based Systems, 5*(1), 3-14.
85. Sengers, P., Boehner, K., David, S., & Kaye, J. J. (2005). Reflective design. In O. W. Bertelsen, N. O. Bouvin, P. G. Krogh, & M. Kyng (Eds.), *Proceedings of the 4th Decennial Conference on Critical Computing: Between Sense and Sensibility* (pp. 49-58). New York, NY: ACM.
86. Sevaldson, B. (2010). Discussions & movements in design research. *FORMakademisk, 3*(1), 8-35.
87. Silver, J. (producer) & Wachowski, A, Wachowski, L (directors). (1999). *The Matrix* [Motion picture]. USA: Warner Brothers.
88. Spool, J. M. (2009). *Great designs should be experienced and not seen.* Retrieved August 3, 2012, from http://www.uie.com/articles/experiencedesign/
89. Storni, C. (2006) Let the divergence converge: On sociability computing. *International Journal of Learning, 12*(1), 135-146.
90. Suchman, L. A. (1987). *Plans and situated action: The problem of human machine communication.* Cambridge, UK: Cambridge University Press.
91. Svabo, C. (2007). A social language of objects and artifacts. Concepts of materiality in practice-based approaches to knowing in organization. In *Proceedings of the 2nd Nordic Conference on Design Research.* Stockholm, Sweden: University of Art..Retrieved August 3, 2012, from http://www.nordes.org/opj/index.php/n13/article/view/187
92. Thomas, K. L. (2006). *Material matters: Architecture and material practice.* London, UK: Routledge.
93. Vallgårda, A., & Redström, J. (2007). Computational composites. In M. B. Rosson & D. Gilmore (Eds.), *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 513-522). New York, NY: ACM.
94. Van Campenhout, L. D. E., Frens, J. W., Overbeeke, C. J., Standaert, A., & Peremans, H. (2013). Physical interaction in a dematerialized world. *International Journal of Design,7*(1), 1-18.

95. Van Der Tuin, I., & Dolphijn, R. (2012). *New materialism: Interviews & cartographies*. Ann Arbor, MI: Open Humanities Press.
96. Van Kesteren, I., Stappers, P. J., & De Bruijn, J. (2007). Materials in product selection: Tools for including user-interaction aspects in materials selection. *International Journal of Design, 1*(3), 41-55.
97. Weiser, M. (1991). The computer for the 21st century. *Scientific American, 265*(3), 94-104.
98. Weiser, M. (1994). Creating the invisible interface (Invited talk). In P. Szekely (Ed.), *Proceedings of the 7th Annual Symposium on User Interface Software and Technology* (p. 1). New York, NY: ACM.
99. Whatmore, S. (2006). Materialist returns: Practising cultural geography in and for a more-than-human world. *Cultural Geographies October, 13*(4), 600-609.