Conceptual Designing and Technology: *Short-Range RFID as Design Material*

Kjetil Nordby*

The Oslo School of Architecture and Design, Oslo, Norway

Short-Range Radio Frequency Identification (RFID) is an emerging technology that interaction designers are currently embracing. There are, however, few systematic efforts to utilize the technology as a tool for the development of new design concepts. This article focuses on technology as a design material and its role in the formative process of conceptual design. My approach involves the use of activity theory and the concept of motives, used to analyze short-range RFID technology when considering the field of design. I employ practice-based research where qualitative design and research methods are used to scrutinize the use of this technology in design. A design material perspective frames the short-range RFID technology as a composite consisting of near-fields and the computational. This material is coined near-field material and is further described through six form-making qualities: Tap and Hold, Multi-Field Relations, Multi-Field Distribution, Field Shape, Context Sharing and Mediation Type. I propose that the near-field material and thus the six form-making qualities cited above, offer designers engaged in creating user-oriented experiences, a morphology of form types. I argue that by synthesizing and analyzing emerging technology in relation to designers' motives for using them, we may further support research and practice by placing technology inside design discourse and culture.

Keywords **–** Conceptual Design, Materials, Computational Composites, Activity Theory, Motive.

Relevance to Design Practice **–** This work develops and presents short-range RFID technology in ways that make it more approachable in early phase design processes.

Citation: Nordby, K. (2010). Conceptual designing and technology: Short-range RFID as design material. *International Journal of Design, 4*(1), 29-44.

Short-Range RFID Technology as Design Material

Knowledge of technology has always been important in conceptual design both as inspiration and as means of realizing ideas. Emerging technology plays an important part by offering designers new potential and functionalities that may enable the development of innovative solutions. As a result, novel conceptual designs are often seen in tandem with new materials. Short-range RFID is an emerging technology that might bring such opportunities to design by allowing devices to read and write to short-range radio transmitters called RFID tags. Such technology has been used in public transport, where commuters encounter ticketing systems that allow them to swipe their RFID-enabled cards past ticket readers that register them for travel. Thus far, much short-range RFID technology has been steered towards such systems, along with payment and security related applications. However, the growing number of RFID enabled mobile phones is changing the scope of short-range RFID technology usage. These phones allow users to access information embedded in RFID tags (or systems) by using their mobiles as terminals (Figure 1). As a consequence, the technology is now more widely available to a large base of developers and designers making consumer oriented mobile applications. It is likely that the increasing base of designers and developers with access to this technology, will make short-range RFID more common in design processes geared towards the development of innovative services.

In this article, I seek to support design that utilizes short-range RFID to develop innovative services by investigating how short-range RFID technology can be used by the designers in the conceptual phase of interaction design as a material for creating novel solutions. I specifically demonstrate that, although the intangible qualities of short-range RFID make the technology hard to grasp, there is a need for better frameworks that may help designers understand the technology. In general, this is not the focus in research and applications where emerging technologies are normally presented through existing end-user solutions. Although such information is useful and important for interaction design, it does not directly address the motives related to the conceptual design phase. Such designing concerns the generation of several new design concepts that are used as a basis for choosing design direction and further detailed design (Horváth, 2000). In this article, I draw particular attention to conceptual design by investigating how it can be supported by experiments in short-range RFID technology. The study is part of a larger research project called Touch, in which an inter-disciplinary

Received July 17, 2009; **Accepted** March 03, 2010; **Published** April 20, 2010.

Corresponding Author: Kjetil.Nordby@aho.no

Figure 1. Reading a RFID tag with a short-range RFID enabled mobile phone enables a user to access phone functionality through tangible interaction.

team is investigating short-range RFID technology as it relates to design and innovation (*Touch Project*, n.d.).

I argue that exploring and interpreting *technology as design material* can provide important knowledge that is geared towards conceptual designing. I address this as a *design-material perspective* on technology. This is to explore, investigate, systematize and present the conceptual form-making building blocks of a technology from a design point of view. To do so, I pose the following questions:

1. What conceptual form-making qualities can be related to RFID technology as design material?
2. How can this material be communicated to support early phase conceptual design?

To answer such questions, a design-material perspective is further discussed in relation to the concept of *motives*. I apply this concept to help us better understand, and consequently support, processes of conceptual designing that use emerging technologies. The concept of motives is drawn from activity theory. It refers to purposes or aims that are critical for the design of innovative artifacts, especially the goals of the designer and the potential intentions of usage (Leont'ev, 1978). Theoretically, I refer to the wider analytical framework of activity theory (Vygotsky, 1962, 1978) to analyze short-range RFID technology in relation to conceptual design. In terms of methods, I apply practice-based design and research inquiries that explore the material affordances for design of short-range RFID technology by construction. In this process, sketching and prototyping techniques are central in producing and exploring design experiments used to develop an understanding of short-range RFID as design material. These design experiments are motivated by activities constructed to uncover the properties of short-range RFID as a design material, rather than to produce user-oriented solutions. The study uses qualitative research methods to collect data during and after the design processes. Finally, the data is analyzed to uncover design-related properties of short-range RFID.

Kjetil Nordby is currently a PhD candidate at the Oslo School of Architecture and Design where he investigates emerging technologies seen as design materials. He holds a Master in Interaction Design from Umeå University. Kjetil has an extensive experience working as an entrepreneur and design practitioner inside the fields of interaction and industrial design. The PhD is part of the Norwegian Research Council funded 'Touch Project' which can be found at www.nearfield.org.

In term of results, my study redefines short-range RFID as a design material by framing the technology components that are particular for short-range RFID form making. This material is further presented through six conceptual form-making qualities: Tap and hold, Multi-field relations, Multi-field distribution, Field shape, Context sharing and Mediation type. These qualities present forms the material may afford designers. With design material and motives as key concepts, I argue that a design-oriented material perspective on emerging technology might support early phase conceptual design, directing attention towards ways that the technology may be transformed into novel solutions.

I begin with a brief introduction to short-range RIFD in research and practice. Next, I describe my theoretical approaches towards motives, materials and conceptual design. This leads to the research and design methods used. The results section is divided into a presentation of short range RFID as a design material followed by the six form-making qualities. Finally, the article discusses findings and presents a number of conclusions.

Short-range RFID and NFC in Research and Practice

This study investigates the emerging, viscerally obscure, short-range RFID technology as a design material. Short-range RFID systems allow communication between devices by means of very small radio-fields (approximately 2-5cm diameter), which I will refer to as *near fields*. Short-range RFID technology has evolved from general RFID systems with no defined range limit, and has traditionally been conceptualized as a replacement of barcodes. The technology has gradually been utilized in other domains and is moving towards becoming a general interaction technology. Today, the development of Near-field Communication (NFC) technology is one of the fundamental drivers of short-range RFID. NFC, a technology standard offered by the NFC-forum, allows developers to implement short-range RFID functionality into devices like mobile phones (NFC-forum, n.d.).

In Human Computer Interaction (HCI), short-range RFID has received interest as a technology bridging the physical and digital. Want, Fishkin, Gujar, and Harrison (1999), who introduced the concept of *physical browsing,* published one of the first examples of HCI. The concept describes how people can use RFID tags in the form of physical hyperlinks. This approach has been much discussed in relation to NFC-enabled mobile phones (Välkkynen et al., 2003; Välkkynen, Niemelä, & Tuomisto, 2006).

Mobile phone related short-range RFID interaction has generally been called *touch* interaction. This term is often used in commercial presentations as a major simplifying feature of short-range RFID systems. Touch interaction communicates that by simply holding together a reader and an RFID tag, short-range RFID interaction is performed. A similar approach used in HCI was short-range RFID interaction, presented as a selection mechanism (Ballagas, Rohs, Sheridan, & Borchers, 2006). Studies have built on this concept and compared touching to other selection mechanisms in a usability perspective (Rukzio et al., 2006). In further developments, Nundloll-Ramdhany (2007) introduces a multi-tag system consisting of a single interface controlled by multiple tags. This is to move away from the widely used hyperlink metaphor and toward the view of NFC interaction as sequences of selections instead. Broll et al. (2008) present NFC technology in the form of a grid of tags placed in relation to a projected screen. Moving the phone over the grid allows interaction with the content on the screen.

I approach short-range RFID from a design perspective as part of the *Touch Project* (n.d.). The study investigates short-range RFID in light of tangible interaction (Hornecker & Buur, 2006) on NFC enabled mobile phones. In doing so, the radio fields themselves, the near-fields, are found to be central in NFC-related tangible interaction since all tangible interaction on NFC-enabled phones is directed by the spatial manipulation of near fields. Such input is unique for short-range RFID systems and separates it from other input technologies. As a consequence, we coin the term Near-field Interaction (NFI) to identify tangible interaction driven solely by the manipulation of the near-fields.

The Role of Motives in Conceptual Designing

It is important to understand how the designers' motives evolve in conceptual design, since this encapsulates the intent or rationales behind the executed activities. Motives can partly be understood by activity theory. Motives allow me to uncover the reasons or intent for material-related activities (Leont'ev, 1978). This approach provides us some means to understand how to support the emergence and forming of such motives in the activity of designing.

Historically, activity theory addresses cognition as transformational and developmental. Vygotsky argued that cognition was realized in social interaction and context (Vygotsky, 1962, 1978). The central theme in activity theory is the unit of an *activity* that is made up of a subject's action alongside a minimal set of context (Kuutti, 1995). The activity is constituted by a subject, who represents the agency of the activity, and an object, towards which the activity is directed. This relationship is mediated by tools or signs that add an historic relationship between the units. The goal of the activity is to transform the object into an outcome. This transformation is not happening all at once. Instead, the activity can be divided into three levels (Leont'ev, 1978). The top level is the activity itself, that is directed by motives. The activity level accounts for why an activity takes place. The activity can further be divided into a series of actions needed to perform the full activity. These concern what we do to perform an activity. Finally, the actions are carried out by operations that are directed by conditions. The operations account for how we do the activity. Together activities, actions and operations constitute a powerful framework that allows us to analyze people's actions in the world.

In activity theory, the concept of motives is what drives the activity and describes *why* it exists. A consequence of this is that all activities must have a motive (Leont'ev, 1978). The motive is in continuous development through the subject's many activities in the world. The motive directs the subject's activity, transforms the environment, and the environment influences the subject, leading to the transformation of the motive. Since the motive defines the activity, any change in the motive will also change the activity. Essential to design, the motive is connected to the subject's personal sense or personality (Leont'ev, 1978). This provides a theoretical framework linking the designer's personal sense (for instance, individual style) directly to the activity of designing. Thus, the activity of designing is directed by a motive formed by both the designer's personal sense and the environment in which he or she acts.

Conceptual design refers to the early phases of the design process where the problem cannot be accurately described due to its complexity and conflicting goals. This has been described as ill-structured or wicked problems (Rittel & Webber, 1973). The conceptual phase, when neither problem nor solution has been fixed, is when the seed for significant innovation is planted in the form of design concepts. These conceptual designs, often consisting of design sketches or plans, contain preliminary design choices that are detailed later in the design process (Horváth, 2000). The designs serve as conceptual frameworks for further designing. In Schön's (1983) spirit, these conceptual designs can be seen as frame experiments that give designers 'back-talk' that can be used to reframe the problem at hand. Conceptual designing is an activity that develops both solutions and a better understanding of the problem. Such a mechanism can be referred to as the co-evolution of problem and solutions (Maher, Poon, & Boulanger, 1996).

Motive plays a central part in this reframing process. When designers engage with the environment through making conceptual designs, they impose their personal motives on the environment through design. Equally important, the back-talk of the environment transforms their motives to enable the creation of new concepts. Each proposed conceptual design is directed by individual motives developed through and by the design process. As a result, the development of alternative motives is crucial in design, as it is the only way new designs can be achieved. Thus, the formation and transformation of motives allows development to happen.

We may see design as driven by a web of overlapping and often conflicting motives. It is the designer's task to develop or find new motives for design in order to propel the forming of new conceptual designs. As a result, the development of motives becomes the central object of the design activity. The designer approaches this object by engaging the environment through designing. I see this as a process of co-evolution of the motive and the environment that simultaneously develops conceptual designs and motives for making them. These motives are not necessarily conscious for the designer, but they nevertheless drive the conceptual design. This shifts attention towards motives as the main driver of design activity. Such an approach is in contrast to much design research that focuses on the solving of problems. My research does not oppose such a view; however, I do emphasize how motives can be used to more closely allow analyses of issues particular to design, and not general for all solution-oriented development.

As part of the environment of the designer, emerging technology can influence the creation of his or her motives. It is critical then, to look into how we can purposely support the development of motives for conceptual design through technology.

Technology as Design Material

I analyze short-range RFID technology in relation to the socio-cultural context of design and highlight the need for supporting the formation and transformation of motives. In activity theory, activities can be supported on a motive level by presenting new objects for activity, otherwise hard to attain for the subject. Kuutti (1995) points toward such support by making an object of an activity graspable by means of information technology. Although Kuutti wrote within the context of computer science, this principle is useful for my design approach. I argue that short-range RFID technology can be made easier to understand and use for designers by appropriating and presenting it as an object for the activity of design. I suggest that one way of doing this is to address the technology as a design material. The technology may thus be interpreted in the activity of design and its web of motives. Similar interpretation is taken up in HCI research where computational technology or information technology has been addressed as design material (Blevis, Lim, & Stolterman, 2006; Hallnäs, Melin, & Redström, 2002; Löwgren, 2007; Löwgren & Stolterman, 1998). These works draw connections between interaction design and the traditional design practices dealing with physical materials, but do not focus on motive.

As designers engage with materials, they transform both their conception of the materials and the motives for using them. Facilitation and communication of materials is important here. Designers can only engage with the parts of the material they see. In industrial design research, attention has been given to the appropriation of materials so that they can be more effectively used in design practice. For instance, Ashby and Johnson (2002) present a taxonomy of materials, emphasizing properties deemed most relevant for product design. Karana, Hekkert, and Kandachar (2007) introduce four types of data for aiding material selection for industrial designers: sensorial properties, intangible characteristics, technical properties and design notes. Manzini (1989) outlines a conceptual framework for physical materials that is oriented towards supporting selection and forming materials, based on the function they are going to fill. Although all of these works are oriented towards physical materials, their focus on designers' motives for using materials is directly relevant for digital materials as well.

When dealing with emerging technology as design material, we may not only communicate a technology, but also form and structure its properties for design. This is because emerging technologies often have little history of usage as design materials. I meet this challenge by proposing new material properties that can influence the designer's possible motives for material usage. To focus on such properties, I use the concept of *form* as it is inherited from industrial design and modified to address computational artifacts. In industrial design, form is used to describe the objective physical structure of the artifact. This is useful as it allows us to separate between the objective structure of an artifact and the cultural expression it mediates through people's activities. With the current emergence of computational artifacts, which are made up of both physical and digital materials, it is of interest to describe the objective structures of digital materials as well. By using the term 'form' to address these structures, we pay tribute to how both digital and physical materials are shaped through the design activity. Maze and Redström (2005) addresses the structure of computational artifacts through the concept of temporal and spatial forms. The spatial concept concerns shapes created in 2D or 3D space, while the temporal deals with structures related to time. This view sees form as both the objective spatial *and* temporal structure of an artifact. The notion of such form is useful as it treats both digital and spatial structures of computational artifacts as equal in terms of form-making.

Ultimately, all spatial or temporal forms are mediated through the properties of physical or digital materials. Consequently, I envisage that the various types of forms the material can afford the designer can be considered important design-oriented properties of materials. I refer to these properties as *form-making qualities,* i.e. they constitute conceptual descriptions of the different types of forms the designer can develop while using the material. These form-making qualities aim to support designers' thinking with materials when conceptualizing designs by describing their thought process in terms of possible transformations. Such an approach exposes ways of transforming materials that might otherwise be hidden or hard to grasp and thus assist designers to use the material in novel ways. In activity-theoretical terms, the form-making qualities present themselves as possible objects for new conceptual design activities. As designers take up these objects into their designing, the qualities may enable the formation of new motives (and activities) that transform the approach to the material at hand. This is important as it allows for the co-evolution of motive environments that is crucial in creative development.

Form-making qualities are directly linked to the design activity by showing the different ways that a material can be transformed. This indicates how the form-making qualities only have an indirect relationship towards users. They do not need to know how a material can be transformed. Rather, the users appreciate the expression of the forms that has been designed using the form-making qualities. Löwgren and Stolterman (2004), who introduce material experiential qualities, followed such a perspective. . These qualities describe ways digital materials can be experienced by users. How materials might both be experienced by users and transformed is important knowledge for designers. This underlines the importance of paying attention to how materials are interpreted through people's different activities. From a designer's perspective, the material may be the object of his or her activity directed towards transforming the material into a new artifact. However, a user might experience the material through activities related to using an artifact. Thus, for users, the material is part of mediating the expression of the artifact.

I suggest that the activity of conceptual design can be realized if we approach technology at a conceptual level. I propose this can be achieved by framing technology as design material with a set of corresponding form-making qualities. I embrace this approach through the application of a *design-material perspective* on technology. These concepts might help inform designers of properties and procedures otherwise hidden or hard to grasp. The material framing and form-making qualities make up a conceptual framework that may enable us to understand and facilitate technology with respect to conceptual design activity.

Applying a Design-Material Perspective on Short-Range RFID

Short-range RFID technology refers to multiple technologies covering a large set of possible hardware types and software implementations. Short-range RFID can be understood as a collection of materials that can be combined in various constellations to make up short-range RFID systems. From a design material perspective, it is useful to frame the technologies providing form-making qualities that separate short-range RFID from other materials. I suggest that short-range RFID can be addressed as a material that consists of near-fields and computational technology. I label this *Near-Field material*. This is based on the analysis of design experiments that showed that the near fields themselves are the unit that provide form variations specific for short-range RFID. The near-fields showed a surprising versatility in application and combination with additional materials, making these fields very useful as a conceptual material in support of designing.

This approach to short-range RFID as the near-field material departs from the normal conception of such systems in that it is *device independent* and does not consider how the fields are realized. This means that, conceptually, tags or reader devices are additional materials that need to be combined with the near-fields to create working systems. This is counter-intuitive, but allows a designer to see the opportunities of near-field interaction in an abstract way, outside the conceptual restrictions of implementation.

In order to be perceivable by users, the near field material needs to be mediated through additional output oriented materials, like screens or speakers. Without them, the near-field material does not exist in user experience because the fields do not have any physical expression. Still, the near-field material can be considered a separate material since, from a design standpoint, it does have physical and temporal form with specific qualities that can be shaped in designing. As a result, despite having no inherent output channel, the near-field material allows expression by affording users possible input.

The framing of the near-field material is inspired by Vallgårda and Redström's (2007) definition of computational composites. These composites consist of both physical material and computation. This corresponds well with the near-field material comprising the fields and computing. In the case of short-range RFID technology, I propose that the computational technology could be expressed through the near-fields. Consequently, the near-fields and the computational technology are interdependent and together they make up an interaction design material that can be addressed as a computational composite.

In the final sections of the article, I move on to analyze short-range RFID technology in search of form-making qualities. In the following sections, I present the design and research methods employed in this study.

Methods

Since short-range RFID is an emerging technology, there is limited history of its usage in design. Moreover, the publications of such usage are predominantly related to how the technology is used in a particular solution, like a ticketing system, but they do not reveal how the technology was conceptualized during design. Such conceptualizations of technology happen inside the design activity and cannot easily be read from the individually designed artifacts produced. This is because the artifacts only show one instance of a produced form, but fail to inform of the additional opportunities the designer encountered while shaping them. This dilemma might in time be solved by conducting quantitative studies of forms created in multiple instances of RFID solutions. However, because short-range RFID is an emerging technology, today such data is severely limited. I therefore pursue a qualitative approach where I investigate short-range RFID from within a series of design experiments. In doing so, I apply a process of *design-oriented research* (Fallman, 2003) where the goal is not only the artifacts we produce, but the knowledge generated from designing them. The main motive of this design-oriented research activity is to transform the object (short-range RFID technology) into a design material described through a set of form-making qualities. These form-making qualities may be taken up by designers as possible objects in the design activity and thus enable the development of alternative motives for designing with short-range RFID.

The design methods that were applied in several design processes were part of the Touch project (*Touch Project*, n.d.) and stretched over two years. Each design process concerned a separate design brief that was collectively formed by the group motivated by the potential to show interesting aspects of short-range RFID interaction. These processes were directed towards making artifacts that represented either expressionals or appliances (Hallnäs & Redström, 2002b). The term expressional concerns artifacts that carry expressions but are not tied to a particular user-oriented function. For instance, I include sketches concerning particular interaction techniques as expressionals, as they are abstract from function. An appliance, on the other hand, is created with the intent to perform a specific function. Hallnäs and Redström use these concepts in analyzing a mobile phone as an expressional to find the ways it articulates itself toward a user. My approach uses analysis of expressionals and appliances as methods for understanding the form-making qualities of short-range RFID as material. I extensively used the method of moving between analyzing expressionals in terms of function, and appliances in terms of finding expressions (Hallnäs & Redström, 2002a). The emerging designs were utilized as an analytical lens for examination of different aspects of the short-range RFID material. The main motive for these design activities was not the expressionals or the appliances themselves. Rather, they were used as tools enabling the interpretation of short-range RFID by providing a focus for the material investigations. As a result, the designs that were developed were selected on the basis of their ability to showcase a varied repertoire of RFID-based forms.

The designs were developed through a set of intersecting activities conducted by our small interdisciplinary group. The group consisted of a civil engineer specializing in programming and two interaction designers with backgrounds in industrial and graphic design. In an activity theoretical framework, these activities were located in and realized between different competencies that shared the overarching motive of transforming short-range RFID. Although all three participants were part of the same design processes, their activities differed in their individual approach towards the shared motive. For example, the engineer engaged with short-range RFID through implementing functionality into a software framework, enabling easy development of RFID interaction on mobile phones by way of Java code. Meanwhile, the designers investigated possible forms through their conceptualizing designs by way of sketches.

The techniques of sketching (Buxton, 2007) and prototyping (Lim, Stolterman, & Tenenberg, 2008) were used extensively throughout the processes. They were used as investigative tools, in addition to making the shared motive of the designing (realizing RFID differently) visible to the group. The sketching was predominantly carried out on paper or in computer drawing software (Photoshop, Illustrator and 3D Max). Generally, the sketches concerned situations of interaction, small scenarios or illustrations of material properties (Figure 2). The sketching was used as a means of inquiry into the selected situations and not only as externalizations of ideas (Fallman, 2003). Thus, the outcome of the sketching led to better understanding of the short-range RFID material in addition to the sketches themselves.

The prototyping method concerned the creation of technical implementations of some of the conceptual appliance designs. In this way, prototyping was an important tool that

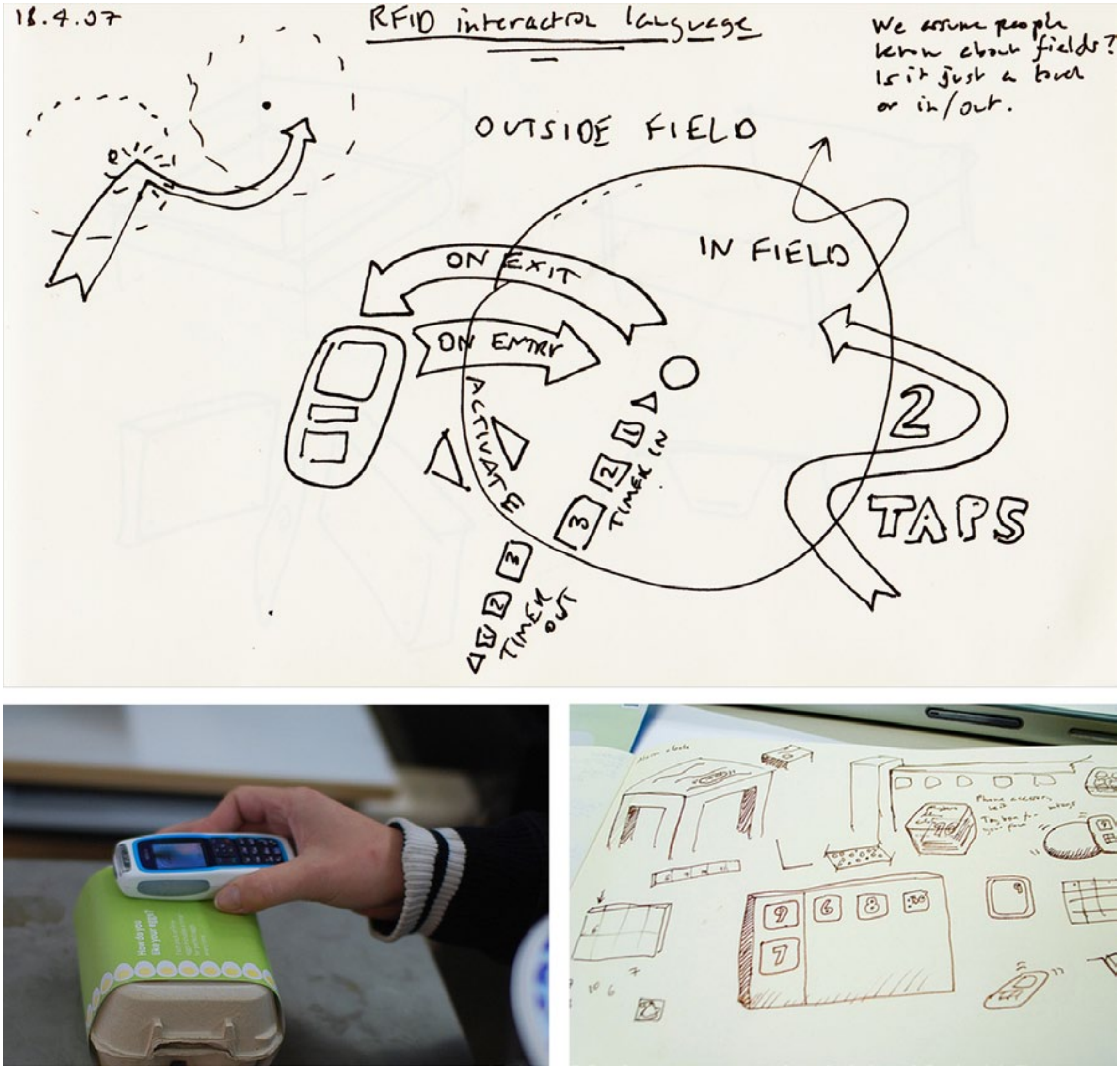

Figure 2. Concept sketches: (Top) Conceptual drawings of tap and hold expressionals, (lower left) a scenario of equipping an egg carton with RFID enhanced functionality and (lower right) RFID appliance sketches.

allowed engagement with the technology through practice so as to explore the material (Lim et al., 2008). In the development of prototypes, there was a tight overlap of engineering and designers' activities, where a constant flow of discussions, notes, sketches and production layouts was necessary to enable shared design activities. The close collaboration between disciplines allowed for efficient knowledge-sharing.

Both the processes of design and the results themselves uncovered important data that could be used to analyze short-range RFID. Two main types of data were collected. The first type related to the material generated through the designing of the experiments. These were notes, sketches, images and the prototypes themselves. The notes were collected and shared on paper or in digital documents. The images and sketches were collected and shared digitally between the team of designers. The prototypes were photographed by one team member to illustrate important aspects of the prototypes.

The second data type concerns properties of short-range RFID that were identified throughout and after the design sessions by the team of collaborators. These were not necessarily readily visible in the design material itself. Consequently, they were described as they emerged, by way of notes, sketches, images and videos. The sketches involved digital and paper drawings highlighting particular aspects of short-range RFID. The images and videos concerned either abstract representations of short-range RFID attributes or user-related scenarios exploring the material through possible usage.

Central to this process was an evolving digital document where properties of short-range RFID were described. These properties were constantly shared and discussed within the group, as well as mediated via our project blog (*Touch Project*, n.d.).

Four Prototypes

Rather than directing attention to ways of transforming the near-field material, the design artifacts were design examples related to the field of RFID-driven interaction. Thus, the artifacts represented a wider set of properties than what was accounted for by the near-field material alone. As a result, the next analytical step concerned our analyzing the design artifacts solely in relation to the defined near-field material. The procedure was carried out by deconstructing the artifacts to find out what the near-fields offered in each example.

The result was a large set of near-field related properties that showed multiple potential approaches towards the material. The properties could, for instance, be related to the interpretation of intersecting fields, the ways that multiple fields could be used, or the spatial shape of fields. In an activity theoretical perspective, the properties serve two main functions. First, each property accounts for a condition for making near-field interactions. Each property supports the operational level of the design activity. Second, the range of properties account for an overview of the near-field material. This aids the action level of activity by supporting the understanding that is needed to design new interactions.

Below is a description of some of the prototypes that we created and used in the analysis. In addition to these descriptions, the analysis was also supported by additional prototypes which were designed in the wider scope of the Touch Project (*Touch Project*, n.d.).

1. The Thingio NFC platform is a development platform which enables designers to prototype new NFC-based applications by using standard web tools like html editors. The development of the platform as a prototype demanded focus on how the properties of the material could be organized to allow the design of multiple application types. In making the NFC development platform, as designers and researchers we are pressed to consider the whole range of opportunities the technology offers instead of focusing on particular functions. As a prototyping tool, the NFC platform is well-placed to help in the investigation of materials as a phenomenon, rather than situated usage alone (a direction to go in time). The platform monitors intersections between RFID tags and RFID-enabled mobiles to allow advanced interaction with web-based applications. This is done by means of a Java application running on a Nokia 6210 NFC phone that interprets all NFC related interactions and that uses a 3G network connection to transfer it to an internet connected server. The Java application doubles as a web browser and shows feedback related to the interactions that are partly found locally on the phone and partly streamed from the internet-connected server. This was important as it enabled us to use any internet-connected devices as output channels, allowing easy development of field controlled interfaces in the real world. The two next prototypes were implemented using the Thingio system.
2. The NFC alarm clock we developed enables detailed control of an alarm clock on a mobile phone through one RFID tag (Figure 3, lower right). This was part of the experiments investigating the opportunities involved in making interfaces entirely controlled by two intersecting fields. The final prototype allows the setting of an alarm clock while a phone rests on a surface embedded with an RFID tag. If the phone is removed from the tag, the alarm application closes. However, if the phone rings while on the tag, removing the phone will stop the alarm and give the user an option to put the phone back on the tag to enable a snooze mode. The implemented example was one of many alarm clock designs explored through sketching in the design process.
3. The office answering machine is a multi-user application, using RFID tags and RFID-enabled phones, that serves as a messaging system that can be attached anywhere (Figure 3, lower left). The system can automatically identify the user who is making an interaction, so as to provide functionality according to his or her particular needs. The system distinguishes between owners and visitors. The owner of the system can record a welcoming message or listen to messages from visitors. The visitors can listen to the welcome message, or record a response. The recording and playing are handled by two separate tags representing record and play. The design and implementation of the office answering machine investigated both how multiple fields could be used

in interfaces, and also how we could dynamically change an interface by monitoring the coupling of fields.

4. In short-range RFID systems, multiple fields may be used to create advanced interfaces. The creation of the Orooni table prototype was motivated by our interest in investigating such aspects of short-range RFID. Besides the technical challenges involved in the production, the table allowed us to experiment, both conceptually and practically, with using multiple tags and tag readers in interaction. The Orooni table is an interactive multi–user toy designed for a science fair that allowed the playing of multiple simultaneous 3D animations. During the fair, several hundred children played with the toy and used it to explore animations and to create small stories. The prototype is made up by a large RFID-reader enabled tabletop interface and a 42-inch screen. This allows as many as 10 users to control a virtual animated character on the screen (Figure 3, top). They do so by moving an RFID tag embedded in a physical character over RFID-enabled areas on the table that represent character moods. When resting on an animation area, a 3D character, representing a specific token, is continuously animated on the screen. The system uses a Mac mini running windows XP, 10 attached USB RFID readers, and a 40 inch LCD monitor. The software is programmed in C++ and uses a proprietary 3D engine to display and animate the characters.

Together, the four prototypes and the other design methods allowed for an understanding of the character of the near-field material and helped inform our knowledge of its qualities.

Six Form-Making Qualities Related to Short-Range RFID

To create the form-making qualities, the material properties were analyzed to find what transformation types the material could offer designers, by searching for variables that designers could manipulate through the design activity. There is an open

Figure 3. Three functional prototypes: (Top) The Orooni table, (lower right) the NFC alarm clock, and (lower left) the NFC office answer machine.

set of variables that may be considered when designing with RFID. These variables may be gleaned from existing research and from experimentation (see below). The variables we offer here are not exhaustive but may currently include: the physical intersections of fields, relations between fields, distribution of fields, combination of information, and physical formation of fields and mediation. We could also add other variables to this list such as the direction and the number of fields. From such a list of variables, a number of transformations can be effected. Here, a transformation indicates how a designer shapes the variable in the process of designing an artifact. The form-making quality is revealed through such transformation. For instance, many of the near-field related properties could be associated to the intersection of fields. This led to seeing the formation of field-intersections as important in the design of new near-field interactions. Thus, field intersections were used as one of the variables leading to the form-making quality of "Tap and Hold", which is presented in the next section of the article. The proposed six qualities shown in the next section (only a partial, possible list) were achieved through a long process of trial and error, seeking to present distinct approaches to form-making.

I have developed six form-making qualities in relation to the near-field material. The qualities are: Tap and Hold, Multi-Field Relations, Multi-Field Distribution, Context Linking, Field Shape and Mediation Type. Designers might work within each of these qualities when forming new multi-field interactions. In addition, the design space might be significantly increased by addressing multiple or all of the qualities inside design. Thus, the qualities represent a set of possible intersecting activities that enable designers to perform multiple parallel approaches towards the material, in search of innovative solutions. However, I do not claim the presented qualities makes for a complete list covering all aspects of near-field related form-making. Rather, further qualities may be formulated by additional analysis. However, I still argue that this list can serve as an important contribution towards a design-oriented understanding of short-range RFID.

Quality 1: Tap and Hold Gesture

Tap and Hold treats the intersection of two fields as a temporal and spatial form-making quality. The term refers to how moving an RFID-enabled phone, in and out of a field (Tap), or holding a phone inside a field (Hold), can be used to create multiple different gesture driven interaction techniques. The interaction events that can be interpreted from the intersection of two RFID fields are central to *Tap and Hold*. These events are: the outside field, start intersection, intersecting, end intersection and outside field again (Figure 4). Using these events, a wide range of interaction techniques can be designed. For instance, the alarm clock prototype starts when the RFID enabled phone is left on an RFID tag (Figure 5, top right). This represents a hold gesture. When the alarm rings, the user can tap the phone in and out of the RFID tag range to initiate a snooze function (Figure 5, bottom). The work was carried out with a mobile phone that interacted with RFID tags. However, the concept of near-field material allows us to use *Tap and Hold* in relation to any fields. Thus, *Tap and Hold* is relevant for all near-field interaction whether a user holds a device, a tag, or if two users hold devices together.

Tap and Hold directs attention towards the use of field intersection in the design of interactions. This is important for

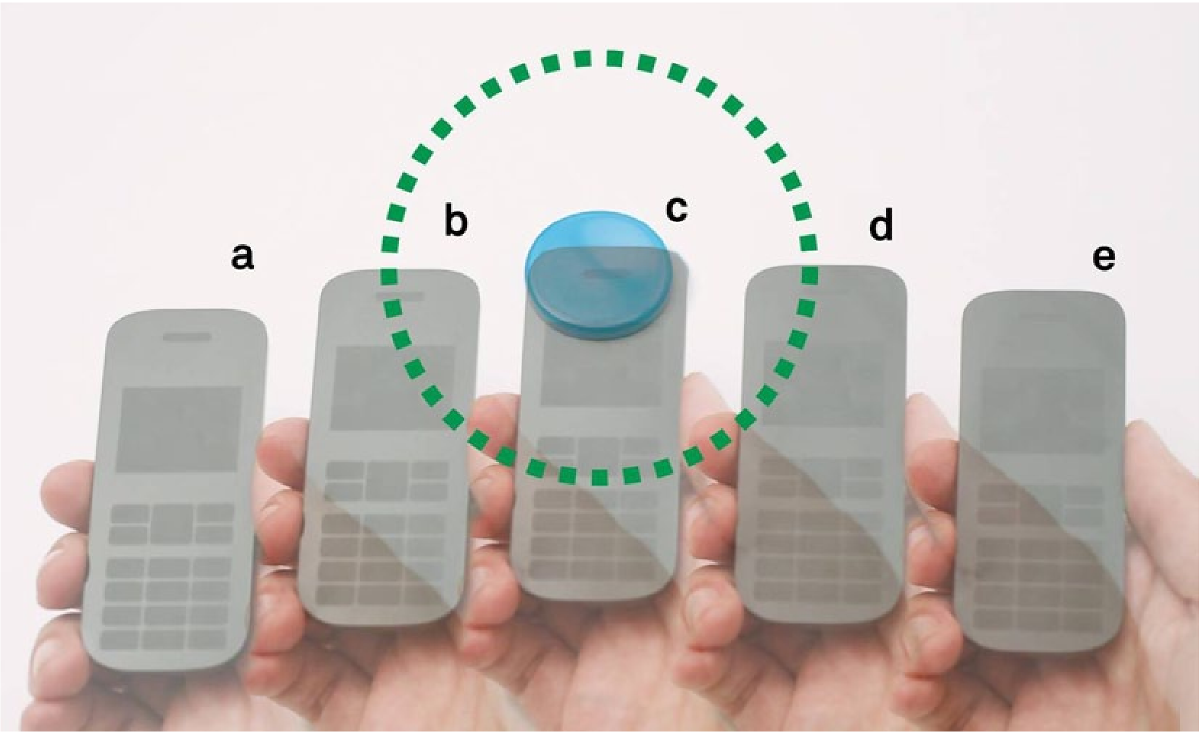

Figure 4. Tap and Hold gesture events related to the intersection of two near fields: (a) outside field, (b) when the intersection starts, (c) the time the fields are intersecting, (d) when the intersection ends and (e) outside again.

Figure 5. Tap and Hold gesture - NFC alarm clock using *Tap and Hold* interaction: (Top left) Phone is outside field. (Top right) The alarm is set and active while the phone rests on the tag. (Bottom left) The alarm rings while on the tag. (Bottom right) The alarm is stopped by removing the phone and the phone offers to start the snooze mode by putting the phone back on the tag.

design because it widens the perspective on short-range RFID interaction from a selection mechanism toward opportunities for rich tangible interaction. *Tap and Hold* does so by exposing *how* we touch, and not only *that* we touch.

Quality 2: Multi-Field Relations

Multi-Field Relations deals with how two or more fields are logically connected so as to provide interactions driven by the manipulation of multiple fields. This addresses the various relations between multiple fields as a temporal form type.

In the simplest variant, *Multi-Field Relation* forms can be composed by grouping fields that are part of the same application. The office answering machine exemplifies this form by consisting of two RFID tags, each representing an interface component, that together make up an interface. Figure 6 shows how a tag gives access to playing messages (left) that can be recorded with another one (right).

More advanced multi-field systems can consist of interface components that are made up by multiple tags. Such components allow the control of one function through the use of multiple related tags. Figure 7 shows an example where three RFID tags simulate a radio button component consisting of three connected buttons. Currently, I am exploring such components in detail by presenting a conceptual framework that supports the design and analysis of multi-field components.

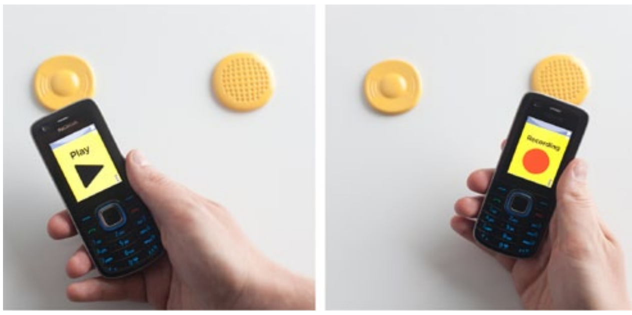

Figure 6. Multi-Field Relations - Office answering machine consisting of two RFID tags: (Left) A message plays after touching the play tag. The application owners hear messages from visitors and visitors hear messages from the tag owner. (Right) Hovering over the record tag allows recording of a message.

Simulating Graphic User Interface (GUI) components with RFID tags has been explored earlier by Nundloll-Ramdhany (2007), who showed RFID tags that acted in similar ways to GUI check boxes and radio buttons. However, this approach differs slightly from the multi-field components that are not limited to RFID tags and can include RFID readers as well.

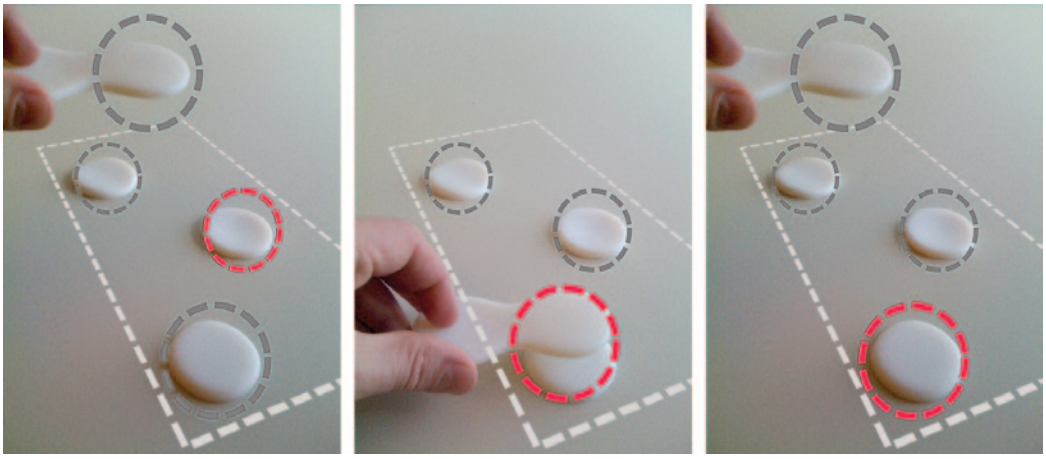

Figure 7. Multi-Field Relations - Context linking represented by a visualization of a radio button component made up of three tags: (Left) The red ring represents the selected button. (Centre) By holding the reader over another tag the selection moves. (Right) The red ring shows the new selected button.

The *multi-field relation* form-making quality shows how multiple fields might be connected in various ways to allow complex interaction. By carefully forming these relations, designers can afford users novel and engaging way of interacting through physical places.

Quality 3: Multi-Field Distribution

The *Multi-Field Distribution* form-making quality involves the use of two or more fields to create spatial forms. This quality views physical distribution of tags as a spatial expression. The most common type of such an expression is to place fields logically according to particular functions with which they are associated. The Orooni table comprises such an interface, where several fields are placed on a surface and structured according to starting particular character animations (Figure 3, top). Poster interfaces serve as another example of such field distributions. These interfaces feature fields that are distributed on graphical posters that communicate the functionality. Figure 8 (right) shows a poster interface where tags are hidden behind the graphics, enabling the pictured groceries to have embedded information.

Figure 8. Multi-Field distribution - (Left) A grid of tags allows continuous tracking of a hovering phone. (Right) Tags are distributed on a poster according to functions related to the graphics.

A different approach to spatial forms is to create continuous patterns of fields. Commonly, such patterns constitute a grid of fields (Figure 8, left). Hardy and Rukzio (2008) present the use of such a grid as an input device to a screen-based application. However, linear patterns have also been used, for instance, to guide visually impaired people (Ceipidor, Medaglia, Rizzo, & Serbanati, 2006). There are essentially unlimited opportunities in distributing different patterns of tags inside or on the surface of physical structures, thereby opening up many opportunities for innovative interfaces.

There is a stark contrast between pattern distribution and grouped distribution of tags. The former represents a fluid form of interaction with surfaces; the latter directs attention towards a more structured approach to interaction. The multi-tag distribution form-making quality may assist designers in their awareness of these opportunities, and to make conscious usage of them in designing interaction with the real world.

Quality 4: Context Linking

The *Context Linking* form-making quality views the intersection of two fields as an event leading to a convergence of information. This quality could expand the conception of short-range RFID interaction as a one-way process consisting of reading data in an RFID tag. The concept is illustrated in Figure 9, which shows two fields with different associated context data sharing them upon intersection. The first image shows an RFID-tag with data representing the color red and a phone with data representing the color blue. In the second image, the phone and the tag have overlapping fields and the corresponding data sets are linked during the intersection. Most importantly, when using the near-field material, *every interaction* produces a context-linking that can be further interpreted in terms of input to a system. This differs from other input devices like the mouse or keyboard that do not sense data beyond the specific action that is performed.

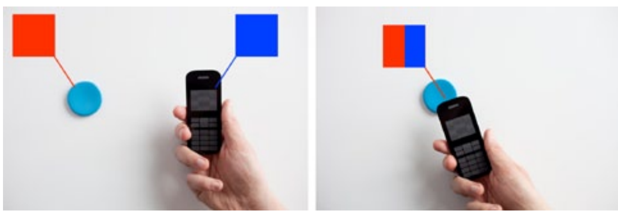

Figure 9. Context Linking - (Left) Two fields have different associated data. (Right) On intersection, the data is shared between the fields.

For instance, the office answering machine demonstrator (Figure 3, lower left) linked the fields associated with the phones to either owners of the systems or regular users. Meanwhile, the fields associated with the tags were linked to either record or play functionality. By moving a phone towards the tag, the context of the phone in the form of a user ID and the context of the tag in the form of a function, were linked to allow the application to react accordingly. The example shows how the context-linking ability can be used to allow separate users to have different experiences using the same interface. Since every field has context information associated with it, this could also be used in multi-user interfaces. The Orooni table (Figure 3, top) allowed such interaction by assigning a near-field enabled token to each user. Since each token was unique, it allowed automatic handling of user session. This made it possible to have up to 10 users simultaneously interact with the table top interface. This example shows the use of static data in interaction. However, by using dynamic data, further interaction opportunities arise in an encounter with other materials. For instance, coupling the near-field material with an accelerometer would enable each near-field interaction to include data about the motions involved in them. This would allow the system to support yet another dimension of gestural interaction.

The connection of data is ubiquitous in computing systems. What is particular to the near-field material is that each individual interaction shares a set of data in addition to the action itself. This is to move away from the view that short-range RFID is merely a tool for reading data, to one that encourages designers to work creatively with new contextual relationships, as part of individual interactions.

Quality 5: Field Shape

The *Field Shape* quality refers to how the physical form of each near-field influences designing. Since the radio antenna design changes the 3D form of the fields, the fields themselves have different form factors. For designers, it is useful to understand how the form of the fields influences the way the fields can be implemented in the physical world. Figure 10 shows a simulation of the radio field cloud that illustrates where a connection between an RFID reader and an RFID tag is achieved. The shape resembles a torus with a sphere resting on the top. The field profile is mapped by using a device that emits light every time the field is detected. The shape of the field intersection can be used to form physical objects that take advantage of the *Field Shape* to direct interaction (Martinussen & Arnall, 2009). For instance, the size and shape of the fields show how multiple tags can be inserted into one object without causing the fields to overlap.

As a form making quality, *Field Shape* directs attention towards both the conscious design of the fields themselves and how that informs the design of their attached objects or places. The near-fields, although intangible, still have physical aspects that are important in the design process.

Quality 6: Mediation Type

Mediation Type emphasizes how the near-field material is mediated through other output materials, like speakers and screens. This is important because the near-field material has no output modality and can only be seen through other materials. The near-field material alone can support user input.

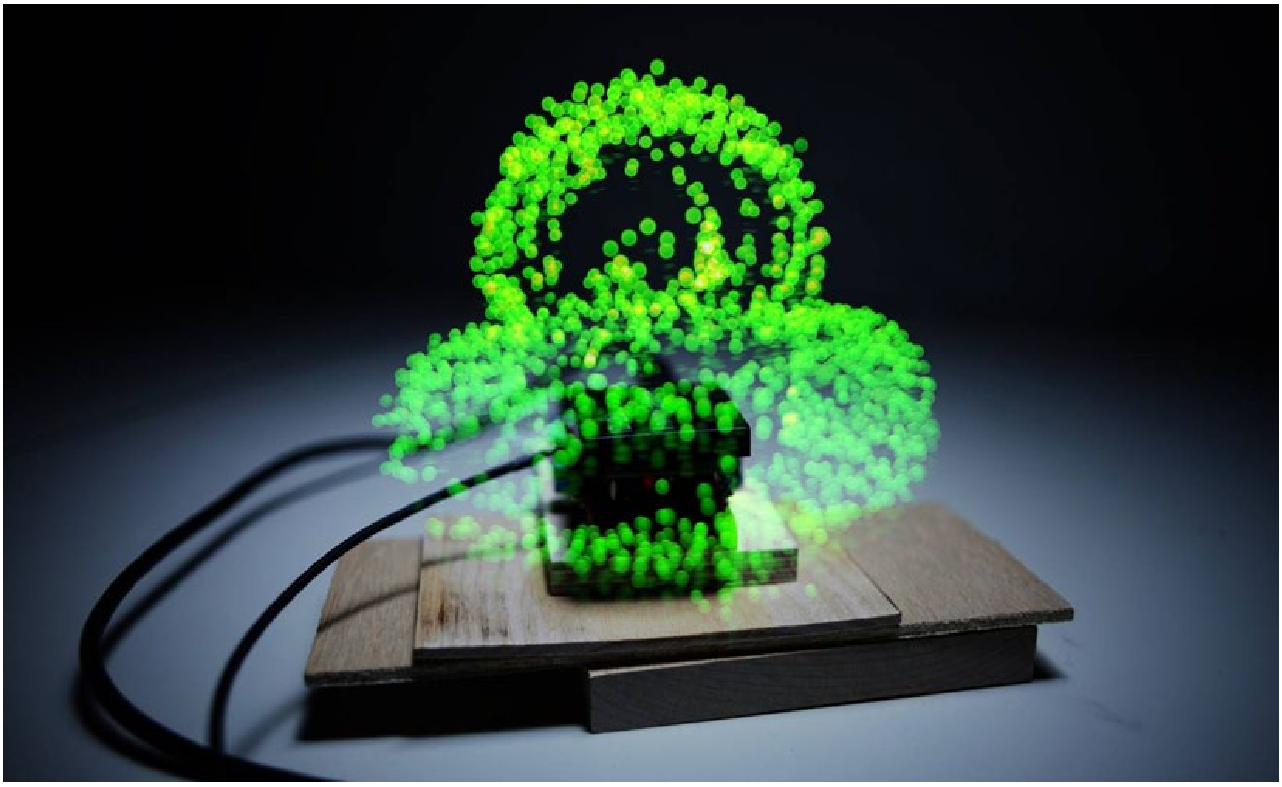

Figure 10. Field Shape - A visualization of the field ranges on RFID reader device: The image produced by the Touch project shows the reader and the outline of the field ranges that was measured.

The near-fields can be combined with a wide range of output-related materials. It is then useful to consider the overarching types of output opportunities available when using the near field material. Figure 11 shows a taxonomy that distinguishes between output-related materials to the meeting place of fields and indirect output elsewhere. Indirect output is either connected to the body or mediated through the environment. Outputs related to the intersection are separated into whether they emerge from the device a user holds, or from the area where the interaction is performed.

Mediation Type stresses the multiple alternative options in designing output for near-field material. This is important in conceptual design since it shows the versatility available in combining the near-field material with other materials.

Reflections

These prototypes and related form-making qualities raise a number of points for discussion. A design perspective on technology has been presented as a way of analyzing an emerging technology, SR-RFID, in terms of materials in relation to conceptual design. In adopting such a perspective, we have framed SR-RFID within activity theory allowing the technology to be unpacked in relation to motives for design. The study has looked into form-making qualities of this particular technology. This approach only covers part of the design activity related to the formation and transformation of motives. However, the work reported above does not show how to support designers' further investigations of materials through the use of form-making qualities. This is taken up in a related study (Nordby, in press) that applies additional concepts from activity theory to address activities on a more detailed level, dividing them into actions and operations. From the material presented above, however, a number of issues warrant further discussion for research and design. These concern conceptual design and technology specifically within SR-RFID.

First, as mentioned earlier, the capabilities of the near-field material are to a large part directed by additional technologies, such as RFID tags and readers. Consequently, we might consider the near-field material as a phenomenon that emerges in the intersection of multiple technologies. However, our study shows that it is useful in the designers' processes of conceptual design to think about the near-fields, rather than the physical components generating them. Thus, the near-field material allows designers to focus on designing interactions driven by SR-RFID, without the need to constantly consider the various hardware and software technologies from which it emerges. It is therefore possible to characterize near-fields as a conceptual material. Such a material is constructed as a reasonable tool that enables designers to shape the effect of technologies, rather than the technologies themselves. This helps designers to better understand how complex emerging technologies may be used in conceptualizing designs.

Second, the near-field material frames six new form-making qualities. These are mapped at a high level so that, when internalized by designers, the form-making qualities might help

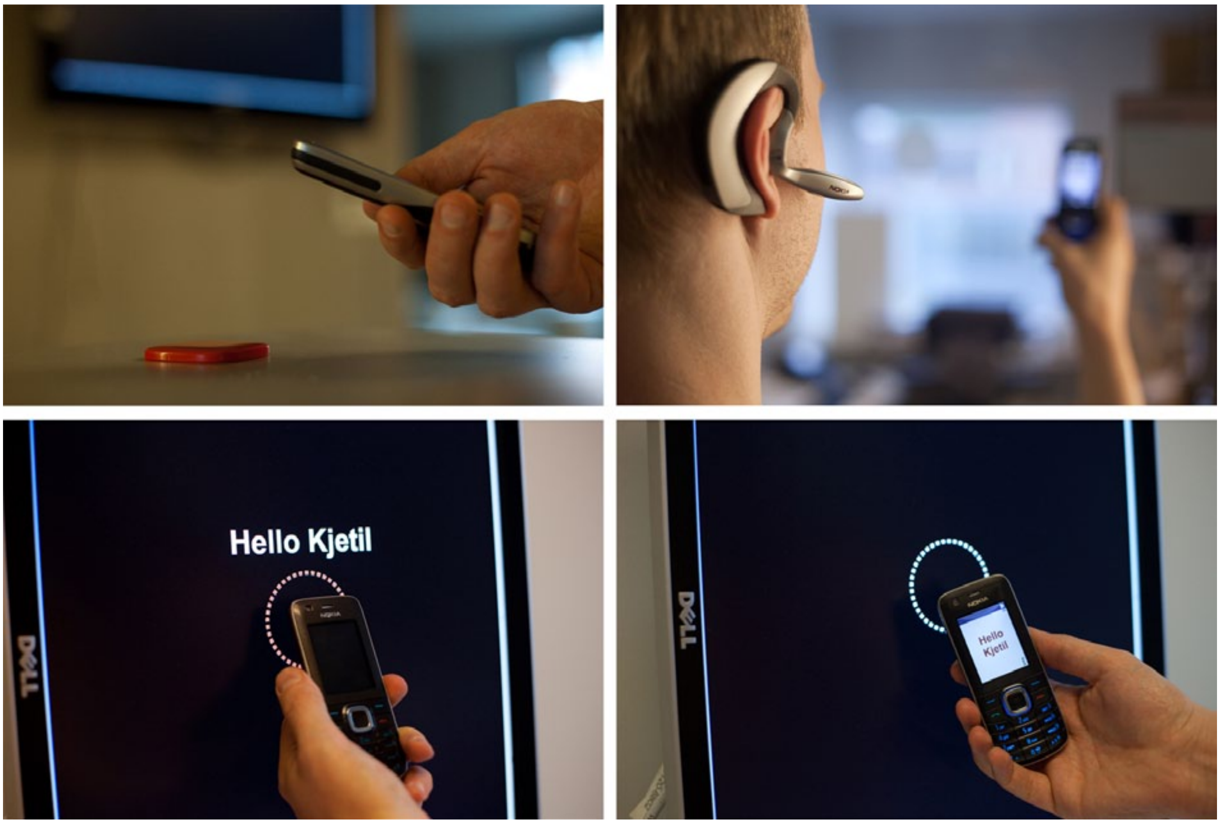

Figure 11. Mediation Type - Different perspectives on output related to near-field interaction: (1) Environmental output. The screen in the background reacts to the interaction in the front. (2) Embodied output. The user gets feedback through a headset. (3) Spot output. The RFID enabled screen gives output directly related to the interaction area. (4) Device output. The held device gives output directly related to the interaction area.

in the creation of an efficient conceptual framework concerning SR-RFID-driven interaction. Although each individual quality is important in its own respect, it is the recognition of it as part of a whole that brings forward the richness of the near-field material. Designers can take advantage of this richness by conceptually experimenting with different ways of combining qualities. In doing so, the conceptual material contributes to a design space in its own right, where designers may generate new personal objects (and motives) that may guide their design.

Third, it is important to acknowledge that the near-field material presented here can be seen as a kind of raw material, usually further refined before being placed in the hands of interaction designers. NFC technology on mobile phones is an example of such a refinement. The NFC-enabled Nokia phones provide technology components that cater for the easy creation of selection-based interfaces, without the need to address the hardware directly. Such an approach can both enhance and obscure properties of this technology, limiting how designers might conceptualize the material in question. It may also curtail the possible form-making qualities that they might use to work with it conceptually. This does not mean that designers should always address raw materials in their design process. After all, refined materials, like the ones provided by NFC, make the development of new interfaces both easy and efficient. Rather, I argue that it is important for designers to be aware of the potentials within raw materials so that they may make informed decisions about when to move beyond the common development tools, in order to make the right design.

Jointly considered these three issues point to a need to think of and analyze emerging technologies as conceptual design material, even when, as our own research has shown, that this takes considerable effort in breaking out of set standards and predominant approaches. Designing and researching in tandem has allowed us to move beyond these limits, challenging us to develop a set of form-making qualities. These form-making qualities may be connected to a wider communicative and interactional 'gestural language' when SR-RFID-enabled phones are programmed to manage a variety of input-output relations. However, we also need a clear understanding and no small measure of conceptual design to proceed from sketches to effective, comprehensible, and communicative interactional forms.

Conclusion

In both design and related research, there is value to be gained through inquiry into designing with technology at a conceptual level. Paying attention to design materials is important because it allows for complex emerging technologies to be analyzed and aligned according to designers' needs. In this research-driven design study, I have investigated the emerging SR-RFID technology as a design material. The study uses activity theory in order to introduce a *design material perspective* as a method to enable interpretation of technology, considering the activity of design. This involves framing technology as design material and developing its form-making qualities. The *design material perspective* addresses technology, as it can be perceived through the activity of design. In applying this framework to SR-RFID technology, I reposition it as a *near-field material* that is a computational composite made up of radio fields and computing. This material can be described through six form-making qualities: Tap and Hold, Multi-Field Relations, Multi-Field Distribution, Context Linking, Field Shape and Mediation Type. These qualities create a form-related vocabulary that makes it possible to understand specific attributes unique to SR-RFID technology. Together, the form-making qualities give us tools to think about specific features of an otherwise complex technology.

Form-making qualities are used to describe material properties that are relevant to design. The research shows that such qualities are particularly useful in conceptual design, where they streamline material thinking toward issues directly related to designers' motives for selection and usage of materials. They do so by addressing how specific materials can be formed without prescribing specific user-oriented solutions. Such knowledge can be hard to grasp through technical specifications or user-oriented examples alone. This is not to say user examples and technical specifications are unimportant to interaction design; I suggest instead that conceptual models representing materials related to design are useful additions that can help designers utilize emerging technology in conceptual design.

Theoretically, I argue that motives are central in allowing us to analyze and, consequently, understand issues related to viewing technology as materials in two ways. First, we need to understand designers' dominant motives for using a technology within design to be able to analyze it as a design material. In our case, that led to a focus on the need of design practitioners to conceptualize interactions that are made possible with SR-RFID. Second, technology inscribes types of agencies for those who utilize it. Such inscribed agencies, however, may not correspond well with designers' motives. Realizing this gap in our project led us to completely reframe SR-RFID technology as a conceptual material, to better align the potential motives carried in the material itself with the designers' motives for using it.

Acknowledgments

My thanks to Andrew Morrison and Timo Arnall for their support and critical comments during this inquiry. This work is carried out as part of the Touch project funded by the Norwegian Research Council through the VERDIKT program.

References

1. Ashby, M., & Johnson, K. (2002). *Materials and design: The art and science of material selection in product design.* Oxford, UK: Butterworth-Heinemann.
2. Ballagas, R., Rohs, M., Sheridan, J., & Borchers, J. (2006). The smart phone: A ubiquitous input device. *IEEE Pervasive Computing, 5*(1), 70-77.
3. 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 2006—Wonderground* (Paper No.0068). Lisbon: Centro Editorial do IADE.

4. Broll, G., Haarländer, M., Paolucci, M., Wagner, M., Rukzio, E., & Schmidt, A. (2008). Collect&Drop: A technique for multi-tag interaction with real world objects and information. In *Proceedings of European Conference on Ambient Intelligence* (pp. 175-191). Berlin: Springer-Verlag.
5. Buxton, B. (2007). Sketching user experiences: Getting the design right and the right design. San Fransisco: Morgan Kaufmann.
6. Ceipidor, U. B., Medaglia, C. M., Rizzo, F., & Serbanati, A. (2006, October 18). *RadioVirgilio/Sesamonet: An RFID-based navigation system for visually impaired*. Paper presented at the Mobile Guide '06 Conference, Turin, Italy. Retrieved January 28, 2009, from http://mobileguide06.di.unito.it/pdf/BiaderCeipidor&al.pdf
7. Fallman, D. (2003). Design-oriented human-computer interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 225-232). New York: ACM.
8. Hallnäs, L., Melin, L., & Redström, J. (2002). Textile displays: Using textiles to investigate computational technology as design material. In *Proceedings of the 2nd Nordic Conference on Human-Computer Interaction* (pp. 157-166). New York: ACM.
9. Hallnäs, L., & Redström, J. (2002a). Abstract information appliances: Methodological exercises in conceptual design of computational things. In *Proceedings of the 4th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques* (pp. 105-116). New York: ACM.
10. Hallnäs, L., & Redström, J. (2002b). From use to presence: On the expressions and aesthetics of everyday computational things. *ACM Transactions on Computer-Human Interaction, 9*(2), 106-124.
11. Hardy, R., & Rukzio, E. (2008). Touch & interact: Touch-based interaction of mobile phones with displays. In *Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services* (pp. 245-254). New York: ACM.
12. Hornecker, E., & Buur, J. (2006). Getting a grip on tangible interaction: A framework on physical space and social interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 437-446). New York: ACM.
13. Horváth, I. (2000). Conceptual design: Inside and outside. In *Proceedings of the 2nd International Seminar and Workshop on Engineering Design in Integrated Product* (pp. 63-72), Zielona Góra: Technical University of Zielona Góra.
14. Karana, E., Hekkert, P., & Kandachar, P. (2007). Material considerations in product design: A survey on crucial material aspects used by product designers. *Materials and Design*, *29*(6), 1081-1089.
15. Kuutti, K. (1995). Activity theory as a potential framework for human-computer interaction research. In B. A. Nardi (Ed.), *Context and consciousness: Activity theory and human computer interaction* (pp. 17-44). Cambridge, MA: MIT Press.
16. Leont'ev, A. N. (1978). *Activity, consciousness and personality* (M. J. Hall, Trans.). Englewood Cliffs, NJ: Prentice-Hall.
17. Lim, Y.-K., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Transactions on Computer-Human Interaction, 15*(2), 1-27.
18. Löwgren, J. (2007). Forskning kring digitala material. [Interaction design, research practices and design research on the digital materials]. In S. I. Hjelm (Ed.), *Under ytan: Om designforskning,* (pp. 150-163). Stockholm: Raster Förlag.
19. Löwgren, J., & Stolterman, E. (1998). *Design av informationsteknik - Materialet utan egenskaper* [Design of information technology - Material without qualitites]. Lund: Studentlitteratur.
20. Löwgren, J., & Stolterman, E. (2004). *Thoughtful interaction design - A design perspective on information technology*. Cambridge, MA: MIT Press.
21. Maher, M., Poon, J., & Boulanger, S. (1996). Formalising design exploration as Co-Evolution: A combined gene approach. In J. S. Gero & F. Sudweeks (Eds.), *Advances in formal design methods for CAD* (pp. 1-28). London: Chapman & Hall.
22. Manzini, E. (1989). *The material of invention. Cambridge,* MA: The MIT Press.
23. Martinussen, E. S., & Arnall, T. (2009). Designing with RFID. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction* (pp. 343-350). New York: ACM.
24. Mazè, R., & Redström, J. (2005). Form and the computational object. *Digital Creativity, 16*(1), 7-18.
25. *NFC-forum* (n.d.). Retrieved January 15, 2009, from http://www.nfc-forum.org
26. Nordby, K. (in press). Multi-field relations in designing for short-range RFID. *Personal and Ubiquitous Computing*.
27. Nundloll-Ramdhany, V. (2007). *Multi-tag interaction: Physical mobile interactions with multiple tags*. Unpublished master's thesis. Lancaster University, Lancaster, UK.
28. Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155-169.
29. Rukzio, E., Leichtenstern, K., Callaghan, V., Holleis, P., Schmidt, A., & Chin, J. (2006). An experimental comparison of physical mobile interaction techniques: Touching, pointing and scanning. In P. Dourish & A. Friday (Eds.), *UbiComp 2006 : Ubiquitous computing : 8th International Conference* (pp. 87-104). New York: Springer.
30. Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.
31. *Touch project* (n.d.). Retrieved October 15, 2009, from www.nearfield.org.
32. Vallgårda, A., & Redström, J. (2007). Computational composites. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 513-522). New York: ACM.

33. Vygotsky, L. S. (1962). *Thought and language*. Cambridge, MA: MIT Press.
34. Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.
35. Välkkynen, P., Korhonen, I., Plomp, J., Tuomisto, T., Cluitmans, L., Ailisto, H., & Seppä, H. (2003, September 8). *A user interaction paradigm for physical browsing and near-object control based on tags*. Paper presented at the Physical Interaction Workshop on Real World User Interfaces, Udine, Italy.
36. Välkkynen, P., Niemelä, M., & Tuomisto, T. (2006). Evaluating touching and pointing with a mobile terminal for physical browsing. In *Proceedings of the 4th Nordic Conference on Human-Computer Interaction* (pp. 28-37). New York: ACM.
37. Want, R., Fishkin, K. P., Gujar, A., & Harrison, B. L. (1999). Bridging physical and virtual worlds with electronic tags. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems* (pp. 370-377). New York: ACM.