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Between the Tag and the Screen

Redesigning Short-Range RFID as Design Material

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Abstract

Industrial and interaction designers are increasingly faced with new computational technologies that may be used as materials in designing. Such materials are important in design practices because they offer conditions for conceptualisation and production of new designs. However, new computational technologies are often very complex and not presented with the intention of supporting design practices.

This study explores such a problem by way of a study of Short-Range RFID (SR-RFID) as design material. SR-RFID is a new computational technology that enables a transaction of information between a radio transmitter and an RFID tag when the two are within a very short range (2-5 cm). As a design material, SR-RFID crosses the traditional boundaries between industrial and interaction design by offering temporal and spatial properties that may be shaped by both disciplines.

In investigating SR-RFID as a design material, we are faced with two important challenges. First, 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. Second, it is difficult to find frameworks that show how to analyse such a technology so as to present it as a material specifically oriented toward industrial and interaction design.

I meet this challenge by applying a process of research by design. In this process, a series of explorative design probes has been carried out with the purpose of exposing design-related properties of SR-RFID. The design research has been conducted by a multidisciplinary team of researchers and designers as part of a larger research project called Touch.

Central to my study is the use of activity theory in building a conceptual framework that allows the analysis of computational technology as design material. This framework has been applied to SR-RFID in order to re-conceptualise it for designing.

The study has found that in order to understand SR-RFID in relation to industrial and interaction design it is useful to reinterpret it as a design material. I offer three main reflections on SR-RFID as design material. First,

I argue that SR-RFID may be seen as *near-field material*. This material is specifically oriented toward industrial and interaction designers' form-making. Second, I present how SR-RFID may be seen as a *conceptual material* that helps us focus on material properties that have special significance in the creation of forms. Third, I argue that when creating design materials for industrial and interaction design, we should pay particular attention to the concept of motive. Motives may help us understand what SR-RFID means in designers' activity.

The results of this study offer one example of how activity theory could be used in interaction and industrial design research to understand materials. Furthermore, it expands upon current research that investigates computational technology as materials. In addition, new insights into the makeup of SR-RFID are offered that may be further appropriated and used in design and design teaching.

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Chapter 1: Introduction

The design of novel interactive experiences increasingly offer information- and communication-technology companies a competitive advantage. The iPod, iPhone, WII, DS and Kinect represent successful examples of such design[1]. New computational technologies are central to the development of such interactive experiences, as they provide novel potentials that industrial and interaction designers may take advantage of when designing. This thesis takes up one such computational technology, Short-Range Radio Frequency IDentification (SR-RFID), which could be used by designers as design material.

The efficient understanding and use of new technologies as materials in designing pose a great challenge to design and design research. Manzini (1986) argued that new materials developed at such a speed that cultural understanding of them could not keep up. Faced with the increasing complexity of emerging materials, Manzini claimed there was a growing gap between what materials made possible and what was thinkable by designers.

This thesis takes a similar stance when investigating the use of new computational technologies in the fields of interaction and industrial design. By "computational technologies," I refer to technology components that may be used to create interactive artefacts. Computational technologies differ from traditional physical materials in that they have other properties that vary over time.

This study seeks to decrease the gap between the possible and the thinkable by way of an investigation of SR-RFID as a computational technology that may serve as a material for industrial and interaction designers. SR-RFID technology is a subset of RFID technology and, like RFID, consists of small radio transmitters in the form of RFID tags and RFID-enabled devices that may exchange data when their radio fields intersect. RFID is a technology often associated with logistics and has been proposed as a possible alternative

[1] Multiple references describe the success of these products. See for instance: (Joel & Michael; Microsoft, 2011; Yofie & Kim, 2010).

to barcodes. SR-RFID differs from RFID in that the technology is limited to very small radio fields. These fields, referred to as *near-fields*, typically reach 2 to 5 cm in diameter, enabling SR-RFID interaction to resemble physical interaction. One commonly sees SR-RFID used in systems dealing with public transport, payment and logistics. For instance SR-RFID enables users to pay for subway travel simply by swiping an RFID-enabled card over an RFID-enabled reader. Figure 1.1 shows an example of such a system in the form of an RFID-driven ticketing machine located in Oslo.

Currently, SR-RFID is increasingly implemented outside its traditional use areas. This development is already gaining momentum as reported in Martinussen and Arnall's work (2009), which shows a number of current RFID-related innovations. This author expects further innovative use when the technology gains wider deployment.

Figure 1.1. Oslo is currently introducing an RFID-driven electronic ticketing system for public transportation. The image shows an RFID card reader at a subway station (2010).

Industrial and interaction designers are central to the further creative development of SR-RFID-driven systems. This is due to their orientation toward using technology in novel ways to create an innovative user experience. However, little research investigates how SR-RFID may be used by such design practices to create new designs. Instead, most design-oriented research explores SR-RFID from the perspective of end users. Such work is important but focuses on existing designs rather than how the technology may be transformed into new ones.

The title of this thesis, *Between the Tag and the Screen*, reflects on the need to understand not only the interfaces of which SR-RFID is a part, but also the makeup of SR-RFID itself. In the case of SR-RFID-driven mobiles, we may do so by asking what lies between the physical RFID tag with which we interact and the feedback we receive through the screen of a mobile phone. This study tackles this problem by investigating SR-RFID as design material. In doing so, attention is drawn toward the design-related abstract properties of a computational technology, rather than how it is used in existing applications. To perform such an investigation, the study applies a process of design research done in context of the Touch project (2010). Touch investigates SR-RFID through practice-based research driven by a team of researchers and designers that has been using the technology to design new artefacts. The research for Touch is carried out by means of research by design, in which designing is used as a method to investigate design-related problems (Sevaldson, 2010).

The research by design process is strengthened by applying activity theory as an analytical tool. Activity theory is a research framework with origins from Russian physiology (Leont'ev, 1978; Vygotsky, 1962, 1978) that allows us to use people’s activities as an analytical perspective on the world. Central to activity theory is the concept of an activity as a unit of analysis that offers a minimal set of context. Specifically, activity theory is used in this study to analyse the relationship between industrial and interaction design, and the technology that designers use as material to shape artefacts. By using activity theory and processes of research by design, the study presents contributions that extend both design theory and our knowledge of how to use SR-RFID inside design practices.

The thesis is based on three published journal articles to which this meta-reflection refers. In this text, the results from the three articles are discussed further and expanded upon. The results from this process point to a possible new conceptualisation of SR-RFID, one that is proposed as better-geared for supporting the work of industrial and interaction designers. Also proposed is an activity theory-informed perspective on industrial and interaction designers’ use of computational technology as potential design material.

INTERACTION AND INDUSTRIAL DESIGN

Although this study encompasses aspects that may be seen in a wide perspective of human-oriented design, the research is specifically concerned with the tradition of industrial design and the emerging tradition of interaction design. This focus has been chosen because SR-RFID, as a material, seems to bridge the two design domains by having both strong temporal and spatial qualities.

Designing interactive artefacts requires careful consideration of both the temporal interactive aspects of computing and the physical manifestation of the interaction in the spatial world. Designing such interactive artefacts using computational technology requires attention to novelty, aesthetics and function. Industrial and interaction designers are well equipped to deal with these issues as both are oriented toward designing artefacts with the eventual user experience in mind (Moggridge, 2006).

Löwgren (2007b) describes how industrial and interaction design can be seen as similar practices that we may broadly separate by the technologies they use in shaping physical and digital artefacts. Moggridge (2006) found that although the two disciplines address different physical and digital technologies, they share important interests: providing inventive, useful, enjoyable and aesthetically pleasing physical and/or digital artefacts. We may therefore see interaction and industrial design as having compatible goals and values that happen to be realised using different technologies.

This study brings together industrial and interaction design as the focus of study is technologies that may be considered within the interest area of both disciplines. Interaction designers tend to focus largely on temporal forms expressed by screens, while industrial designers focus mainly on spatial forms expressed by physical objects (Edeholt & Löwgren, 2003). However, the differences between the two disciplines may increasingly blur as industrial design uses progressively more computational technology (Edeholt & Löwgren, 2003). Likewise, interaction designers may take part in shaping the physical manifestations of their interactions. Such development sees the line between the two disciplines merge by way of new technologies that may be adopted and formed within both disciplines. SR-RFID is one such bridging technology.

WHY DESIGN MATERIALS MATTER

Britannica defines materials as ‘the elements, constituents, or substances of which something is composed or can be made’[2]. For industrial and interaction designers, computational technology may be seen as materials that can be used to shape designs (e.g. design materials). This important move helps us situate an otherwise abstract technology into the concrete context of industrial and interaction designers’ activity.

The selection and use of materials is a crucial element in industrial designing. Karana et al. (2008) found that for designers, materials play a significant role in both the final production of the design and the important process of supporting the conceptualisations of new ideas. This positions materials, from a design perspective, as both the enabler of the final artefact and the enabler of ideas.

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[2] http://www.britannica.com/bps/dictionary?query=material

Materials are important in all disciplines. However, what are considered materials and how these are thought of and manipulated in the process of making something varies significantly. For instance, an industrial designer and a carpenter may have very different approaches to wood. The carpenter sees it in light of crafting a specific product. The industrial designer, however, may never touch the wood and is more oriented toward the process of conceptualising new products. In both cases wood is the material at hand, but the carpenter and the industrial designer have different tools, expertise and goals related to its use.

This example shows how the meaning of a material depends on the person using it. Different people will have different history, knowledge, tools and skills related to the material, and because of this, they experience it differently. This makes it relevant to ask whether technologies used to create artefacts may also be identified, analysed and better appropriated as materials directly oriented toward particular design approaches. By studying designers' information needs related to their selection of physical materials, Kesteren (2008) argues for such a view. Then designers' material-related activities might need particular types of knowledge. In this study, I suggest that such knowledge is neither trivial nor readily available. This raises the question, how may we create conceptual frameworks that help us analyse and redesign new technologies so as to make them more efficient as design materials?

COMPUTATIONAL TECHNOLOGY AS MATERIAL

In industrial design, materials have been closely linked to physical matter, such as wood or metals. However, the introduction of interactive systems has made an exclusive link between matter and materials questionable. Although partly immaterial, computational technologies such as sensors and screens are also shaped by people with the intention of producing designs.

My work supports the emerging tradition of seeing materials in a wide perspective that also embraces computational technologies as materials. Such perspectives are taken up by Löwgren and Stolterman (1998), who describe information technology as a material without qualities, and by Hallnäs and Redström (2002, 2006), who discuss how computing as material needs to be mediated through some kind of spatial material.

Analysis of computational technology as material is not straightforward. First, the intangible characteristics of computational technologies make them more abstract than physical materials. Where the properties of physical materials may be more or less static, the main properties of computational technologies are dynamic.

Secondly, computational technologies are always constructed with many different components. They may be seen, therefore, as complex composites. Vallgårda and Redström (2007) have coined the term computational composites. They argue that computational things can be seen as made up of the temporal characteristics of computational processes and the spatial form given by the additional materials that mediate the computation. Seeing computation as largely temporal and other material as mainly spatial has been mentioned before, for instance by Hallnäs and Redström (2006) and Edeholt and Löwgren (2003). Even earlier, Manzini (1986) discussed similar characteristics of interactive systems.

Thirdly, in the case of traditional materials, there usually exists an historical and cultural use of the material in design processes. For instance, industrial design draws on a large range of examples and research regarding the use of plastics, metals and different biological materials. Examples include research by Manzini (1986) and Ashby and Johnsons (2002). This might not always be the case for computational technologies. Although many computational technologies are extensively mapped, some of them are relatively new and may have no extensive documented history of use in either existing designs or processes of designing. All three of the problems mentioned above may be associated with SR-RFID.

CHALLENGES IN EXPLORING MATERIALS IN DESIGNING

When designers engage with new computational technologies as materials in designing, they may generate new insights that they could take advantage of when creating new designs. Schön, by studying how designers use Lego as material, investigated how such insights are part of designers' personal or shared design space, producing limitations and opportunities to the design situation (Schön, 1992b). He found that designers create their own interpretations of the materials, thus making it personal. Schön’s observation suggests that material-related knowledge for designers exists in the meeting of technology and its use by designers.

Analysing materials as connected to specific activities, instead of as isolated artefacts, poses some interesting challenges for design research. How do we investigate materials in designing? Further, how do we systematise and present such knowledge so as to further material-oriented discourse inside the fields of design and design research?

Indeed, investigating materials through design activity is not easy. For instance, observing designers using materials in designing may be difficult. Material-related insights that emerge in designing may not be spoken of or drawn. In addition, externalised material knowledge in the form of sketches, text, images or spoken words may not be entirely understood outside the knowledge space of the individual or groups of designers performing the design. After all, although investigating materials is part of design activity, exploring materials with the aim of producing material-related knowledge is not usually the focus of such activity.

As designing is not oriented toward material exploration itself, there is little research on how to collect and systematize such knowledge. Currently, when designers discover new material-related opportunities, the new knowledge is seldom shared with a wider community of designers. Instead, material-related knowledge is, in the best case, internalised into the designer's personal repertoire of material opportunities, or in the worst case, simply deemed unimportant, and forgotten.

RESEARCH AIMS AND QUESTIONS

The object of this study is to investigate SR-RFID as design material. In doing so I expand the current body of short-range RFID-related research, by analysing it from an industrial and interaction design perspective. Other work has taken up the creation of computational materials. (Hallnäs, Melin & Redström, 2002; Löwgren, 2007a; Vallgårda & Redström, 2007). I have found no work that has explored SR-RFID in order to build an understanding of it as material in design.

Furthermore, I aim to use activity theory to expand current theoretical understandings of design materials. I do so by analysing SR-RFID through a design activity perspective. Other works takes up design activity inside activity theory (Desai, 2008; Y Engeström, 2006; Hyysalo, 2005; Tan & Melles; Tarbox, 2006). However, I have not come across any works using activity theory to analyse technology as materials in design activity. My work shifts the attention from users to designers as the subject in design-oriented activity theory-informed research.

I summarise the aims of the research in three questions that move from micro to macro levels:

1. How may SR-RFID be presented to support industrial and interaction designing?

2. In what way may we re-conceptualise new computational technologies as material for design?

3. How may we better understand the use of materials in industrial and interaction design?

To be able to answer the questions, I use research by design and activity theory as the dominant approach.

RESEARCH BY DESIGN

Research by design is increasingly acknowledged as a valid way of addressing research problems that cannot easily be solved by observations alone. For instance, Zimmerman et al. (2007) proposes that design research may add to current HCI research by helping to solve problems that are hard to tackle through sciences and engineering methods. In my study I use it to expose, explore and design properties of SR-RFID.

In an article investigating the different modes of design research, Sevaldson (2010, p. 11) defines research by design as: ‘A special research mode where the explorative, generative and innovative aspects of design are engaged and aligned in a systematic research inquiry.’

This study qualitatively explores SR-RFID using a series of design probes. The designing, carried out by a small team of designers, engineers and researcher, was used to uncover how the material could be seen from within design as opposed to observing designers doing work using SR-RFID. The processes resulted in a range of prototypes, sketches, images and written concepts that were analysed further in search of material-related properties of SR-RFID.

Research by design has allowed the Touch project to uncover aspects of SR-RFID not previously described. These aspects, this author believes, would have been difficult to discover without engaging with SR-RFID through designing. However, to further situate the findings in a design perspective we also needed to create an adequate theoretical framework that helped us contextualise the findings. I have done so by using activity theory.

ACTIVITY THEORY

Few theoretical writings present tools that allow the unpacking of new technology as material for industrial and interaction design. In this thesis, I suggest activity theory as a useful means to this end. Activity theory is a research framework that emerged from Russian psychology through the works of Leont’ev (1978) and Vygotsky (1978). Kuutti defines activity theory as:

> ‘a philosophical and cross-disciplinary framework for studying different forms of human practices as development processes, both individual and social levels interlinked at the same time.’
>
> (Kuutti, 1995, p. 24)

Activity theory has previously been taken up inside Human Computer Interaction (HCI) as an alternative to cognitive psychology. Activity theory was seen as a way to move from a focus on people's cognitive capabilities to a wider understanding of users in a social and cultural context. (Bannon & Bødker, 1991; Bødker, 1991; Kaptelinin & Nardi, 2006; Kuutti, 1995). There has also been a growing interest inside design research, much for the same reasons (Blumenthal, 1995; Hyysalo, 2002; Popovic, 2007).

In this work I use activity theory to gain a better understanding of computational technology designers' use as materials. In doing so I expand the object of study from SR-RFID to how SR-RFID may be seen as a material in designers' activity. I use activity theory to analyse and structure technology as design materials, and draw particular attention toward the concept of *motive* as used inside activity theory[3]. Leont'ev (1978) argues that motive is what directs activities and gives them meaning. The thesis will discuss why motives represent a particularly important aspect of industrial and interaction design and how these may be used to better analyse designing with materials.

It is important to be aware that using activity theory is not without problems. As I will cover later in this thesis, activity theory as a research approach has received extensive criticism. Despite such criticism, this study has found activity theory tremendously helpful in bringing order to the complex activity of using SR-RFID as material in interaction and industrial designers' designing.

STRUCTURE OF THESIS

The thesis is structured in two parts. The first consists of three published articles that are briefly presented in Chapter 5. The second part is the final contribution, this text, which extends the key findings of the articles.

Part 1: The journal articles

The thesis is based on three published journal articles that make up a comprehensive study of SR-RFID as design material. Together, they also show how strategies of research by design can be used to develop new knowledge. Following is a brief description of the articles.

1. *Designing tangible interactions using short-range RFID (Nordby & Morrison, 2010).*

The first article reports on the design of tangible interactions using RFID-enabled phones and RFID tags. By applying the concept of affordances to activity theory, the article shows that the tangible interaction opportunities RFID offers to designers may be addressed as motivational, instrumental and operational design affordances. The article moves on to introduce a rich set of design affordances for RFID. This includes the concept of tap and hold, a model describing tap and hold and a set of possible input techniques that may be created using the aforementioned model.

[3] This study strictly follows motive as described in activity theory. This is important because motive in activity theory is placed within a larger theoretical context that is important for its interpretation.

2. *Conceptual designing and technology: Short-range RFID as design material (Nordby, 2010).*

The second article focuses on narrowing the definition of SR-RFID while broadening the perspective on RFID-related form-making. Theoretically, it takes up how we may analyse and present technology to support conceptual designing. The article presents six motivational affordances. Two of these, *multi-field relations* and *tap and hold*, are presented in detail in articles one and three.

3. *Multi-field relations in designing for short-range RFID (Nordby, 2011).*

The third article explores interactions using multiple SR-RFID fields. The article explores a set of design probes and uses the findings to construct a conceptual model of such interactions. The concept of multi-field relations is presented, as well as four different types of multi-field relations: one-way, two-way, sequence and multiple relations. These are discussed in relation to 11 different input techniques. A full summary of the three articles may be found in Chapter 5 of this thesis.

Part 2: The exegesis

This text is divided into five chapters:

Chapter 1: Introduction contains a high-level view on the research problems, theory and approach. In *Chapter 2: The context of study*, I outline current research in interaction and industrial design, RFID-related research, materials and activity theory. It also presents a brief description of the Touch project as the origin of this thesis. *Chapter 3: Methods for exploring materials through designing* covers the methods used in this thesis together with the empirical material created in the process. It also provides a discussion of my approach to research by design.

Chapter 4: Connecting SR-RFID and design is the most extensive chapter, discussing the three main arguments in the thesis. This chapter is split into three sections: The first contains a re-conceptualisation of SR-RFID and summarises the RFID-related findings from the journal articles into one model. The second contains a description of how computational technologies may be analysed as materials, and the third contains an analysis of materials in industrial and interaction designing.

Chapter 5: Articles presents the scope and findings of the three published journal articles. *Chapter 6*: *Conclusion* discusses the conclusions of the research, the potential implications and the potential for further research.

Overall, I argue that in order to analyse computational technology as materials, we should pay attention to all the layers of the design activity. Furthermore, I argue that we may create special materials that can support designers engaged in designing with computational technologies. I call such materials conceptual materials. These are materials created to support designers' conceptualisations of new artefacts. I further propose that SR-RFID may be re-conceptualised as near-field material. This particular material is a conceptual material geared toward making the possibilities of SR-RFID thinkable for designers.

This concludes the introduction to this thesis. In the following chapter the context of this study is presented further.

Chapter 2: The context of study

The current approach, rooted in design traditions, is multidisciplinary and to be able to unify all the aspects of the research topic, this work spans multiple research traditions, including design research, psychology, computer science, HCI and the social sciences. In the following text the context of study has been divided into five sections. The first section concerns the Touch project. The second section takes up my perspective on interaction and industrial design. The third section presents SR-RFID and approaches related to it in research and practice. The fourth elaborates upon the concept of materials in designing. Finally, the fifth section presents activity theory as a potential approach to analysing materials in design activity.

THE TOUCH PROJECT

This thesis is part of a larger collaborative design research project called Touch (2010). Touch investigates the use of SR-RFID in interaction design. The project has three main areas of interest: first, the development of new interactive artefacts displaying novel use of SR-RFID; secondly, investigating cultural and visual aspects of SR-RFID as it is embedded in society; thirdly, understanding SR-RFID as design material. The latter approach is covered extensively in this thesis.

One may view the research in the Touch project as a counterpoint to the RFID-related research performed inside engineering and HCI, which, in general, concerns specific implementations of applications or are oriented toward usability. The Touch project had a clear technology focus, but the technology was seen from the perspective of what it meant for designers rather than end users.

Initially, Touch focused on Near-field Communication (NFC), a particular implementation of SR-RFID oriented toward mobile phones. NFC is proposed, developed and marketed by the NFC forum. This is a joint venture among several leading technology companies. Their aim is to provide a standardised platform for short-range RFID technology on everyday electronics (NFC-forum, 2009).

During the project, the focus has expanded to all SR-RFID-related technologies, including applications beyond mobile phones. This change was a response to the findings acquired by the design probes conducted as part of the study.

A research by design project

Research by design is a central research mode in the Touch project. As previously mentioned, such research uses the 'explorative, generative and innovative aspects of design' to perform a research inquiry (Sevaldson, 2010). The research and design processes were carried out over three years by a multidisciplinary research and design team consisting of seven people with specialisation from a number of different disciplines including industrial, interaction, media and graphic design. In addition, the project included participants from social research, software engineering and ergonomics. Also, the project worked with masters' level students of interaction and industrial design courses from Oslo School of Architecture and Design (AHO).

Figure 2.1. The Touch project has participated in numerous exhibitions of the projects' work. The images are from the Nordes '09 conference at the Oslo School of Architecture in 2009.

As SR-RFID is a relatively new technology with a limited range of design examples, the project relied heavily on the construction of prototypes and design visualisations to be able to investigate it.

Touch publications

The Touch project has resulted in a number of publications in which the format mirrors the project's focus on research and design. In addition to the traditional publication channels like books, conferences and journals, the project has also emphasised exhibitions, blogs and lectures. Figure 2.1 shows an exhibition that the project held at Oslo School of Architecture. The project's blog, found at www.nearfield.org, has also been used extensively in communicating the projects' findings to a wider audience.

The project’s first research publications involved communication associated with SR-RFID. This included a study of a graphic language for RFID-based interaction (Arnall, 2006) and a more general study of markings in public places (Arnall, 2005). Figure 2.2 shows an image of various proposed graphics for communicating SR-RFID functionality. Publications related to two specific RFID-based designs followed. The first introduced an RFID-powered toy for blind children (Johansson, 2009). Figure 2.4 offers an image of the toy. The second described a study related to a media player for children using RFID-powered tangible interaction (Martinussen, Knutsen & Arnall, 2007). The input device is shown in Figure 2.3.

Figure 2.2. Examples of work that aims to offer a graphic language for RFID interaction. The icons represent various types of RFID-related interactions (Arnall, 2006).

These works led to a number of more abstract explorations of RFID technology. Martinussen and Arnall (2009) discussed the spatial aspects of SR-RFID design. This author’s publications took up further aspects of SR-RFID technology in designing (Nordby, 2010, 2011; Nordby & Morrison, 2010). The latter work is extensively described in this text. Finally, the project began exploring using video to communicate SR-RFID-related findings from the project (Arnall & Martinussen, 2010). A full list of all the Touch related publications can be found on the Touch blog at www.nearfield.org.

Figure 2.3. 'Bowl' was a video player driven by an embedded RFID reader in a wooden bowl. By placing various RFID-embedded objects in the bowl, video streams could be controlled on a connected TV set (Martinussen et al., 2007).

Figure 2.4. 'Sniff' allowed blind children to trigger various behaviours in a toy by 'sniffing' RFID-embedded objects (Johansson, 2009).

Between the Tag and the Screen inside Touch

This thesis, although part of Touch, shows a theoretical perspective that is not used elsewhere in the Touch project. Because my focus has been on the relationship between the designer and the technology, the further communicative perspectives taken up in Touch have not been in the forefront of my study. In the following four sections I present the additional context of my thesis, starting with interaction and industrial design.

T O W A R D   I N D U S T R I A L   A N D   I N T E R A C T I O N   D E S I G N

Design, a widely used term in both research and practice, covers a wide range of domains. The multiple practices that make up the general field of design have vastly different values and goals (Carvalho, Dong & Maton, 2009). Although difficult to achieve, a formal definition of design for design research is useful, notes Buchanan, who presents the following: 'Design is the human power of conceiving, planning, and making products that serve human beings in the accomplishment of their individual and collective purposes' (Buchanan, 2001, p. 9).

Buchanan’s definition deftly reveals design’s wide perspective of human purposes, which can include functional as well as cultural and personal considerations. Inside this wide and general definition of design, multiple sub-disciplines occupy different niches. Among these are architecture, graphic design, motion design, interior design and industrial design—to name but a few.

Each design discipline has a different set of approaches, interests and tools. Consequently, each discipline’s approach to materials may also differ. This makes it useful to limit our investigation of designing with SR-RFID to some of the specific disciplines normally involved in shaping this particular material. In this thesis, it is limited to industrial and interaction design.

Industrial and interaction designing: a close relationship

SR-RFID signifies material that may occupy both temporal and physical space. As such, it crosses the domains of both interaction and industrial design. Given this assumption, the current study relates to both disciplines. Both are directed toward different orders of designing, yet this study treats them as disciplines that have more unifying than conflicting qualities. To understand this, I first address the roots of the disciplines.

Industrial and interaction design have vastly different histories. Industrial design has long adopted technology to create new artefacts focusing on novelty, aesthetics and functionality. The Industrial Designers Society of America (iDSA) defines industrial designing as follows:

> Industrial design (ID) is the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer.
>
> *(iDSA 2008)*

Whereas we can trace industrial design back to its origin from the crafts, interaction design has a much more recent history. It may be seen as originating in part from industrial design. Löwgren (2007b) describes how interaction design may be seen as coming from three main schools: informatics, HCI and industrial design. This contrasts slightly with Winograd's view of interaction design:

> It draws on elements of graphic design, information design, and concepts of human-computer interaction as a basis for designing interaction with (and habitation within) computer-based systems.
>
> (Winograd, 1997, p. 157)

Here Winograd omits the influences from industrial design and leaves the influences of design practice on interaction designing to graphic design. This may be taken as an example of the multiple different perspectives that exist regarding interaction design. In some sense, it is seen as a direct extension of the field of HCI, and from other perspectives an extension of design practices like industrial and graphic design.

Other approaches to interaction design disregard the connection to digital materials altogether. Buchanan (2001) proposes that interaction design should be used in connection to the design of people's actions. Thus, interaction design will also encapsulate design with non-digital materials. Buchanan argues connecting interaction design to digital media alone is a 'misunderstanding.'

This study follows the more traditional approach of seeing interaction designing as dealing with digital materials as it engages with SR-RFID as design material. Further, interaction design is seen within a wider approach that also includes graphic design, digital arts, new media and communication. These added disciplines represent traditions that also deal with computational technologies and as such may be seen as part of interaction design. Still, this thesis will maintain a focus on the relations between industrial and interaction design, which share a core orientation toward innovations of function.

Moggridge, who originally coined the term *interaction design*, together with Verplank, offers the following bridge between industrial and interaction design:

> Like industrial design, the discipline would be concerned with subjective and qualitative values, would start from the needs and desires of the people who use a product or service, and strive to create designs that would give aesthetic pleasure as well as lasting satisfaction and enjoyment.
>
> (Moggridge, 2006, p. 14)

Moggridge's definition of interaction design may not be supported by all practitioners who call themselves interaction designers. However, in this thesis, research is oriented toward Moggridge's version of interaction design. Here, interaction design differs from industrial design mainly in that it specialises in the shaping of digital rather than physical artefacts (Löwgren, 2001). By digital artefacts I mean applications, services or products in which information technology plays a significant role.

Currently, the artefacts created by industrial and interaction designers have more and more overlapping aspects as computational technology is increasingly embedded in traditional physical products (or as physical elements become part of digital services). Edeholt and Löwgren (2003) illustrated this by pointing out the necessity of knowledge from both disciplines to design for ubiquitous computing. However, this point may very well be extended beyond the specific tradition of ubiquitous computing and onto all categories of products that combine digital and physical elements.

In this view, technologies like SR-RFID, which has both temporal and spatial characteristics, represent the boundary between industrial and interaction designing. It is possible to address both disciplines as one when we see them in relation to a material they both deal with in pursuit of similar goals. This indicates that the separation between the physical- and digital-oriented design disciplines may not be very rigid.

Having shown how we can view interaction and industrial design as closely related disciplines that occasionally overlap in material use, I now move on to how we may understand designers' approach to the design situation.

Design as reflection in action or rational problem solving

Interaction and industrial design have been associated with the term *creative design* as a way to describe an approach centred on problem solving. Löwgren (1995) contrasts this view with engineering design. Where engineering design works toward solving a specification with a rigorous model, a creative-design approach constantly reframes the design and research question as a tool to arrive at a divergent set of solutions.

This separation of design approaches can, according to Dorst (2004), be connected to two main directions: the *'rational problem solving paradigm'* and the *'reflective practice paradigm.'* The former sees designing as a systematic process to solve well-defined problems (Simon, 1969). The latter direction is introduced through Schön's work. Schön (1983) emphasises design as practices dealing with reflection in and on action. In such processes designers create designs that they reflect upon during and after designing. These reflections generate 'backtalk' the designer can react upon so as to be able to make new design moves. This is part of a *'problem framing'* activity in which the practitioner both reframes the problem at hand and generates possible solutions. Schön's model places emphasis on how designers must generate design proposals as part of his or her thinking.

Reflection in action is an essential component of processes of research by design (Sevaldson, 2010), as it emphasises the need to experiment with a problematic situation through design processes so as to discover new knowledge.

Wicked problems and co-evolution

One of the reasons the design community received Schön's model favourably is that it focuses on the subjective interpretative process of the designer. This is rooted in views that see design problems, in many ways, as undetermined and, thus, ones that cannot be solved by a separated process of problem solving. To account for the undetermined nature of the design problem, the term *wicked problems* appeared in design research, for instance in works by Buchanan (1992). Coined by Rittel and Webber (1973), wicked problems refers to ill-defined problems that are unique to the situation, have no clear formulation and no true solution. Buchanan (1992) claims that design problems may be addressed as wicked problems because designers need to find or create the subject matter of each specific design situation.

Seeing the design problem as wicked has important implications on how we understand the design process. Because the problem, in essence, is not properly defined, the movement from problem to solution may not be carried through in a linear fashion. Thus, Maher and colleagues (1996) argue for viewing creative designing as a process of co-evolution of problem space and solution space. They suggest that designing deals with situations in which the problem, not apparent at the beginning of the process, emerges during the design process together with the development of solutions.

The concept of co-evolving and reflection in action are both important in understanding designing. As such, they also become important in understanding the process of research by design conducted in this study. Here we observe that co-evolution of problem and solution fits well with the process of research by design. There too we see the problem (or opportunities) yet to be defined through the process of designing. In addition, reflection in action is an essential component of processes of research by design because it emphasises the need to experiment with a problematic situation through design processes so as to discover new knowledge.

However, such views seem to be general for all design, whereas we orient our attention toward industrial and interaction designing. To get closer to these branches of design practice, we need to explore their prime concern with experience.

Seeing interaction and industrial design as experience-oriented

The orientation toward user experiences is one way to understand the goal of designing. Buxton (2007) outlines this principle in addressing how designing is about not only the artefact produced, but also the experience it evokes as part of users' activities. Thus, the user experience may be seen as dialogical. It is dependent not only on the artefact itself, but also on what the user, the experiencer, brings to the situation.

Such views are supported by Desmet and Hekkert (2007), who see experiences as the outcome of people's interaction with products. They expand upon the concept of experience by dividing experiences into emotional experiences, aesthetic experiences and experiences of meaning. Wright et al. (2008) describes aesthetic experience as characterised through three themes:

> '*A holistic approach* to experience wherein the intellectual, sensual, and emotional stand as equal partners in experience.'
>
> (Wright et al., 2008, p. 4)

> '*Continuous engagement and sense-making* wherein the self is always already engaged in experience and brings to each situation a history of personal and cultural meanings and anticipated futures that complete the experience through acts of sense-making.'
>
> (Wright et al., 2008, p. 4)

> '*A relational or dialogical approach* wherein self, object, and setting are actively constructed as multiple centres of value with multiple perspectives and voices and where an action, utterance, or thing is designed and produced but can never be finalized since the experience of it is always completed in dialog with those other centres of value.'
>
> (Wright et al., 2008, p. 4)

The orientation toward user experience and aesthetic experience is useful, as it helps us move beyond problem solving or creativity as the prime concern of the design practices. Designers shaping artefacts are not just creative or inventive; they are also oriented toward making designs that connect with people on an affective level.

In further work concerning experience-oriented design, Forlizzi and Battarbee (2004, p. 264) offer a framework of user experiences and offer three archetypical types of experiences. Experience (happens constantly when interacting with products), an experience (has a beginning and an end and can be articulated and named) and co-experience (emerges in collaborate product use). Bødker (2006) places experiences within the context of HCI by claiming that the profession is moving from a mostly work-oriented second wave of HCI toward the third wave of HCI, focusing on culture, emotion and experience. Bud et al. (2003) argue, from an origin in industrial design, that we view experience design as a common ground for the multiple design practices.

Seeing design as oriented toward artefact-mediated experiences allows us to place people’s personal tastes, culture and feelings as a central topic of industrial and interaction designing. Thus, experiences are a fruitful perspective on design practices, which may be attributed, but are not limited to, industrial and interaction design.

When designing for other people, industrial and interaction designers must continuously consider other people's eventual experiences. These experiences may be hard to grasp. After all, they emerge in interaction with artefacts not yet designed. Thus, people’s potential experiences may be seen as a central part of designers' (wicked) problems. A consequence of this is that designers’ processes of reflection in action or co-evolution of problems and solutions are principally oriented toward and directed by users' potential experiences.

However, people's potential experiences are not the only concern of designers. For instance, people’s experiences are mediated by the technologies that are used to make up the artefact with which they interact. Due to this, detailed knowledge about such technologies is essential to the creation of artefacts that mediate experiences. In the following section I will explore SR-RFID as one such technology.

SR-RFID TECHNOLOGY

Designers’ skills and knowledge of the transformation of technologies is an important condition for design activity. For industrial and interaction designers, this is often contrasted by the differences of computational technology and physical materials. However, I have argued that we may view the technology differences between the disciplines as a continuum rather than a gap. SR-RFID technology exemplifies this continuum by having both strong temporal and spatial qualities.

SR-RFID technology already allows us to unlock a door or pay on the subway, all by a simple swipe of an RFID-enabled card over an RFID reader. The simplicity of a touch or swipe interaction has become synonymous with SR-RFID. However, a great deal of complexity related to the forming of SR-RFID interaction may be found beyond the simplified notion of a touch. In exploring this, I will now present the technology and related works that investigate various aspects of RFID-driven interactions.

RFID technology

We can consider RFID a collection of technologies that share some fundamental traits. In essence, it consists of radio transmitters that can communicate with small tags known as RFID tags. Figure 2.6 shows examples of SR-RFID readers, and Figure 2.7 shows an array of SR-RFID tags. One recognises three types of tags: passive, active and hybrid. The *passive tag* serves as a radio reflector and uses an incoming radio signal from an RFID reader to generate power, enabling it to send a signal back to the RFID reader. *Active tags* have an embedded power source, normally in the form of a battery, enabling them to send signals autonomously. *Hybrid tags* have embedded batteries but rely on an incoming signal to trigger the response signal, thus enabling much greater read and send ranges. The read and send ranges of RFID varies significantly and range from a few millimetres up to several meters.

Figure 2.6. There are many kinds of RFID readers. The image shows a small collection taken from the Touch project’s archive of technologies.

Figure 2.7. RFID tags may be embedded in all kinds of objects. The image shows a small part of the (passive) RFID tag collection from the Touch project.

Although considered emerging, the technology is far from new. Rather, it has been gradually developed over many years. Landt and Catlin (2002) provide a rich introduction to the history of RFID, tracing it back to a 1948 article by Harry Stockman: ‘Communication by means of reflective power.' Landt and Catlin show how the technology has gradually moved through several phases to the present.

Traditionally, RFID has been seen as a suitable successor for barcodes. Such use would give each individual package a unique identity, and a large number of artefacts would be automatically traceable. However, currently, several hurdles must be surmounted before large-scale applications can be made. For instance, the price of RFID tags needs to be reduced, and technical impediments related to efficient scanning of multiple tags simultaneously must be addressed.

Up until now, RFID has mostly been connected to infrastructural applications and not directly used by interaction and industrial designers. However, this is currently a changing matter with the introduction of SR-RFID-based systems.

Limiting the scope to SR-RFID

SR-RFID, a subset of RFID, orients itself to RFID systems with very short ranges. By reducing the range of RFID systems to about 10 cm diameter, the user experience changes dramatically. As users must actively ‘connect’ the fields of the tag or the tag readers, the user experience is very physical and represents a form of tangible interaction (Hornecker & Buur, 2006); in traditional RFID-driven systems, the tag can be read over a range, which makes the interaction more indirect, representing scenarios associated with ubiquitous computing (Weiser, 1991). In many ways, SR-RFID changes the conception of RFID from a technology that monitors people to a technology wherein people physically control the interaction.

Recently, there have been substantial moves toward standardising the manner in which SR-RFID systems work across devices. Near-Field Communication (NFC), one of these attempts, shows much progress in providing fundamental frames for allowing a variety of devices to communicate through SR-RFID. The NFC standards are put forward by the NFC Forum, which consists of a set of large companies interested in promoting the technology for everyday use (NFC Forum, 2009).

RFID on mobiles

A present trend is the coupling of SR-RFID with mobile phones. Figure 2.8 shows three early examples of SR-RFID-enabled phones. This also represents one of the fundamental trends inspiring the creation of the Touch project in the first place. Joining RFID and mobile phones has significant impact on how people control RFID technology. A user holding a tag (e.g., a key card) to be scanned by an external device characterises normal usage of SR-RFID. In stark contrast, by allowing the user to hold the reader to scan the environment, as in the case of RFID-enabled mobile phones, the user scenario is, in effect, the opposite. Figure 2.9 shows an example of a ‘smart poster' interface comprising an RFID-enabled phone and a poster embedded with RFID tags. The empowered user has the ability to read tags in the environment. The phone still maintains the option to act as a tag to be read by external devices, but this is also controlled in the user device. Thus, it is possible to enable the user to modify what is read. In this way, the RFID-enabled phone moves the control of information from the external reader to the user’s device.

The merging of RFID technology and mobiles is already widespread in Japan, in particular, propelled by payment services driven by the Felicia system. Although it is expected that a similar trend will happen in the West, this is far from definite (Sixto, 2006). One problem with the rollout might be the lack of compelling arguments for end users to adapt the technology. After all, payment, ticketing and security alone do not necessarily make a wholly convincing argument for buying a new mobile device as today there exists well-functioning alternatives. Despite this, there is currently a strong move toward applying NFC technology on smart phones globally. For instance, there has recently been increased support for NFC in the Android mobile operation system.

Figure 2.8. Nokia has been pioneering the marketing of RFID-enabled mobiles in the West. Shown are three RFID-equipped Nokia handsets that have been used in the Touch project (from top right, the 5140i, the 6131 and the 6212).

Figure 2.9. A smart poster equipped with an RFID tag may be read by an RFID-enabled phone.

The commercial development of SR-RFID has had a narrow focus on a few use areas deemed potentially profitable (ticketing, payment and security). However, when the technology is made publicly available on a grander scale through new mobile handsets, it is likely that entirely new categories of services will emerge. What's more, the innovative use of SR-RFID will benefit from the high-speed development made possible through emerging applications stores on smart phones. While waiting for these developments to happen on a large scale, we may look into current SR-RFID-related research to understand the potential that SR-RFID offers to designers.

Physical browsing

An increasing interest in investigating SR-RFID-driven interaction has come from the field of HCI, where multiple projects explore different user-oriented applications of SR-RFID.

A strong trend inside HCI has been on browsing a tagged physical environment by means of handheld devices. Such physical browsing allows people to use the tangible world as an interface through which they might access data. The rationale for physical browsing has been to enable easy and efficient access to specific functions. By placing tags containing data relevant to a user's situation, a user can skip many steps of the more cumbersome browsing process needed to find the same data on the mobile.

Want and colleagues (1999), who equipped a handheld computer with an RFID reader, first demonstrated physical browsing. Kindberg and colleagues (2002) suggest such physical browsing could benefit from being an extension of the current Web infrastructure. They suggest places, things and people may all have a unique Web presence. In such view RFID is seen as a technology that may allow everyday physical artefacts to become directly linked to the Internet.

However, RFID tags are not the only method for enabling physical browsing. Välkkynen and colleagues (2003) suggest touching, pointing and scanning tags in the environment as possible ways of interacting with the environment through mobiles. *Scanning* refers to searching the immediate environment for RFID tags. *Pointing* refers to selections made by aiming the mobile device toward a tag. Such cases use optical methods. Finally, *touching* refers to directly coupling the mobile with a tag by way of SR-RFID technology.

A study comparing the three interaction methods, not surprisingly found that touching worked well for physical browsing and that people preferred touching when the tag was within reach (Rukzio et al., 2006). Similar studies found that users considered touch-based mobile browsing to be easy to operate (Isomursu, Isomursu & Komulainen-Horneman, 2008).

Physical browsing, although important in adding knowledge about RFID-driven interaction, only scratches the surface of how SR-RFID may be shaped in designing. To move further into the design of SR-RFID technology, we need to revisit our understanding of touch.

Expanding the notion of Touch

Selection has been proposed as a form of interaction offered by SR-RFID. When Ballagas and colleagues (2006) investigated the smart phone as a generic input device, they noted that RFID tags function well at performing selection tasks. Välkkynen (2007) sees touching as one of three ways such physical selection can be performed.

The research on SR-RFID, predominantly usability-oriented, has asked questions about whether selection may be coupled with button press (Välkkynen, Niemelä, & Tuomisto, 2006), user acceptance of physical-mobile interaction (Herting & Broll, 2008) and studies of user perception of RFID-based interactions (Mäkelä, Belt, Greenblatt & Häkkilä, 2007). This is all useful research, but we may see it as connected to specific kinds of solutions related to selection as a given interaction form. To support the design of new kinds of interactions driven by SR-RFID, we need to look beyond such studies.

Still, the introduction of the concept of selection is an important one as it expands the notion of touch from a one-to-one relation to a selection within many possible alternatives. This can be best illustrated by the increasing focus on multi-tag-based systems. The PERvasive serviCe Interaction (PERCI) project pioneered this domain and demonstrated a set of multi-tag prototypes (Broll et al., 2008; Nundloll-Ramdhany, 2007; PERCI, 2008). The work from the PERCI project was carried out further in the Multi-tag project (2010). Here they introduced *touch and interact* as an interaction domain using an array of RFID tags behind a projected screen to allow a mobile phone to interact with the screen content (Hardy & Rukzio, 2008). This approach continues in Blöckner and colleagues' (2009) projects, which show the implementation of a similar system in a museum context.

Ailisto and colleagues (2009) show an extensive set of examples of possible variations in RFID interfaces by describing and analysing eight different NFC designs. They summarise their findings in relation to potential user problems and opportunities. However, the designs also offer good examples of different ways to shape SR-RFID interactions. They highlight tag size and format, spatial perception, tag position, one-touch to multiple selection and consistency of feedback as important aspects of SR-RFID designs.

Adding SR-RFID to mobiles phones has changed the very nature of the technology. Earlier conceptions of the technology dealt predominately with unique data on tags read by reader devices. However, because mobile phones act as both reader and carrier of data, the focus has shifted to transactions of *any* data between phone and tags, when they are within range of each other. Thus the tags as carriers of a unique identity are less important than the tags as carriers of a set of changeable data. Currently there is an increasing set of interaction techniques presented that focus more on the exchange of data than the scanning of unique identities. For instance, *Touch & Connect* is an interaction technique in which a user may set up a connection between a computer and a phone by bringing them together (Seewoonauth, Rukzio, Hardy & Holleis, 2009). The demonstration uses a tag-equipped computer and an RFID-enabled mobile. However, the system could easily be made up of two mobiles, thus rendering the dichotomy of phones and tags meaningless. The work of this thesis meets this challenge by investigating the design of RFID-driven interaction as independent of the mediating physical devices like tags, RFID readers or phones (Nordby, 2010).

From touch to tangible user interfaces

When exploring approaches to RFID outside the field of mobile computing, more opportunities for interaction appear. Grønbæk and colleagues (2003), Klemmer and colleagues (2004) and Römer and colleagues (2004) all show examples of how it is possible to sense when an RFID tag and reader devices both meet and part from each other's field ranges. This finding questions both touch and selection as sufficient descriptions of the interaction potential of SR-RFID. These contributions, in addition to experiments done in the Touch project, led to the redefinition of touch to *'SR-RFID-based tap and hold'* (Nordby & Morrison, 2010) in this thesis research.

Physical interaction has received much attention inside the fields of HCI and computer science as a potential successor of current interaction technologies. The work on physical interfaces was motivated by the work of Fitzmaurice et al. (1995) in 'Bricks: Laying the foundations for graspable user interfaces.' These researchers described a set of physical bricks that could be used for manipulation of digital data through direct manipulation of the bricks themselves.

Ishii and Ullmer (1997) developed the concept further and introduced *Tangible User Interfaces* (TUI). Such interfaces augment the physical world by coupling digital information with everyday objects. Ishii and Ullmer claimed that one of the key features of a TUI is not only its function as an input device, but also its ability to provide output directly through the tangible object at hand.

Representational significance is a key term connected to TUIs. Ullmer and Ishii (2000) position the physical form itself as a significant information holder in TUIs. This marks a strong tradition in TUI research that distances TUIs from other input devices by valuing the direct metaphorical value of the physical object used for interaction. For instance, Fishkin (2004) defines a taxonomy for describing and placing tangible interfaces by using embodiment and metaphors in a two-axis diagram. He suggests that a truly tangible interface relies heavily on being embodied and metaphorical.

From TUIs to tangible interaction

Such views on tangible interfaces do not fit entirely with this study's focus on physical interaction driven by SR-RFID. At the current stage of investigating this emerging domain, abstract interaction opportunities hold more interest than metaphors for user interfaces. As a result, in this study I move toward the umbrella term *tangible interaction* that deals with systems relying on embodied interaction, tangible manipulation, physical representation of data and embeddedness in real space (Hornecker & Buur, 2006).

Figure 2.10 shows an example of a system that uses tangible interaction, designed by the author in collaboration with ABB Corporate Research Center. The system allowed the programming of paint robot trajectories by using a spatially tracked tangible interface combined with an augmented reality visualisation (Pettersen, Pretlove, Skourup, Engedal & Løkstad, 2003).

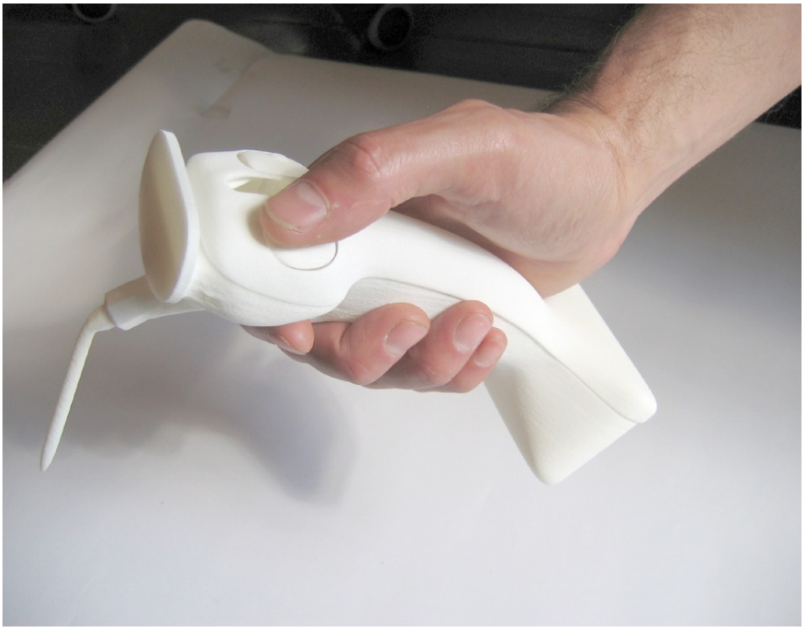

Figure 2.10. A prototype of an interface offering tangible interactions for programming robots created by the author for ABB research.

Tangible interaction helps to turn the predominant perspective in HCI-inflected research on SR-RFID technologies from a focus on the interface to that of interactions themselves and their design. This is in line with Beaudouin-Lafon's (2004) call for HCI research to focus on interactions as opposed to interfaces. The focus on interactions is an important shift in the interdisciplinary field of interaction design that allows us to focus on the un-situated building blocks of interfaces. In my research one of the main motivations, therefore, is designing the means for tangible engagement, not only the important qualities and character of the contextualised interfaces.

By applying the perspective of tangible interaction upon SR-RFID, we narrow down the focus from the array of existing interfaces to the particular interactions the technology offers designers. In doing so, the attention moves toward the design of new types of experiences, as opposed to examining old ones. In the next section I take such views further by addressing SR-RFID as material in designers' design activity.

MATERIALS IN DESIGNING

Having an interaction focus might not be sufficient when investigating design opportunities related to a specific emerging technology. For instance, we can use tangible interaction to describe the interactions made possible with SR-RFID. However, to create tangible interactions, we need to understand how we can shape SR-RFID itself through design. We may do so by applying a material perspective to SR-RFID.

Martinussen and Arnall (2009) offer insights into how we can embed SR-RFID into physical forms. They show how the fields of SR-RFID have a specific form that should be taken into account when designing the physical objects in which we embed RFID. Their work treats SR-RFID more as a material with properties than a technology specifically oriented toward offering interactions. My work follows the same line of thinking, in that it sees SR-RFID as a provider of possible temporal and spatial forms instead of simply possible interactions. I do so by interpreting RFID technology as a potential design material. This reflects the expansion that was done in the thesis after article one (Nordby & Morrison, 2010), which addressed only interactions and not the full form-making potential of SR-RFID.

Seeing SR-RFID as a material allows us to reinterpret it inside a developmental and research design frame targeted ultimately at designers grappling with new and challenging design situations. *Materials,* a wide-ranging term, deals with the subject matter from which something is made. Following this definition, we may view SR-RFID as one of the materials designers use to create a design. This important move enables us to see SR-RFID in terms of the specific function of enabling the making of artefacts.

Defining SR-RFID as material may be seen as counterintuitive when viewed from the perspectives of industrial design and architecture. Here, materials are often associated with matter and directly refer to physical materials like metals, wood and polymers (Doordan, 2003; Fisher, 2004; Manzini, 1986). However, an increasing range of research takes up computational technology as materials (Dearden, 2005; Hallnäs & Redström, 2002; Löwgren, 2001; Mazè & Redström, 2005). The second article referred to herein addresses these perspectives (Nordby, 2010). However, this exegesis text will elaborate further on how material qualities can be investigated in relation to design.

Repertoires or precedence

As my research into RFID technologies focuses on material properties as seen in relation to design, material repertoires for designers are of interest. Schön's perspectives help us to understand how we can support design by way of the notion of *repertoires*. He uses repertoire to describe images, ideas, examples and actions that practitioners draw upon to address the design situation (Schön, 1983). A repertoire of familiar situations offers exemplars for engaging the unfamiliar and the emergent in the act of designing. A repertoire does not directly overlap a new situation but may be used as a frame of reference for the assembly of new solutions to a (design) problem.

The notion of designers' repertoires that appears in both design and in HCI literature allows us to place weight on the activities of designing. We may thus relate Schön's research to interaction design (as well as industrial design) as a practice that may also deal with reflection in action and practitioner knowledge.

In HCI there have been many moves toward gathering knowledge from practice into communicable repertoires usable for design. Most notably in HCI, Alexander and colleagues' pattern languages (1977) have been adopted as a means of expanding interaction among designers' repertoires. In HCI, a pattern is a 'proven solution to a re-occurring design problem' (Borchers, 2000). We can further hierarchically organise these solutions into a pattern language. Pattern languages, originally created for architecture and urban planning, served as a way of communicating well-known solutions to problems.

The notion of pattern languages was later adopted by computer science and most recently as a method in HCI in which they provide a framework for capturing and communicating design knowledge. Löwgren (2007c) moves further in this direction by noting that as interaction design is seen as a creative design discipline, patterns of more inspirational qualities are useful. He introduces the notion of I-patterns or inspirational patterns, which relax the need for a successful solution. Key to these kinds of repertoires is user-related problems at the centre of the organisation.

Pattern languages may be useful, but they are not entirely usable for all kinds of design processes. For instance, pattern languages are ready-made couplings of user problems and solutions. However, in a creative design view, each problem and solution pair can be unique to the situation that needs to be further discovered and interpreted in the very activity of designing. We may say that the coupling of user problems or needs and material opportunities in a situated design practice is not fully realized until the designer perceives it through the act of designing. This is what Dorst points toward by describing design as situated problem solving (2004). In such situated problem solving, prescribed solutions are not sufficient, as the nature of the problem is not fully known outside interventions done through designing.

Repertoires consisting of pairing of material opportunities and user problems are useful as inspiration for new design, but ultimately, the designer must often break up the pairings to see if the resulting user need or material solution, as separated entities, might be used in other couplings. If they are not separated, there is a danger that patterns essentially override the conceptual process of designing, with the result of automating parts of the design activity itself. Although in many cases this might be seen as a beneficial development in moving designing to other, more overarching problems, I suggest that more abstract repertoires, where user problems and technological solutions are separated, are also important in industrial and interaction design.

Material-oriented repertoires

With this in mind, three kinds of repertoires for designing are proposed: 1) user-oriented repertoires referring to user-related knowledge, e.g., a specific user problem or particular user attributes; 2) material-oriented repertoires addressing the materialities of the substances to be made to meet a specific design motivation and 3) solution-oriented repertoires dealing with coupling of material and user-related repertoires.

This study argues that material repertoires for designing are of interest as they are abstract from solutions and not entirely dependent on users, but rather are directed toward the developmental potential for designing. This also concerns the potential for digital form-making. In my research I investigate such repertoires as they are useful as a means to inform processes of designing.

Material affordances for design

To further refine an approach to such repertoires, we can turn to the term *affordance* as conceived by Gibson (1966) and then interpreted in HCI and adapted to activity theory (Bærentsen & Trettvik, 2002). Affordances are a much discussed theme in design and research. Gibson (1977) coined the term and described it, in short, as what the environment offers the animal. This has later been adapted to HCI by Norman (1988) whose adaptation of affordances was oriented toward perceived affordances (Norman, 1999). In this work I follow the original definition of affordances as a relational quality. This is because this research deals with things the world offers that are not placed there with an intention of being perceived. Rather, I address the world's offerings as the potential the world offers specific beings, based on their full capabilities.

When addressing material-oriented repertoires, the concept of affordance is of interest. Affordances are taken up in article 1 (Nordby & Morrison, 2010). In short, Nordby and Morrison propose that design affordances may be used to account for what a material offers designers. This is useful in an approach to material repertoires. By focusing on computational technology as material for design, we can view the relationship between the designer and the material as that which the material affords the designer. We call this relationship one of material affordance for designing. This contrasts with Fisher's (2004) treatment of materials and affordance, which sees it in light of the relationship between users and materials. Design affordances relate to possibilities the environment (materials, for instance) offers the designer. Importantly, this is not the typical approach to affordance in HCI that commonly refers to affordance in relation to end users.

The literature includes research on design material and the relation between a designer and the material; for instance, Schön (1992a) addresses designers' personal interpretations of materials. Such perspectives show that to support a designer building a material repertoire, we need to consider the material's potential for designers. I do so in this work by using affordances as a key term. However, affordance as a term has shortcomings in regard to opportunities related to people's full activities that include mental actions as well as physical ones. As Bærentsen and Trettvik (2002) note, activity is central in Gibson's affordance because it is through an activity the affordance is realised. However, they argue that Gibson's approach to affordance is not sufficient for HCI, as it ignores the socio-cultural dimensions of human activity. We may extend such shortcomings to industrial and interaction design as well.

To meet these shortcomings, Bærentsen and Trettvik (2002), whose work I use extensively in my first article (Nordby & Morrison, 2010), relate affordance to activity theory. This offers a framework for analysing material affordances in relation to designing as our core focus. It is to this theoretical frame that we now turn.

PERSPECTIVES ON ACTIVITY THEORY

Material affordances show us how a material may be viewed differently by different subjects. Due to this, research into general material properties is not sufficient. Rather, we need to develop an understanding of the relationship between the material and the subject. As proposed below, activity theory is useful for such analysis.

Activity theory uses the concept of an activity to analyse a minimal unit of human doing in the world (Kuutti, 1995). Kuutti defines activity theory in this way:

> … Activity Theory is a philosophical and cross-disciplinary framework for studying different forms of human practices as development processes, both individual and social levels interlinked at the same time.
>
> *(Kuutti, 1995, p. 24)*

Activity theory allows us to place an activity, such as designing, at the centre of our analysis. Further, activity theory sees all human activities as mediated through tools or signs (Leont'ev, 1978; Vygotsky, 1962). This makes activity theory very useful for analysing technology as design material, as it inherently provides analytical tools that enable us to see technology and design activity as part of the same system.

In recent years activity theory has seen increased use as shown by Roth and Lee (2007), spanning multiple research domains. For instance, in HCI it has appeared in an increasing number of works, most notably those by Nardi (1996), Kuutti (1995), Kaptelinin and Nardi (2006) and Bødker (1991).

It has been noted that activity theory as a name is slightly problematic because activity theory is not a fully developed theory with a fixed set of rules. Rather it is an expanding body of knowledge in continuous development (Kuutti, 1995). Thus, it is misleading to address activity theory as complete theory. Because activity theory is a developing framework, it is of interest to look into its history. Engeström proposes that we may see three generations of activity theory (Y Engeström, 1996). The first generation refers to Vygotsky's work that takes up mediation of object-oriented actions as a key concept. The second generation deals with Leont'ev's introduction of collective activity. Finally, the third current development of activity theory relates to Engeström's model of interacting activity systems.

Cultural-historical psychology

Activity theory may historically be traced to Soviet cultural-historical psychology and the works of Lev Vygotsky. His academic career lasted a short 10 years, but during this time he produced work still highly influential today. Vygotsky's study centred on children's development and learning, but has also been influential in many different fields.

In the early 1920s, behaviourism was important in psychology. Behaviourism may be described as: 'study of the mind which excludes consciousness as a legitimate category within the science’ (Blunden, 2010, p. 126). Vygotsky found behaviourism problematic and strived to develop a new psychology based on Marx’s and Hegel’s work. Such an approach saw that the mind must be understood in context of people’s conscious interaction with the material world (Blunden, 2010).

Through his work, Vygotsky introduced many important contributions to contemporary soviet physiology. One of the most important, from an activity theoretical perspective, is his concept of mediation. Vygotsky followed Marx’s ideas that human doing in the world was object-oriented and in essence social. Vygotsky (1978) was able to expand this concept by introducing the artefact mediation of actions. This concept saw no direct link between a subject and the object of his or her actions. Instead, the actions were mediated by an intermediate artefact. This artefact could be both physical things, such as tools, and concepts, such as signs or language. By introducing the meditating artefact Vygotsky had created a framework that included human culture as essential in human doing and thinking.

Central to the concept of mediated action was the idea of internalisation. Vygotsky noticed that actions mediated by external signs could often transform over time. For instance a person could suddenly stop using a sign (for instance a map) and as a consequence increase the efficiency of the action (Kaptelinin & Nardi, 2006). Vygotsky showed that this transition happened when the external action was taken over by an internal mental one. Thus, internalisation shows how external culturally mediated actions become internal culturally mediated actions as well (Kaptelinin & Nardi, 2006).

In extension of the internal-external dimension, Vygotsky moved on to address the relation between individual and collective. Vygotsky saw the internal-external and individual-collective as a dynamic relationship. In acquiring a new physiological function, the function first took the shape of an interpsychological phenomenon that gradually transformed into an intrapsychological function during the learning process (Kaptelinin & Nardi, 2006). This process of moving from interpsychological to intrapsychological was formulated as Vygotsky’s 'universal law of psychological development.'

The relation between interpsychological and intrapsychological processes was used to develop the concept of the *zone of proximal development (ZPD)* (Vygotsky, 1978). ZPD is used to measure the skill of a child in the process of maturing. It does so by measuring the child’s problem-solving skills both alone and together with a more capable teacher. The differences between these levels are the zone of proximal development.

By making social culture an essential part of the development of the mind, Vygotsky in many ways reflected the time in which he lived. Vygotsky’s work was in every sense a Marxist approach to psychology, and he can be considered inspired by the Russian revolution (Blunden, 2010). Despite this ideological connection, his work is an important contribution to understanding people's interaction in a social world. The concepts of mediation, internalisation and proximal development have been of fundamental importance to many fields, and are still very much alive today.

For design research, Vygotsky's work may be used to better understand designers' tool-mediated actions. This is important for my analysis of SR-RFID as design material, as it helps us theoretically position the technology as a mediating link between designers and the object of their design processes. This allows us to move from SR-RFID as independent of people and toward seeing SR-RFID as a material mediating design actions.

The emergence of activity theory

Many of Vygotsky's ideas have been adapted into activity theory as we know it today. Still, Vygotsky did not formulate activity theory itself. That was achieved by his colleague Leont'ev, who is commonly referred to as the father of activity theory.

Leont'ev was part of a group collaborating under the supervision of Vygotsky. Their studies were centred on the psychological development of children. However, Leont'ev also had his own ambitious research agenda that resulted in the development of activity theory. Leont'ev's project was to develop an account of the evolution of the mind from primitive forms to advanced human consciousness. To be able to make an account of the evolution of the mind, Leont'ev took up activity as an analytical tool. This latter development made up the foundation of activity theory. Kaptelinin and Nardi (2006) note that we may see that Leont'ev's project produced two major research outcomes: the development of activity as an analytical tool, which evolved into activity theory, and an account of the evolution of the mind.

Leont'ev was critical of Vygotsky's focus on actions. He maintained that the study of an individual's actions did not account for why the action was performed. This positioned people's actions as insufficient in understanding people's interactions in the world. Also, Vygotsky's (1978) approach did not integrate social relations or how other people influenced an activity. Leont'ev used the concept of the collective activity to bridge this gap.

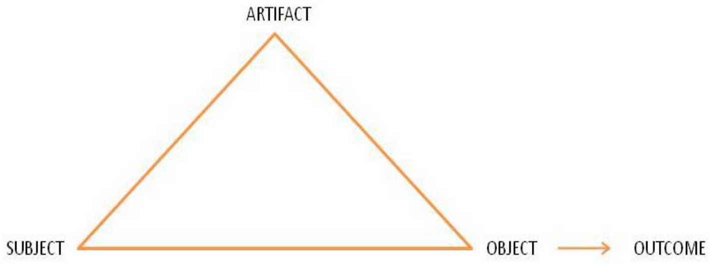

Figure 2.11. Leont’ev’s activity model is based on a subject transforming an object into an outcome. The activity is mediated by an artefact.

Leont’ev proposed that an activity is used as a unit for analysing human cognition. Further, Leont’ev envisioned activity as a collective concept influenced by both the subject(s) doing the activity and the society in which the activity is performed. An activity consists of a subject transforming an object into an outcome (Leont'ev, 1978).The subject may be seen as a person or people doing the activity. The object signifies a situation or thing that people may see as having the potential to fulfil a need. During the course of the activity, the object is transformed into an outcome that may or may not meet the need of the subject. People may be simultaneously engaged in multiple activities. However, each activity may be separated from the others by its object (Leont'ev, 1978). Leont’ev never provided a graphical version of his system. However, Figure 2.11 shows the by-now classic triangle visualisation as developed by Engeström (1987).

The relationship between the object and the subject is mediated by artefacts in the form of tools or signs. The tools or signs are what the subject interacts with to transform the object. These shape users’ perception and transformation of the object. The *tool* may be seen as ‘an objectified human capacity’ (Blunden, 2010, p. 175).

Activity	-	Motives
Actions	-	Goals
Operations	-	Conditions

Figure 2.12. Leont’ev’s three levels of activity

An activity can be divided into three levels according to Leont'ev (1978): activity, actions and operations, as shown in Figure 2.12. The top level is the activity directed toward motives. The motive gives the activity meaning for the subject. Hence, motives are a necessity for an activity to exist. The activity is achieved by a sequence of conscious actions directed by goals. The actions are individually performed but always connected to various activities. Further, the actions are carried out by a set of operations. The operations are automatically performed and steered by conditions enabling and limiting the operations.

Activities, actions and operations are not fixed entities. A key concept of activity theory holds that the elements of the different levels of activity can move. An activity losing its motive may become an action. Further, an action can move up to become an activity and so forth.

Together, the concepts introduced by Leont'ev make up a powerful analytical framework that may be applied for analysing materials related to industrial and interaction design. Leont'ev's work allows us to see materials as embedded in design praxis when mediating design activity. This relationship may further be understood according to activities, actions and operations.

Activity theory does not end with Leont'ev. Multiple people have expanded upon Leont'ev's work, both extending the general framework of activity theory itself and refurbishing it for different fields of research.

Expanding the activity model

Activity theory continued its development in the late 1980s in the West. Here, an important development was led by Engeström (1987), who systematised Leont'ev's model even further and introduced new elements of the basic structure of an activity. Engeström is the director of the Center for Research on Activity, Development and Learning (CRADLE, 2011). He has been instrumental in the development of what is often called Scandinavian Activity Theory. In particular his work is oriented toward analysing collaborative work and processes of learning.

Engeström illustrated Leont'ev's structure of an activity into a triangle diagram inspired by Vygotsky's model of mediation of actions. However, he expanded the triangular model to include community mediated by collaboration and rules. This structure has been used extensively in different communities as a way of analysing collaborative work processes.

In Engeström and colleagues' work (2009), which he addresses as part of the third generation of activity theory, the focus is expanded to deal not only with an individual's activities, but with larger spaces of intersecting activities. This view sees two intersecting activity systems as the minimal unit of analysis. By seeing multiple activities as the minimal context of analysis, Engeström seeks to develop a model that is better equipped to deal with issues related to groups of people oriented toward the same goals, but which are ultimately part of separate activities.

Engeström has developed several important additions to activity theory in his work. Of these the concept of *expansive learning* has received much attention (Y Engeström, 1987). Expansive learning proposes that we see learning as an expansive social process moving from abstract to concrete through a series of steps. Such learning is initiated as the result of disturbances that raise questions about the current practice. These questions lead the subject(s) through a process resulting in a new practice. Thus expansive learning is seen as a process of knowledge production oriented toward changing social activities.

Expansive learning is relevant for design, as it describes learning as a process of intervention and creativity. This is also taken up by Engeström by introducing the concept of expansive design. Expansive designing views interaction design in the context of producing new collective activities as opposed to mere artefacts. Engeström (2006) notes that expansive learning and expansive designing are two sides of the same coin.

Engeström's work is important and somewhat useful for this research. Yet, there are fundamental issues in his approach that do not conform to the direction chosen for this thesis. Kaptelinin (2005) summarises the differences between Engeström's and Leont'ev's approach to activity theory. In short, he states that Engeström's work is oriented toward analysing collaborative work and organisational change. Leont'ev, on the other hand, was predominantly oriented toward an individual's psychology. Given that my work is oriented toward understanding materials in industrial and interaction designers' design activities and not the role of materials as a shared tool in a multidisciplinary cooperative design activity, my approach seems better suited for Leont'ev's original view.

However, this is not to say Leont'ev's approach is without problems for design-oriented analysis. One of these problems concerns the relation between objects and motives in Leont'ev's activity theory.

Separation of objects and motives

In using activity theory to investigate designing, attention has been drawn toward the concept of motive as it is specifically used in activity theory.[4] The rationale for this is that the concept of motives seems to capture central

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[4] This must not be confused with motivation as it has been pursued in other domains, for instance through the works of Maslow (1943). Although related, activity theory's notion of motives is an integrated part of a larger structure enabling the analysis of human doing.

aspects of designing. I address the role of motives in my second article (Nordby, 2010); in addition, motives receive extensive description in the results section of this thesis.

Briefly, Leont'ev notes that transforming the object into an outcome is what motivates the activity. This transformation is driven by motive(s) directing the activity. The motive may be seen as the reason the activity is carried out. Leont'ev (1978) describes the motive as a need meeting its object. The motives may, as such, be seen as placed in tension between the objective object and the subjective need. For designers, this is of particular interest as it ties people's agency to both personal subjective needs and the culture people live in. In this way, the concept of motive allows us to see activities as driven by the combination of social culture and personal needs.

The relation between the motive and the object is somewhat confusing in Leont'ev's original text. There he describes the object of an activity as its true motive (Leont'ev, 1978). Kaptelinin describes this as problematic, as it renders the object and the true motive as identical propositions (Kaptelinin, 2005). Further, Kaptelinin argues there is confusion as to whether a motive directs an activity or just influences it. This is due to Leont'ev's mentioning that an activity's motive "arouses" an action, but the actions are in reality directed toward a goal (Leont'ev, 1978). Kaptelinin moves on to suggest a separation of the motive and object as a way forward. He proposes the relations between motives and objects may be described as follows:

> *(a) there is only one object of activity, no matter how many motives are involved, (b) the object of activity is cooperatively determined by all effective motives, and (c) the object of activity is both motivating and directing the activity.*
>
> *(Kaptelinin, 2005, p. 17)*

By separating the object and motive, Kaptelinin presents a framework of activity that is very useful in the analysis of design activities. Such activities lie in the tension of other people's activities and concern objects of great uncertainty. One way of interpreting this uncertainty is that the design activity is directed by several conflicting motives. This makes the object of designing always poly-motivated. In such a sense Kaptelinin's model makes great sense when analysing material use in designing.

Design in activity theory

Much of the current research using activity theory has been associated with learning (Y. Engeström, 1999; Roth & Lee, 2007) and HCI (Bødker, 1991; Kuutti, 1995). However, strong links also exist between design perspectives and activity theory. This is often pursued in two directions: investigating designing as a collaborative activity focusing on the shared development of new solutions (Y Engeström, 2006; Hyysalo, 2002, 2005) and the use of activity theory to analyse user behaviour as part of user-oriented design approaches (Blumenthal, 1995; Desai, 2008).

Many works suggest activity theory as a good method for supplementing a designer's toolbox related to the study of users in context of work. However, some have criticised this approach. Collins and colleagues (2002) reported difficulties in communicating the concepts of activity theory in practical design situations. Citing this example, Rogers (2004), in an extensive review of theory in HCI, concludes that activity theory needs specialists' knowledge to be useful in design processes.

The move toward using activity theory to investigate collaborative designing is laudable. Yet, few works deal directly with the specific activities of industrial and interaction designers as subjects. This is not surprising given the tradition of focusing on collaborative and user-participatory designing, particularly in Scandinavian countries where activity theory has strong roots. In fact, the subjective agency that designers bring to the design process is noted as a potential danger in product development.

Engeström (2006) addresses this in viewing the design process as potentially self-absorbed and the object of design becoming an object of affection. This may lead to the belief that the design will have the same meaning for the eventual user as it has for the designer. Bødker (2006) cites a concern for designers' possible lack of serious concern about users. Bødker notes the danger that designers do not balance the focus on experience with usability.

I would agree that an imbalance of usability and a focus on experience is undesirable in designing. Still, it is important to be aware that subjective reflections represent an integral part of all design activity and, in particular, the activities of industrial and interaction designers. Designers as acting subjects are important when considering the use of SR-RFID as material in design. This is because materials must be seen in relation to the full activity in which they are used and not as independent artefacts.

Thus, an activity theory-informed analysis of materials in design may help us understand materials as mediating design activity. However, as Schön found (Schön, 1992a), materials are not only external instruments or tools in design activity, but are also interpreted into designers' internalised repertoires. Thus, an analysis of materials in collective processes is not sufficient to understand materials in designing. It is not just an artefact mediated between people, but one that is internalised by individual designers.

It is therefore important to take note of how materials are mediating design seen as a collective multidisciplinary activity and also how industrial and interaction designers, as subjects, interpret materials in their activity. Both approaches hold the design activity as inherently social. However, the latter approach allows us to focus on industrial and interaction designers' subjective perspectives that may later be placed in a wider context of collaborative design.

In this approach, industrial and interaction design practitioners' activity is seen as co-existing with the overarching design activity shared by many participants. In this cooperation, I suggest the design practitioner, due to his or her particular approaches to the design situation, offers important contributions to the overarching design process. This work directs attention to how to support the industrial and interaction design practitioner’s material-oriented activity so as to strengthen his or her contribution to the shared design process.

This shows that SR-RFID technology as material may be seen from different perspectives, for instance as a mediator of a multidisciplinary process or as a mediator of industrial and interaction designers’ activity. Although connected, these two perspectives of SR-RFID are different, and might be governed by different motives, goals and conditions.

Linking individual and collective activities

Stetsenko (2005) discusses the importance of the flow between individual and collective activities. She addresses these as co-evolving and, as such, inherently bound to each other. This is crucial for design practices and allows for a theoretical understanding of how individuals function in collective activities. Inside activity theory, such analysis seems underplayed, as many efforts are focused on shared approaches alone.

For instance, Bertelsen (2000) takes up designing as a heteropraxial activity, stating that it involves multiple participants with different backgrounds. Bødker (1998) poses a similar view, seeing designing as a cooperative practice and defining design as the creation of something new. By doing so, she embraces a common usage of the term that is broader than the context of the traditions related to design practitioners. Hyysalo (2002) uses a tighter focus by addressing product design as it can be analysed through activity theory. However, Hyysalo’s analysis is also directed toward cooperative work as the dominant interest.

Granted, designing can be seen as, and mostly is, a shared activity. However, the dynamics between the subjective agency and the cooperative activity, as shown by Stetsenko (2005), needs more attention in activity theory approaches to designing. This is because the industrial and interaction design practitioner has particular intentions, interests and skills in the shared process of designing that need to be supported in their own right.

Orienting attention toward how SR-RFID as materials is taken up by industrial and interaction designers in their design activity allows us to steer our focus toward one aspect of collective designing that has not seen much attention in activity theory. This is important, as individual agency is necessary to creative development. More so, personal expression, so important to experience-oriented designing, almost certainly has its origin in each designer. Thus, analysing materials in relation to designers' activity helps us understand how materials are not only tools in the production of artefacts, but may also support designers' creative development of artefacts oriented toward mediating people's future experiences.

Critiques of activity theory

Critiques have been raised about activity theory. For instance, Josephs argues that activity theory overlooks the subjectivity of individuals when considering motives as reflecting societal needs (Josephs, 1996). Also, Blunden (2009) critiques activity theory's notion of collective motivation. He argues that such a concept is inaccurate difficult as it describes a society that is made up of a set of objective needs. Such a view might have been appropriate in uniform communities, but are far less so considering how we see modern Western societies. Blunden tries to resolve this project by offering project as a more relevant concept substituting activity.

Other criticism claims that activity theory is moving into a rigid structure void for the rich dialectics of the original offering of Vygotsky (Langemeyer & Roth, 2006). This criticism is directed in particular toward the works of Engeström, whose triangular diagram has been influential in the activity theory community. (It may also be transferred to the use of triangles to describe the works of Leont'ev.) Langemeyer and Roth's most fundamental problem with Engeström's approach is the loss of dialectic understanding of the societal intra- and inter-individual dimensions of practice.

Backhurst (2009), having a philosophical perspective, finds that activity theory is developed in two strands. The first deals with using activity as a basic unit to understand the mind. The second deals with analysing peoples' activities with the purpose of understanding and facilitating human practice. Regarding the first generation of activity theory, he wonders if there is any need for the concept of activity at all. He questions whether activity is so general a concept that it is devoid of meaning.

Regarding the second strand of activity theory, he points to a number of weaknesses. For instance, he notes that activity theory may be well positioned to help the understanding of particular kinds of well-defined activities. However, other activities, such as writing music, might be harder to understand using activity theory. Bakhurst also discusses problems with the rigid structure of the second strand of activity theory. He writes that: 'we must be very cautious about given, stable, structural representations where you aspire to understand dynamism, flux, reflexivity, and transformation.' (Bakhurst, 2009, p. 207). In general, Bakhurst argues that because activity theory is not a stable body of work, one should be cautious in taking its concepts for granted when applying it in research.

Despite the criticism of activity theory, I have found it useful in this work. It offers a large set of concepts that seems to capture central aspects of experience-centred design. Also, it helps structure these concepts in ways that I have found useful for analysing processes of research by design. In effect, we may see a design activity as a social project in which the notion of collective motive makes a lot of sense because it manages to capture the dichotomy of personal and societal (including users') needs that in effect direct design activity. The fact that activity theory manages to bridge these usually separate dimensions of designing into one system makes it very interesting for design research, as it helps us bring order to core problems in design and design research. However, applying it has not been easy given the several different perspectives held inside the works within activity theory and the lack of direct examples of use within material-oriented analysis.

SUMMARY

This thesis tries to apply activity theory to analyse the use of SR-RFID technology inside industrial and interaction design. However, this attempt is not an easy one, as activity theory may not be considered *one* unified theory, but rather a continuous expanding set of approaches. Due to this, it has been important for this thesis to select certain aspects of activity theory that seem fitting for the analysis of technology from an interaction and industrial design perspective.

My research views Leont'ev's work as particularly suitable for such analysis. In addition I pay particular attention to the works of Kaptelinin and Stetsenko. The first allows us to better understand the relationship between the object and multiple motives. This is an issue seen as central to the analysis of design activity. The second helps us see collective and individual activities as inherently bound together. As such, a designer's personal contribution and agency may be seen as part of a collective process of designing and not directly steered by it.

In Chapter 4 I will use activity theory further to give a theoretical account of the role of materials in designing. There, I use activity theory to re-conceptualise SR-RFID as a material for design activity. Further, activity theory is used to analyse the presented material and place it in a wider context of analysing computational technologies for design. Finally, materials are analysed in relation to motives, which in this thesis is considered an important aspect of material-oriented analysis.

My approach is an expansion of current works in activity theory. For instance, in Kaptelinin and Nardi’s book *Acting with Technology* (2006) technology is seen from the perspective of what it means for users. There activity theory is used as an extension of HCI’s strive to understand users interacting with technology. My study takes up the perspective of what technology means as material for designers creating such interactions. Thus, the table is turned, placing focus on creative construction of artefacts for users. I argue that these two approaches are not contradictions, but are complementary. Understanding people’s use of technology in their everyday lives is only half the way to good designs. Designers also need knowledge in how to transform materials into user-oriented artefacts.

Chapter 3: Main approaches and methods

This thesis focuses on supporting the use of SR-RFID technology in designing. Consequently, the research process has focused on developing new understanding and tools that may help designers' creative processes using SR-RFID. To be able to develop such knowledge, this study has drawn on recent developments that positions design processes as an integrated part of design research. This has been carried out through discussion, evaluation and designing in a collaborative design research project and through publishing the work to an online community of designers. In addition, the results are published by way of peer review to a wider range of researchers for further evaluation.

The study takes a practice-based approach and engages with technology as materials in design. In doing so the study may be seen as having two objects: investigating SR-RFID and developing a theoretical approach to SR-RFID as material. Such an approach sets up a reflexive relationship between research and design methods that were shaped during the design and analytical phases of the project.

Activity theory was used extensively as a tool that helped connect the ongoing exploration of technology with the development of tools supporting the design activity. However, even though the theoretical study was important in this research, the design process itself was instrumental in developing a framework that allowed analysing technology as materials. This in itself was an intersecting activity system in which each research object simultaneously served as a tool in each other's process. The intersecting activities provided both processes with much-needed momentum, where design development spurred theory construction and theory construction motivated design development.

This chapter is split into three main sections. The first describes a macro view on the approaches used in this project. This is followed by a description of specific methods. Finally, a short refection on how the methods and approaches have progressed is presented.

TECHNOLOGY-DRIVEN RESEARCH BY DESIGN

Initial surveys of research approaches to SR-RFID in HCI and ubiquitous computing revealed an emphasis on lab experiments, user studies and presentations of novel interaction techniques. Although such work is useful, few of these studies showed research aimed toward supporting creative development within industrial and interaction design practices. To move toward the latter perspective, I investigate SR-RFID from a design perspective by applying a process of research by design. In such a process we investigate SR-RFID by engaging with it through designing. This allows us to understand the technology through its use as material in processes of design. Such a method permits a dual perspective of SR-RFID technology, partly as material mediating design and partly as research object. Thus, observations of SR-RFID may guide further design processes, and design processes may lead to new observations of SR-RFID.

Research by design also added generative aspects to our analysis of SR-RFID technology. We did not seek to merely explore SR-RFID, but to re-configure it for designing. Thus, the observations and reflections on SR-RFID in design are also used to generate new conceptualisations of SR-RFID itself. In such a process, design and research are integrated into a single process of research by design. Zimmerman (2007) and Wolf et al. (2006) can be cited as examples of applying design processes in research on HCI problems. However, these examples address design methods as an addition to HCI, yet not from within the creative design disciplines themselves.

Sevaldson proposes science and technology studies driven by research by design as one possible form of design research (2010). He describes the approach, saying: ‘New design practices are developed as a response to new technologies and knowledge.' In this approach design researchers bridge concepts or technologies from other fields of research to the design practices. Sevaldson lists the following advantages and disadvantages of such research:

> Advantages: Systematising this perspective might create a larger awareness toward implementation of new technologies and knowledge into design. Big advantage in doing this more actively than just by assimilation over time. Large innovation potential.
>
> Disadvantages: This approach might become narrow in its scope. Technology push is sometimes dominating on the costs of theorising. Results are often shown through innovations rather than generalised knowledge.
>
> *(Sevaldson, 2010, p. 27)*

Binder and Redström (2006) propose that design research may be steered by way of a process of ‘exemplary design research driven by programme, experiment and intervention.' In such a process, a research program serves as a frame from where design experiments are carried out. The goal of such a process is to show the possibilities of the design programme and to propose changes to design practice. Binder and Redström cite projects related to the MIT Media Lab and the various projects steered by the Interactive Institute as examples of such research. Such a view may be transferred to the Touch project, which offers a frame and foundation for the design experiments carried out through the process of research by design.

There is no detailed account of how to perform a process of technology-driven research by design. However, one aspect of such a process is that it is driven by design interventions that again use design methodology. Thus the entire process is driven by engaging with the subject matter to develop it through design. Therefore, the design process of industrial and interaction designers may be seen as one of the methods used to make sense of the research problem. Central to such an approach is a dialectical relation between design and analysis.

REFLEXIVE INTERPRETATION IN RESEARCHING SR-RFID

The research conducted in this study may be seen as a research-driven mode of designing oriented toward meaning-making and tool creation. In a process of research by design, a continuous interpretation of the ongoing results is necessary. Nelson and Stolterman (2003) argue that interpretation is an essential part of the design process. However, they argue that the interpretation in design cannot be done without understanding the directions of the interpretations. In this thesis project, the processes of interpreting the ongoing results from the design research process was directed by the need to understand and transform SR-RFID into a material for design.

However, the interpretation of SR-RFID as material is not a passive process. Also central to the process of research by design is reflection in (and on) an action as described by Schön (1983). Here designers actively engage with a design problem by doing experiments. Through reflections done during and after these experiments, the designer may reshape his or her understanding of the design situation.

The reflexive and interpretative process may call for what Mörtberg and colleagues (2010) term a ‘methodological sensibility’ in design research. Such sensibility directs attention to what the researchers are ‘hearing, listening, seeing and understanding during their field work or design work.' Such a sensibility is important in processes of research by design, which in essence are processes of exploration as well as experimentation. Such a methodological sensibility has been important in a project which has seen many changes in approach as a result of the ongoing design processes.

In the project the meeting of design interventions and research analysis has resulted in a process of dynamic development. The findings from the design focus have changed the research focus, and changes in research focus have resulted in changes in the design focus. We may see this relationship as a process of hermeneutic design interpretation. In hermeneutics the meaning of a part can be understood only in relation to a whole (Alvesson & Skjoldberg, 2000). However, the whole is the sum of its parts and can only be understood through these. This is seen as a hermeneutic circle. Hermeneutics solves this problem by addressing the circles as a spiral. In such a move, the shifting focus between the two oppositions will gradually develop a better understanding of both ends (Alvesson & Skjoldberg, 2000).

THE COLLABORATING DESIGN RESEARCHERS

In the Touch project, one of the core goals was the extended collaboration and communication with the professional practices as well as research communities. To achieve a cultural foundation in professional practice, it was important that the design team had not only research background, but also had practiced as professional designers for a considerable time. The Touch project included a wide range of both design and research talent that covered many fields, including industrial, interaction, media and graphic design practitioners. These were supplemented with social researchers and software engineers.

Three people were particularly instrumental in the design work directly related to this thesis: Timo Arnall, Stian Børresen and the author. All three have extensive professional experience. The project leader of the Touch project, Timo Arnall, who was central to the development of the demonstrators I present here, has extensive background in graphic design, interaction design and movie and Web development. Stian Børresen has vast experience in advanced software development and a strong background of work on emerging technologies.

The professional experiences of the author are also considered important for this thesis as the research analysis and carrying out of design was an interwoven process. Thus my professional experiences as a designer also informed the analytical process. I have worked as a professional industrial and interaction designer for more than 10 years, both as part of research facilities and institutions and start-ups and as a sole designer. I hold a master in industrial design with specialisation in interaction design from the Umeå Institute of Design in Sweden (Umeå Institute of Design, 2011). Further, I have extensive experience in the development of new conceptual designs using new technology and high-end visualisation tools. I argue that the hands-on experience working with new technologies in design practice have been important to the development, application and linking of research and design methods in this thesis and its analysis of SR-RFID.

DESIGN RESEARCH METHODS

Seven main methods were selected and used in analysing SR-RFID by design. These were: 1) Collaborative design, 2) Self and group reflection, 3) Deconstructing SR-RFID, 4) Creating models, 5) Documentations of SR-RFID-related phenomena, 6) Visual tools for analysis and 7) Creating prototypes. I now present each of these briefly.

1. Collaborative design

The process of research by design has been informed by both first- and second-person perspectives (Sevaldson, 2010). The first-person perspective deals with the practicing designer, while the second-person perspective deals with collaborations.

By participating in the design collaboration, I got a firsthand perspective on the design process. In doing so I got an inside view on how SR-RFID was understood by the collaborating group. I was also able to insert findings from the analytical work into the planning and carrying out of the design briefs.

The most important collaboration happened during informal meetings, or workshops, where the designers and engineers could discuss and elaborate upon the various concepts and ideas we encountered in the project. In such meetings, the participants made notes and sketches, ones that were used widely during the collaboration. In addition, the collaborative processes were constructed as ad-hoc meetings to discuss, elaborate on and evaluate individual contributions; they were seldom carried out over extensive periods. Communications between the participants were often mediated through mail that enabled us to discuss different solutions and to share production material. The collaborations were also organised around a series of design briefs that were formed by the design group. These were carried out over various time spans depending on the complexity of the design goals. Most of the design processes were completed in two to four weeks.

Sketches, images, notes and renderings were gathered from the processes of collaborative design. The results of the process were discussed in collaboration and led to the formation of new plans for further designing.

2. Self- and group reflection

During the design processes, attention was sometimes given to how SR-RFID was used in the design process. These reflections were carried out by the author or in collaborative discussions inside the group of designers. We may see this in relation to breakdown and focus shifts (Bødker, 1996). Breakdowns refer to work being interrupted by something, and focus shifts refer to user-initiated perspective changes on the work. The focus shifts and breakdowns accounted for the continuous change between the design object of solving a design brief and the research object of understanding and developing SR-RFID. An example of a breakdown in the design process is, for instance, when a prototype did not behave as expected. A focus shift could happen when there was discussion of an application in the group, and attention was shifted to what the applications told us about SR-RFID.

3. Deconstructing SR-RFID

In the first attempts to investigate the technology, we mapped full interactions on RFID-enabled mobile phones. This included diagramming various input methods in addition to SR-RFID and the various outputs related to mobile phones. However, the process proved ineffective given the very large number of variables.

Later in the study, when the near-fields had been identified as a frame for investigation, we limited our attention to near-field-only primitives. The attention also shifted from an orientation on input primitives to form primitives. *Input primitives* may be seen as the small pieces of interaction a user may perform (Rohs & Zweifel, 2005). For instance, this may concern moving a phone into a field. In contrast, the form primitive is material-centric and focuses on the different forms a material can provide that may eventually lead to the mediation of user experiences (Nordby, 2010).

The shift of focus underlines our material approach to the technology. Where the term interaction primitives mostly refers to dynamic properties of a material, form primitives acknowledge that the material consists of both dynamic and static variables, which may be used to shape the final artefact. Thus the form primitives expand our focus to the entire range of material properties, and not just the ones related to interactions.

4. Creating models

Creating models has been important in this study as a way of mapping different aspects of SR-RFID. Such models have been used extensively in HCI research, for instance in mapping interactions on touch screens (W. Buxton, 1990) or interface widgets (Chen, 1993). The models were created by a process of extensive sketching and diagramming of the dynamic relations between different properties of SR-RFID. One example of such diagramming is the RFID-driven tap and hold model that shows how two intersecting fields may be interpreted in different ways (Nordby & Morrison, 2010). Other examples are the descriptions of multi- and single-field input techniques (Nordby, 2011; Nordby & Morrison, 2010).

5. Documentation of SR-RFID-related phenomena

By tackling design problems, it was possible that novel ways of understanding SR-RFID could appear throughout the design process. Thus, the data collected comprised a range of descriptions of interaction techniques and notes related to SR-RFID-related observations. The data from the design processes were collected in various formats, for instance, pictures, sketches, CAD models and the prototypes themselves. Multiple findings concerned behaviour rather than fixed artefacts. These were drawn in simple models or written down. We maintained this material in digital format and shared it among the participants.

6. Visual tools for analysis

Although the overarching research process was a collaborative one, it is important to note that each participant did significant individual work as part of the cooperation. During the design processes, the individual designers used many traditional design techniques. This involved sketching, 3D Computer Aided Design (CAD), video and simple paper prototypes.

In design, sketching may be considered a way of thinking as well as a way of externalising ideas (Fallman, 2003). Sketches were used extensively throughout the entire project. They were of various qualities and were performed by the whole team. Most were carried out on paper and some of these were scanned for future reference. Some design works were carried out in CAD software, such as 3D Studio MAX (Figure 15). This allowed both the generation of renderings and physical output through our rapid prototyping systems. For instance, the Orooni table used CAD techniques for both sketching and prototyping (Figure 3.1).

Video proved central to the Touch project in communicating the productions to a wider online audience. These often consisted of live video with digital elements incorporated into it. This enabled efficient visualisations of various services (see nearfield.org for examples). Arnall and Martinussen (2010), fellow researchers in the Touch project, present how such videos may be used in exploring SR-RFID. The videos helped us understand temporal characteristics of SR-RFID interaction without always needing to go through technical prototypes.

7. Creating prototypes

The development of prototypes was used as a method to direct the investigation of SR-RFID. Lim et al. (2008, p. 3) highlight the following aspects of prototypes:

> 1) prototypes are for traversing a design space, leading to the creation of meaningful knowledge about the final design as envisioned in the process of design, and
> 2) prototypes are purposefully formed manifestations of design ideas.

Developed in collaboration with a software engineer, the prototypes enabled us to test and experiment with RFID interaction as an important addition to our design sketches.

Figure 3.1. Examples of 3D work made as part of the study. The top images show renderings of a tag design for the Thingio concept (design by Nordby and Arnall). The lower image shows 3D characters that were printed with a sintering machine for the Orooni table demonstrator (designed and rendered by Nordby).

Each prototype was the result of a design process driven by a design brief, which were created for two purposes. One of the purposes was to develop interesting examples of SR-RFID use. The second goal was to test, develop and reflect upon the ongoing exploration of SR-RFID. Fallman (2003) describes how prototypes may be considered a form of sketching in HCI. An important aspect of such a view is that the making of prototypes also may be considered a form of thinking through sketching. In the Touch project the prototyping was used for such reflexive purposes, and the focus was not on the actual prototypes produced but on the knowledge gained from producing them.

We developed four approaches to prototypes in which each was oriented toward different aspects of designing with SR-RFID. The four prototype approaches were NFC hyper linking, interactive table interface, java-driven NFC phone prototypes and platform development. Each of these prototyping approaches may be considered a method aimed toward investigating different aspects of SR-RFID in designing. The following offers brief descriptions of several of the prototypes produced in the Touch project.

NFC hyper linking

Our first set of prototypes was used to map the present attributes and limitations of the NFC-enabled phones as they were presented to end-users. By engaging with the phones and software directly, we sought to gain a wider understanding of what NFC offered at the time. Our initial experimentation used the Nokia 6131 NFC phone, which, at the time of the experiments, was the most current NFC-enabled model available in Europe. We used the software included on the phone to create simple examples of NFC functionality (Figure 3.2). These examples included embedding hyperlinks and other small data sets on the tags.

The experimentation revealed that user feedback in relation to the intersection of the radio fields in NFC was only indirectly conveyed. Users only had an indication of being inside a field when a tag was fully read, not while it was being read. This was not a problem using the standard tags provided by Nokia, but when using tags with more storage space, which resulted in much longer reading time, there seemed to be a great deal of ambiguity in understanding when the fields overlapped.

This finding directed our attention toward the phenomenon in relation to field intersections and how they could be used in designing better feedback. At this point, it is important to note that our interest did not directly concern potential usability problems. Rather, the problems related to understanding when the fields intersected helped us to uncover an area of NFC we had previously overlooked.

Interactive table interface

The second demonstrator type concerned a multi-user tabletop interface. The development of this prototype was used to investigate two aspects of SR-RFID design. First, it allowed us to investigate SR-RFID technology outside the limitations imposed on us by the inbuilt software in phones. In doing so, we could explore the feel of near-field-driven interaction in optimal conditions. Second, it allowed us to investigate and design for the use of multiple simultaneous RFID readers and tags.

Figure 3.2. The Touch project created a small demo of a smart poster using the inbuilt functionality of the NFC phone. Although simple, it provides hands-on experience of the current offerings in RFID-driven phone interactions.

The prototype was created for use at an exhibition at a national science fair in Oslo. The setup explored the use of multiple readers and multiple tags where a user could move RFID-enabled physical characters on a table with interaction hotspots (Figures 3.3 and 3.4). The table consisted of nine near-field readers connected via USB to a Mac-minicomputer embedded in the table. Interacting with the readers were 10 physical characters with embedded RFID tags. When a character was placed on a reader, a 3D version of the character appeared on a screen and played an animation related to the hotspot. The virtual character was present as long as the physical character was present over the reader, and it disappeared when the physical character was removed.

This table is in the tradition of tangible user interfaces, which often use the placing of objects as an interaction technique (Mattsson, 2007). To enable such interaction, the system interpreted when a character was placed upon a field by monitoring the data streams from the RFID readers. The RFID readers streamed data continuously when a tag was inside a field, constantly repeating the data. We used the first incoming data to indicate an ‘in’ event and the end of data streaming to indicate an ‘out’ event. The same approach is used in multiple RFID systems related to ubiquitous and tangible computing (Grønbæk et al., 2003; Klemmer et al., 2004; Römer et al., 2004).

Placing interaction technique as implemented by SR-RFID proved useful in relation to the table experience, and it thereby raised questions as to whether the interaction mechanism could be implemented in the NFC phones and, if so, how such functionality could be combined with other interaction techniques.

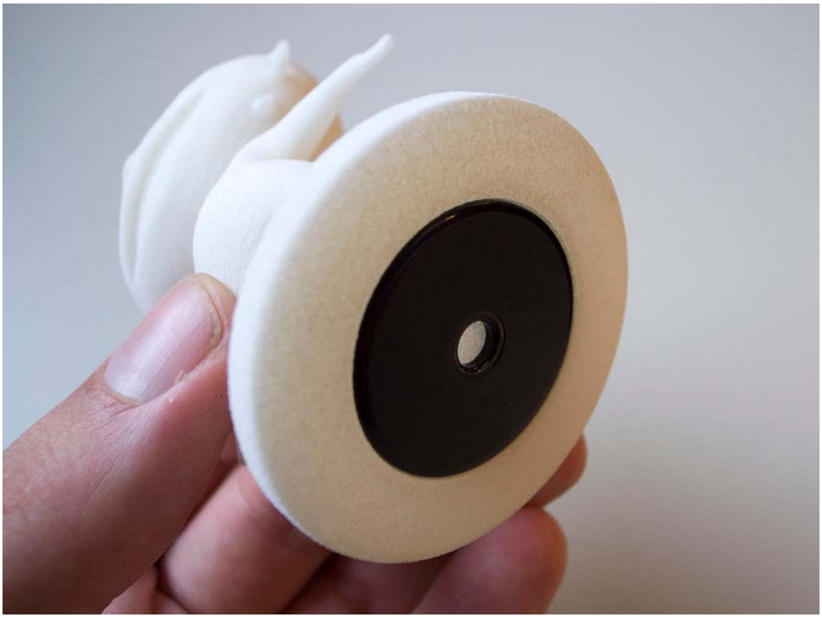

Figure 3.3. The Orooni table was driven by small 3D printed characters with RFID ships embedded in them as shown in this image.

Figure 3.4. Orooni table: An RFID reader is mounted under each of the 10 circles in the table. Moving a character over the circle would trigger a continuous animated event on the screen.

Custom NFC phone prototypes

The next prototype sessions focused on taking the interaction mechanisms from the previous prototype to the mobile phone so as to explore them further (Figure 3.5). The prototypes were used to better understand the different aspects of SR-RFID that had emerged in the study. Several prototypes were designed and implemented and reflected upon. The creation of these prototypes allowed us to test, develop and reflect upon SR-RFID as material.

We collaboratively chose five design cases to develop demonstrators. The applications comprised an exhibition information system for Thinglink (Thinglink, 2011) (a small, Web-based company dealing with data attached to things): an egg timer, an alarm clock, an office answering machine and a system for associating data between tags. We developed the three applications using JavaME and a proprietary NFC library from Nokia.

1) Thinglink allows people to create online portfolios that relate to physical things. Each physical thing gets a unique code, which can be used to access the content in a Web browser. Our prototype allowed users to engage with the digital content by using an RFID-enabled mobile phone to scan RFID tags attached to a number of things registered in Thinglink. The Thinglink interface had two interactional techniques associated with one tag: a) by selecting the tag, an information page directly appeared on the phone's display with no extra key presses, and b) on holding the phone toward the tag it would, after a short pause, use the phone to play an audio stream.

2) The second application dealt with packaging design enhanced by NFC (Figure 3.5). We placed an RFID tag inside a redesigned egg carton. The tag added an egg boiling timer functionality that was accessed only through tangible interaction using the phone. It had three aspects: a) the egg timer started a countdown to an alarm while the phone was resting over the tag; b) if the phone was removed before the time limit, the application stopped and c) removing the phone after the alarm rang would end the ringing.

3) An alarm clock application was designed to be attached to a bedside table (Figure 3.6). Rather than using the RFID tag to set the internal alarm clock on the phone, our application allowed further functionality accessed through tangible interaction. This operated as follows: a) the alarm clock was set and activated by resting the phone on the tag; b) upon removing the phone, the application would be deactivated after 10 seconds; c) during the shutdown period, the application showed an interface allowing the setting of the default alarm time, and pressing any key aborted application shutdown; d) when the alarm rang, picking up the phone would end the ringing and e) placing the phone back on the tag after ringing initiated a snooze function.

Figure 3.5. The egg carton allows access to a timer application when the phone hovers over it.

Figure 3.6. The alarm clock with an RFID-enabled phone ‘pillow.'

4) The office answering machine consisted of two RFID tags attached to a door. The system is a multi-user application that differs between the owner of the system and visitors. The owner may record a welcome message and listen to messages from visitors. Visitors may listen to the welcome message and record their own message. The sounds are stored online, so the SR-RFID tags are only serving as interface. Importantly, all functionality is handled by way of tag interaction.

5) The final system allowed a user to associate two tags by moving a phone between them. The example that was implemented allowed a user to use a tag containing position data coupled with a tag representing a weather service.

The prototypes were used to explore tangible interaction on the phones through engaging with application design. In contrast to the predominant crop of NFC applications, our examples used the tag as a dynamic interaction mechanism rather than spots for singular selection. Working with these simple demonstrators, we developed a richer understanding of the interactive opportunities related to manipulating near-fields. In particular, we saw opportunities in coupling multiple interaction techniques in the same interface so as to enable advanced engagement using the near-fields as the sole means of input.

Platform development

Throughout the process of developing prototypes, we were involved in developing and gathering input techniques. Our work further involved incorporating these input techniques into a software toolkit in the form of a Java application that allowed fast deployment of tangible interaction on NFC phones. This designing forced us to systematise and generalise the interactions so they could effectively be assembled in the application running on Java-enabled NFC handsets. Working collaboratively with the development of the software toolkit helped the process of systematising the current findings related to SR-RFID-driven tangible interaction.

The toolkit allowed us to access the interaction techniques through a scripting language, which immensely eased the implementation of advanced tangible interaction on phones. Of core significance in the system is the ability to call the interactive methods from a browser component on the phone. This enables the interaction designers in the Touch project to implement advanced tangible interaction using high-level code based on Web standards.

This shows some of the prototypes with which this author had direct involvement in inside the Touch project. In addition, other participants created multiple prototypes. The additional prototypes also inspired the development of near-field material. However, the analysis of these was less extensive than those contributed by the author, due to the inside perspective gained through designing.

CHANGING PERSPECTIVES IN SR-RFID

During the design processes an ongoing need was to clarify how we could limit the scope of the technology so as to bring forward aspects most relevant for design. This took the shape of creating specific definitions of SR-RFID so as to align our object of study with possible needs of interaction and industrial designers (or frame experiments in the spirit of Schön, [1983]). The new definitions were made by finding and analysing the elements that made up SR-RFID. These were further evaluated in relation to their importance for design. This resulted in multiple perspectives on SR-RFID that were further investigated by the group of designers and researchers.

In the process of research by design conducted in Touch, each individual design process conducted may be seen as part of a dialectic between research and designing. The design brief was devised to orient design efforts toward areas of SR-RFID deemed interesting by the collaborative design group. One example of such interest was the use of multiple fields, which were explored in the design of the Orooni table. In carrying out the design process, new knowledge about SR-RFID was developed within the design group. The new knowledge was analysed, described and shared within the group. The new knowledge was then used in the developing of fresh design briefs directed toward new interest areas uncovered during the previous research and design process.

I was part of carrying out the circle out four times with different means of prototyping in the project. Continuously during these steps the perspective on SR-RFID changed dramatically. Table 3.1 shows how the research focus on SR-RFID in the study changed reflexively throughout the project. It started with a focus on interfaces and ended with a focus on forms.

Research focus
Interfaces on SR-RFID-enabled phones
RFID-driven tangible interaction
SR-RFID as general input mechanism
Near-field material and forms

Table 3.1. Layers of the research focus on SR-RFID

The top three focuses show a gradual reduction in research scope. However, the bottom item shows a more significant shift in focus from interaction-specific phenomena to a general design-oriented form perspective. It is the latter focus that is further described in Chapter 5 of this thesis.

The evolution of research focus in my study is a testament to the reflexive nature of the process of research by design actively carried out in this study.

It also shows that in conducting an interpretative qualitative study of SR-RFID, one must be aware that the initial approach to a material needs to be continuously evaluated during the course of action in response to the emerging findings. I now turn from these methodological concerns to the main reflections on the study.

Chapter 4: Connecting SR-RFID and design

When looking beyond payment, ticketing and security-based applications, SR-RFID in essence represents a technology that offers users a new way of interacting with their environment. My task has been to situate this technology inside a design perspective and expose its properties for designing.

A central move in this analysis is to consider the SR-RFID technology a design material. Such an approach substitutes the traditional perception of materials as something physical, classifying materials as what people use to make spatial or temporal artefacts. Multiple authors have shown how materials can be seen in relation to temporal technologies as well as physical ones (Hallnäs et al., 2002; Löwgren, 2007b; Redström, 2001).

The concept of SR-RFID as design material developed after a long process of exploring the technology in which multiple analytical perspectives were applied. This includes seeing SR-RFID in relation to interfaces and later interactions. Other perspectives that have been followed are the use of pattern languages and concepts like tangible interaction. However, in exploring SR-RFID, none of these approaches seems to capture the full range of opportunities SR-RFID could offer interaction and industrial designers. The material perspective was selected because it allowed us to look at the technology in terms of creating forms. Therefore I could expand the notion of interactions to any kind of form and disconnect the technology from prior uses by end users.

In this chapter, I will connect the research done through the development of SR-RFID-related prototypes and designs to a number of selected meta-findings related to SR-RFID, materials and designing. I do so by connecting the results from applying research by design as a strategy for investigating SR-RFID (interactions, models, etc.) to activity theory as an overarching frame. Activity theory has been chosen here because it offers tools that help us analyse materials in the context of peoples' activities and not as independent objects.

The thesis links results from design practice carried out in a research project with activity theory-informed analysis. This approach situates activity theory in a design and design research context (i.e. not HCI and education). In doing so, I highlight the importance of how making, reflection and understanding working with new tools, materials, technologies and interactions needs to be taken up in activity theory. This is the direction Engeström (2009) goes in his argument for 'wildfire' and the *Journal of Mind Culture and Activity* has moved in looking to extended activity theory beyond the domains of work and learning. Design is not typically taken up outside of computing in this 'tradition.'

In the published articles a number of theoretical and practical developments have been presented. Following is a short summary of these results:

1. RFID-driven tap and hold describes tangible interactions made possible using an RFID-enabled phone and one RFID tag. The concept expands upon the common notion that SR-RFID is used for select interactions and shows a much richer design space (Nordby & Morrison, 2010).
2. The tap and hold model contains a set of basic components of tap and hold-based inputs and shows how they relate to each other. The tap and hold model may be used to analyse tap and hold inputs and help the design of new ones (Nordby & Morrison, 2010).
3. Twenty tap and hold input techniques have been shown. These comprise a set of possible input techniques derived from the tap and hold model. The techniques may be used directly in the design of new SR-RFID-driven tangible interactions (Nordby & Morrison, 2010).
4. Near-field material is presented as a subset of SR-RFID technology. Near field-material help designers focus on central aspects that are unique to SR-RFID when designing.
5. Multi-field relations is a concept that shows how the relationships between multiple near-fields may be used to understand inputs (Nordby, 2011).
6. Multi-field relations model presents four types of multi-field relations. These may be used to analyse and design multi-field inputs (Nordby, 2011).
7. Eleven multi-field input techniques have been presented. These are possible input techniques that are described by the multi-field relations model. The techniques may be further used as components that may be used in designing new SR-RFID-driven interactions (Nordby, 2011).
8. Form-making qualities are introduced as a concept that shows the different types of transformations a designer may impose on a material (Nordby, 2010).
9. Six form-making qualities have been presented. These qualities show different ways SR-RFID may be transformed in design. The

form-making qualities expose the possibilities for creating temporal and spatial forms when using SR-RFID as material (Nordby, 2010).

10. Design affordances describe what a technology offers designers in the design activity. Three types of design affordances are presented using activity theory: need-related affordances for designing, instrumental affordances for designing and operational affordances for designing (Nordby & Morrison, 2010).

The results show a wide approach to SR-RFID and to design materials. In an effort to draw lines between the works I will now focus on three orientations that have emerged when processing the results from the articles. This involves an elaboration of SR-RFID as material, what kind of material this is and what this material adds to our understanding of industrial and interaction design activity. Together, the three arguments use the concepts of near-field material, conceptual material and motive finding to bridge the gap between industrial and interaction designing and SR-RFID technology.

These three concepts are important in allowing us to draw a connection between SR-RFID, materials and design. Near-field material allows us to summarise the practical contributions related to SR-RFID and collected in this thesis into one system. The near-field material helps us understand and navigate the complexities of SR-RFID by focusing on aspects that are seen as particularly important for design. Conceptual material shows us how we may understand the near-field material in a theoretical context. The conceptual material lifts the discussion from SR-RFID to materials in general. At last, motive finding draws attention to aspects of design activity that are of great importance for understanding the position of materials in industrial and interaction design activity. This is important in allowing us to see how materials need to support the development of designers' motives as well as the carrying out of actions and operations.

From an overarching perspective, the following work shows how, by focusing on the details of SR-RFID observed through design-driven intervention, we may develop concepts that may further enhance our knowledge of design practice and research. The presented research matters in a wide perspective that sees research emerging from design practice used to inform the development of new, design-oriented theoretical frameworks.

4.1 FROM SR-RFID TO NEAR-FIELD MATERIAL

In the three articles, a wide range of different SR-RFID-related interaction models and techniques have been presented. I have also proposed that we may place SR-RFID inside a design context by analysing it as a design material through the concept of near-field material. However, the definition of near-field material is spread over three articles and not collected within one unifying framework. I will, in the following section, combine all the SR-RFID-related findings from the three articles and present a more complete version of the definition of near-field material.

Challenges in using SR-RFID in industrial and interaction design

Although SR-RFID often is communicated as a technology offering simple touch interaction, it is not a simple technology. Our study has uncovered a large set of SR-RFID-related properties that show us that SR-RFID offers a complex (and compelling) set of opportunities for design. However, the complexity also makes it likely that using SR-RFID as material for industrial and interaction designing is not a straightforward process. Through the Touch project’s experimental work, several problems were found that limited the use of SR-RFID as material in industrial and interaction design. The problems were identified by investigating SR-RFID firsthand through research by design, literature reviews of SR-RFID in research and surveying documentation of SR-RFID.

The problems can be summarised as SR-RFID being 1) ill-defined, 2) pre-determined and 3) pre-conditioned for domains other than design.

1. SR-RFID as ill-defined

Although SR-RFID may be seen as a distinct technology providing specific features, its structure as a design material remains somewhat unclear. First, it compromises several discrete elements that each represent multiple form-making opportunities (Nordby, 2010). Namely, it comprises radio transmitters, programming interfaces, memory, several possible output modalities and so on. For instance, an SR-RFID ticketing machine uses a passive RFID card, which is scanned by placing it onto a large box. This system gives feedback via sound and the physical opening of a couple of gates. The complexity of such systems illustrates the many separate components that may be associated with SR-RFID. Even when SR-RFID is reduced to RFID tags and RFID readers, a whole range of components is involved. This results in difficulty in analysing SR-RFID as one single material for designing.

2. SR-RFID as predetermined

SR-RFID is strongly associated with the services of payment, ticketing and security. These are areas in which SR-RFID may work well. However, the strong association with particular types of applications situates SR-RFID as a solution to a specific set of problems rather as opportunities for new innovations. The problem with such presentations is that some types of SR-RFID use may overshadow or completely hide alternative types of applications possible with the technology. In relation to SR-RFID, for example, the notion of touch as an interaction method was dominant in almost all examples we encountered related to SR-RFID-enabled phones.

3. SR-RFID as preconditioned for domains other than designing

Finally, our work found that most communication of the details of SR-RFID was, in essence, oriented toward implementing the technology. Such communication routinely covered programming languages and detailed information of the workings of radio transmitters. However, the Touch project found little information specifically tailored to interaction or industrial designers.

This led us to believe that the technology is predominately constructed for engineers and not design practitioners’ processes. That is not to say that existing data may not be used for conceptualisation. Rather, it emphasises the need to search for alternative ways to approach technology specifically oriented toward supporting industrial and interaction design.

Toward SR-RFID as material

To solve the aforementioned problems, I took up the perspective of design materials, which is presented in article 2 (Nordby, 2010). Design materials help us move attention from the relationship between users and SR-RFID to designers’ interpretation of SR-RFID in making artefacts for other people. It also moves attention from mapping individual interaction and interface types to the creation of an overarching model covering important design-related aspects of SR-RFID technology.

In interpreting technology as material, the problems mentioned previously were tackled. This involved focusing on aspects of SR-RFID important for design activities (problem 3), a clear definition of the physical and digital 'matter' of SR-RFID (problem 1) and seeking to present the properties of the material in ways abstract from solutions (problem 2).

This was useful as it enabled us to meet complex technologies by assessing their attributes in relation to a particular activity and re-conceptualise the technology so as to extrapolate these attributes. By doing so, complex technologies like SR-RFID may be redefined into new material that can be treated more like traditional materials in design discourse by making them consistent and more easily graspable for design.

However, one must not confuse the definition of SR-RFID as design material as a definitive perspective on SR-RFID technology. Rather, it is a considered choice, made by the people proposing it, which brings attention to particular technological properties judged important for designing. In this way the material definition may be seen as a potential part of an ongoing material-oriented discourse inside the design community. The following section shows how the author applied the materials perspective on SR-RFID and redefined parts of it as design material.

Near-field material

Reinterpreting SR-RFID as a design material was not straightforward. It was achieved through a long process of investigating both the details of SR-RFID and the potential applications of them. The final material, the near-field material, was developed among a group of designers based on parts of the technology providing clear and interesting opportunities for designing.

The near-field material was arrived at during our process of research by design. In analysing SR-RFID on mobiles, attention was drawn early to the spatial physical manipulation of tags and phones. This led to the definition of SR-RFID-driven tap and hold interaction. In the first article, this type of interaction was identified as a tangible interaction (Nordby & Morrison, 2010). During the analysis of tap and hold interaction, it was clear that the interactions were driven by the intersection of radio fields.

However, later research showed that the fields could be seen from other perspectives than intersection of two fields. For instance in working with the Orooni table, for article 3, we saw that the act of selecting one field among many could be interpreted as another form of input. Also, emerging research in the Touch project showed that a field's spatial form was an important quality of SR-RFID and could influence the design of SR-RFID-driven artefacts (Martinussen & Arnall, 2009).

The emerging results led to an increased focus on the radio fields of SR-RFID technology. In article 2, the radio fields were used in the redefinition of SR-RFID as the near-field material. The name was inspired by NFC specifications addressing short-range radio fields as near-fields. Further, this naming led to the definition of interactions enabled through SR-RFID as near-field interactions (Nordby & Morrison, 2010).

Near-field material is a subset of SR-RFID technology that cannot exist outside the ecosystem provided by additional material related to SR-RFID. Despite this, I argue that near-fields offer a clear definition of critical properties related to SR-RFID technology. Interestingly, near-fields seem to make little sense outside of designing. For instance, near-fields are never directly shaped in the production of artefacts, but emerge as a result of the production of other components (like transmitters and software codes). Instead, near-fields serve as a conceptual placeholder of critical properties that can be taken up into designers’ personal repertoires and inform the shaping of SR-RFID-based interactions.

In my second article (Nordby, 2010) I addressed near-field material as being a computational composite. This may not be entirely correct according to the intentions of Vallgårda and Redström. Strictly speaking, the near-field material may be seen as only accepting input into computers. Thus, in Vallgårda and Redström's terms, it may be regarded as a material with only a rear side (Vallgårda & Redström, 2007). Whether computational composites need a front side to be considered a computational composite is unclear.

Physical and computational materials may be seen as a continuum in which physical form and temporal behaviour are overlapping qualities. Thus, we do not differentiate between computational and physical materials per se. Rather, I follow Mazè and Redström (2005) in seeing computational materials as largely about behaviour and physical materials as largely about fixed matter. In this continuum, the near-field material may be placed in the middle as having both a strong physical and a strong computational presence. For instance, the interactions created by the near-field material are not only dependent on the temporal qualities offered by computing. Also important are users' physical manipulation of fields through tangible interaction, which depends on both the spatial form of the fields themselves, how they are embedded into objects (Martinussen & Arnall, 2009) and the distribution of fields in a space (Nordby, 2010). This makes SR-RFID a technology that bridges the traditional material boundaries of industrial and interaction design.

Focusing on near-fields significantly reduces the complexities of SR-RFID. This does not mean that design opportunities are reduced. The heightened focus allows us to delve deeper into the shaping of opportunities afforded by the near-fields alone. This enables us to traverse complexity so as to uncover more opportunities for variation that we might not have discovered if we continued to address the entire spectrum of SR-RFID-related technologies.

The near-field material is an expansion and not a contradiction to current SR-RFID-related knowledge. Existing research concerning SR-RFID is also important in design research and practice. However, this thesis argues that defining near-field material as a focus of interest is particularly important for conceptual development done by interaction and industrial designers (Nordby, 2010). This is because it helps clarify important aspects of SR-RFID that may be considered a system of technologies with unclear boundaries. For instance, additional output technologies are often seen as an integrated part of SR-RFID in research literature (in HCI research, SR-RFID is usually dealt with through applications rather than as a material). The near-field material allows us to cut through such complexity so as to enable designers to better focus on the shaping of new SR-RFID-driven artefacts.

Detailing near-field material

Following I will combine all SR-RFID-related findings from articles 1, 2 and 3 into the near-field material. To create this new model of near-field material I use design affordances as they were presented in article 1 as a starting point (Nordby & Morrison, 2010). These comprise need-related design affordances, instrumental design affordances and operational design affordances. As mentioned previously, such offerings can connect to Gibson's affordances (1977), which can describe the relation between the designer and the material. However, Gibson's approach may be expanded by applying Leont'ev's (1978) structure of activity. Bærentsen and Trettvik (2002) argue that this can be structured as three levels of affordances: need-based (motivational), instrumental and operational.

Article 2 introduced form-making qualities (Nordby, 2011). These were seen as particularly oriented toward supporting motive development in industrial and interaction design. Linking this result to article 1, form-making qualities may be seen as a need-related design affordance.

In summing up the work of the first and second article, a name change is proposed: material-oriented instrumental design affordances may be called form-making instruments and, consequently, the material-oriented operational design affordances are called form-making operations. This slight reformulation of concepts aims to bring consistency to the treatment of affordances, form-making qualities, levels of activity and materials.

The different levels of affordances may be seen as representing why, what and how knowledge (Bærentsen & Trettvik, 2002). We may use this as a guide when analysing how our findings related to SR-RFID may be placed in context with the overall near-field material. I will now move to organising the interaction techniques and models found in articles 1, 2 and 3 according to form-making qualities, form-making instruments and form-making operations.

Form-making qualities for the near-field material

Form-making qualities are need-related design affordances, which constitute an efficient way to get an overview of material properties. Each represents a distinct type of spatial or temporal form made possible with near-field material. The study found six form-making qualities that were presented in article 2 (Nordby, 2010): 1) tap and hold gesture, 2) multi-field relations, 3) multi-field distribution, 4) context linking, 5) field form and 6) mediation type.

The form-making qualities show in what ways the near-field material can be transformed. The six form-making qualities significantly expand our understanding of shaping SR-RFID. It does so by providing a large set of potential form-types that may be combined in many ways. Together, the form-making qualities give us an account of the range of possibilities that near-field material offers designers.

By presenting multiple different ways of transforming near-field material we may see an important structure of opportunities for designing spatial and temporal forms inside SR-RFID. This is a significant expansion of current RFID-related research that does not usually present RFID-related findings inside a framework that allows us to see the potential for creating varied designs. Instead, various demonstrators are presented and analysed in relation to user experience. Such an approach is useful, but has a tendency to overlook how SR-RFID may be used to create new alternative experiences.

The form-making qualities of SR-RFID have some interesting inconsistencies. Whereas tap and hold, multi-field distribution and multi-field relations deal with forms created by directly manipulating the fields themselves, the rest of the qualities do not. Field-form describes both the creation of the fields' actual spatial form and how the field-forms influence the shaping of the physical materials encasing the fields. In addition, the main purpose of context linking is to expose field-interactions as a two-way information transfer instead of a one-way reading. It concerns the information following the fields and not the fields themselves. Finally, the mediation type points toward the different ways a field input may be communicated spatially. Thus, it shows how the fields may be experiences through additional forms of output.

Despite these inconsistencies, these qualities were included because they were considered important in relation to designing and experiencing near-field interactions. In the design of the near-field materials, these bordering aspects of shaping the fields were included as they were judged to be important aspects of the near-fields that designers should consider. In this sense the definition of the fields as focus for the material remains intact. However, the interpretation of what may be considered their qualities must be judged in the creation of the material. In this case the additional qualities were added because they were seen as important design-oriented knowledge relevant for designers' understanding of near-field interaction.

Form-making instruments for near-field material

Form-making instruments are instrumental design affordances that consist of models that explain possible ways of understanding the structure of a form-making quality. There are no fixed formats for these models as long as they help describe the makeup of a form-making quality.

Two form-making qualities were described in detail at the instrumental level in this study: tap and hold and multi-field relations. Tap and hold showed a graphic representation of the cyclic behaviour of the interactions. Multi-field relations, on the other hand, divided the affordance into a set of categories that helps us separate the different input techniques.

In addition to the form-making instruments that have been shown in my articles, a parallel effort in the Touch project can help to extend the model further. Arnall and Martinussen (2009) provide one taxonomy of elements of RFID forms. They include direction, balance, ergonomics, similarity and geometry. Such results seem to be compatible with the field-shape form-making quality. It is likely that with some work, these ‘elements’ may be included in the overall model of near-field material.

Also, in article 2, multi-field distribution, context linking and mediation type are briefly discussed and some properties revealed (Nordby, 2010). However, these have not been sufficiently explored to present possible form-making instruments or operations.

The form-making instruments presented in my articles serve as another expansion of our knowledge related to SR-RFID. The instruments lay out the structure of the previously presented form-making qualities. Overall, the form-making instruments offer a toolbox of models that help us understand the forming of important aspects of SR-RFID technology.

Importantly, as each form type may be unique in structure, the related form-making instruments may also be unique. Moreover, some form types may lend themselves to multiple parallel descriptions or be difficult to describe in a model at all. Thus, whether a form-making quality has one, several or no form-making instruments is uncertain. Still, form-making instruments may motivate us to look for models explaining the structure of form-making qualities, because if found, they may significantly expand our knowledge of making forms.

Concerning SR-RFID, in this thesis most attention has been given to the shaping of multiple fields (by introducing multi-field relations) and tangible interaction (by introducing tap and hold). The multi-field relations instrumental model expands current research on multi-tag systems by showing how, by focusing on the relations between fields, we could describe possible input to a system through a set of relations between fields. Such an approach focuses on the meaning of joining fields. One important aspect of this approach is to remove the concept of tags and tag readers that are common in research related to short-range RFID. This allows us to focus purely on the meaning of joining fields rather than on whether a user holds a reader or a tag.

RFID-based tap and hold expands on the current conceptions of SR-RFID as provider of touch or select interactions. The tap and hold model shows how interactions between two single fields may actually be interpreted as a series of states. These states can be connected to different functions that together open up for a fine-tuned control of RFID-based tangible interaction.

However, it is together that the full potential of the models emerges. As they deal with properties that can be combined, the solution space described by the models expands by order of magnitude when they are seen as part of the same opportunity space. The material perspective may, in this way, show that we could better serve creative developments using SR-RFID by analysing full materials instead of singular interactions or interfaces.

Form-making operations for the near-field material

The project created a large set of operational design affordances in the form of form-making operations. These represented different input techniques that can be made following the form-making instruments offered by tap and hold and multi-field relations' form-making qualities (Nordby, 2011; Nordby & Morrison, 2010). In the first article, 20 form-making operations were described related to SR-RFID-based tap and hold. In the third article, 11 form-making operations, derived from two multi-field relations, were presented.

The form-making operations offer practical examples of possible forms related to a form-making quality. Crucial for the operational affordances was that they represented abstract forms that could be used in further form-making. Thus, they may be seen as automating part of form creation by providing examples that may be used directly in design.

The form-making operations presented in articles 1 and 3 constitute many examples of possible RFID-related forms in the form of input techniques. Many of the forms have been seen in other research projects. However, the form-making operations presented in this study bring two important additions.

First, they show abstract forms rather than forms as part of different applications. They were created to be used, as is, in the design of new interactions or interfaces. This is an important contribution to the knowledge of RFID in that it shows us that the technology may in fact be described outside the solution despite its intangible nature. The representation of such interactions was achieved through experimentation with ways of diagramming the operations in articles 1 and 3 (Nordby, 2011; Nordby & Morrison, 2010).

Second, the operations represented larger sets of multiple interactions rather than sole examples. This also counters much of current research that has a tendency to present single interactions in articles, disconnected from the system of forms from which they actually emerge. The processes conducted to arrive at the interactions presented in such articles most likely have revealed multiple additional possible interactions. However, these are not usually presented as part of studies, thus leaving out important design-related information. My study avoided this by presenting all the form-making operations discovered in working with each article. Therefore, each form can be seen as part of a larger set of opportunities.

Model of near-field material

The near-field material is summarised in Table 5.1. The left column shows the form-making qualities, the middle form-making instruments and the left form-making operations. The table shows that only two qualities are fully developed. Of the rest, one is partly developed by Martinussen and Arnall's work in the Touch project (Martinussen & Arnall, 2009). The other three qualities are only briefly touched upon in article 2.

Near-field material thus offers an overview that also may show where more efforts can be placed. Further research should focus on developing further form-making instruments and operations. Further research may uncover additional form-making qualities or entirely new material definitions in SR-RFID.

Form-making qualities	**Form-making instruments**	**Form-making operations**
Multi-field distribution	None	2 form examples
Context linking	Partly developed in article 2	None
Tap and hold gesture	Tap and hold model	20 input techniques
Field form	Partly developed (Martinussen & Arnall, 2009)	None
Mediation type	None	4 mediation types
Multi-field relations	Multi-field relations model	10 input techniques

Table 5.1. A model showing the complete structure of the near-field materials design affordances

Conclusion

At the beginning of this project, SR-RFID was identified as a multifaceted technology not oriented toward industrial and interaction designers' activity of conceptualising new designs. This thesis took up this problem by asking: How may SR-RFID be presented to support industrial and interaction designing?

In moving toward answering this question I proposed reformulating technology as a design material. In applying a material perspective to SR-RFID, I suggest that the formulation of near-field material may help solve the problem in re-conceptualising SR-RFID for design. The near-field material moves SR-RFID-related discourse toward supporting designers' activity of creating new spatial and temporal forms that may be used to create new interactions and interfaces. Such a move may be seen as an expansion of current approaches to SR-RFID in research. For instance, the focus on touching (Rukzio et al., 2006; Välkkynen et al., 2003) or selection (Välkkynen, 2007) mechanisms are expanded by a focus on the entire shaping of RFID-based engagement. Also, research on SR-RFID in specific scenarios like browsing (Want et al., 1999) or poster applications (Rukzio, Schmidt & Hussmann, 2004) are expanded with a wider understanding of specific properties of SR-RFID that may be used in shaping new designs. More design-oriented explorations of SR-RFID directed toward its use in designing has been extended (Ailisto et al., 2009). Instead of mapping aspects of RFID in its entirety, near-field material consists of only a few central aspects of RFID technology that are unique to RFID. The material is presented as abstract from solutions so as to offer opportunities for industrial and interaction designers to create new kinds of forms that may be used in the conception of future interfaces.

The near-field material is not a finished or complete description of near-fields as materials. Multiple areas of the material may be expanded upon. Further, the near-field material does not represent a definitive view of SR-RFID in designing. It may very well be that better models can be created for designing with SR-RFID. However, by presenting one perspective on the technology interpreted through a design-driven analysis, I seek to make the technology more accessible so as to support further material-oriented discourse of SR-RFID technology.

The near-field material exposes aspects of SR-RFID that are important for the formation of interactions. Hopefully, by orienting the discourse toward form-making rather than the technology in context of applications or as independent from people’s activities, has increased the accessibility of SR-RFID in innovation so as to enable more people to perceive the full potential of designing with SR-RFID.

4.2 TOWARD CONCEPTUAL MATERIALS

In the previous section I presented an analysis of SR-RFID technology from the perspective of designing. In article 2 I did so by applying a design material perspective on technology (Nordby, 2010). Such an approach comprised the development of a clear definition of a computational technology rooted in designers' possible needs. The new definition is further presented through descriptions of properties relevant for design. Having defined the near-field material we now explore what this material may add to our general understanding of materials in design.

The near-field material is not material in the traditional sense as it is not rooted in physical matter. It also does not follow the material approaches seen inside works addressing computational technology as materials. It does not consist of computing alone, nor can it readily be characterised as a composite of matter and computing. This raises questions of whether near-field material may be considered a material, and if so, what kind of material.

In previous sections we saw that near-field material is constructed with the purpose of supporting designers' conceptualisation of forms. Importantly, the forms realised in the finished artefact or design are not dependent on the near-field material. Instead, the forms are realised through other materials. Near-field material holds no interest for those seeking to realise an artefact described by a design. However, it is useful in developing the design itself. Near-field material then defies the traditional relation between the production of artefacts and materials, yet, it has the ability to be shaped in design.

The term *conceptual material* is proposed to account for this phenomenon. Conceptual material was briefly introduced in the discussion in article 2: 'Such a material is constructed as a reasonable tool that enables designers to shape the effect of technologies, rather than the technologies themselves' (Nordby, 2010). This makes conceptual material a material-oriented conceptual framework that captures key characteristics of computational technologies that is relevant for designers' activity of designing artefacts. However, it is not only the physical boundaries of the material that are captured. Rather, it is a set of properties designers engage with in shaping physical or temporal forms.

The near-field material may be considered as a conceptual material derived from SR-RFID technology and design activity combined. This result is only drawn from the analysis of SR-RFID used in processes of research by design. However, it is of interest to consider whether the conceptual material may be useful for analysing other computational technologies. It is also of interest to find in what way such analysis could be carried out.

Redefining computational technology as conceptual material

Even though this study has only investigated SR-RFID as conceptual material we may find that the problems found in this study related to using SR-RFID in design may also hold for other computational technologies. For instance, because computational technologies, in essence, are composites, they consist of multiple technologies that together make up the properties the designers work with (Vallgårda & Redström, 2007). This makes most computational materials complex systems consisting of different technologies, wherein all of the components may be independently shaped. Such complexity makes it likely that more computational technologies than SR-RFID may be considered ill-defined design materials and may benefit from a design-oriented re-conceptualisation. This makes it of interest to see if the conceptual material may be applied to other computational technologies in the future. I have not researched whether seeing SR-RFID as preconditioned for non-design practices and as predetermined for particular types of applications may be applied to other computational technologies. However, if this is the case, it seems likely that the conceptual materials may be used to resolve such problems on other technologies than SR-RFID as well.

Based on the near-field material we may describe how we may re-conceptualise computational technologies as conceptual materials. Each of the problems presented above may direct us to a need the conceptual material must answer. In doing so, we may devise a system that can help us analyse computational technologies with the purpose of transforming them into conceptual materials. This is summarised in the following three arguments.

1. Conceptual materials need to be shaped in line with needs of the design activity. Here, we need to see the material from a perspective related to the design activity for which it is created. This activity differs from other disciplines and, thus, may need to address different perspectives on the computational technology than the ones that are needed in, for instance, engineering.

2. The subject matter of the conceptual materials needs to be clearly defined with definitive boundaries. The technology needs to be reduced to its essentials and specified accordingly so that it is possible to understand and design its properties in a clear way.

3. Conceptual materials need to be defined as abstract from, and not through, possible solutions. To be considered as a material, the computational technology needs to be detached from particular solutions so as to enable designers to appreciate its abilities as opportunities for novel creations.

Specifying features of computational technologies that are of interest for designers' form-making

A key aspect of the conceptual material is to bring forward particular material aspects that are interesting from a form-making perspective. The selection and definition of such aspects is very much a design decision based on what is deemed useful for industrial and interaction designers' form-making. This separates the conceptual material from traditional views on materials, which usually originate from particular categories of technologies or raw resources. In contrast, the conceptual material is constructed by analysing a computational technology in relation to designers' activity of designing temporal or spatial forms. Thus, the origin of the conceptual material is the meeting of computational technology and the designer's activity of shaping it.

Traditional physical materials, such as wood, for instance, lend themselves to be easily understood as materials. Their physical boundaries are clear, and their properties in design are well documented. However, when considering computational technology as material, the definition as material becomes hard to grasp. This is due to how computational technologies are put together using many components; they represent not just one composite, but many different potential variations of a composite. Each of these components may be considered a material in itself, making forming the composite a matter of negotiation in the forming of multiple materials. Thus, computational technologies may be difficult to define as a stable material as they, in effect, consist of many individual materials. These materials may be formed separately, bringing attention toward the technicalities of the separated components, at the expense of the conceptual subject matter of the computational technology as a whole. The conceptual material seeks to overcome this by analysing and re-conceptualising technologies from a form-making perspective. Individual components enabling a technology to work are subordinate to the properties that enable forms.

Populating the new material with form-making qualities

Considering the properties of a conceptual material, we may use Table 5.2 to summarise the method used to analyse near-field material. The model shows how each level of affordances corresponds to form-making qualities. Also included are questions that may be used to find the corresponding form-making qualities, instruments and operations. The questions are: In what way can this material be formed? How can the form-making qualities be described? What forms can be made with this form-making quality?

Affordance type	**Form-making category**	**Question**
Need-related affordances	Form-making qualities	In what way can this material be formed?
Instrumental affordances	Form-making instrument	How can the form-making qualities be described?
Operational affordances	Form-making operations	What forms can be made within this form-making quality?

Table 5.2. Attributes of the conceptual material comprising three levels of affordances, the corresponding form-making quality, instrument and operation and a set of questions that may guide the analysis of the conceptual material.

Discussion

Designers are increasingly wrestling with intangible, nested or composite computational technologies. These technologies are often oriented toward disciplines other than industrial or interaction designing, and because of this, can often be considered ill-defined design materials. Thus it is necessary to reformulate computational technologies as materials oriented toward design activities. The main purpose of these materials is to serve as descriptions of technology as they relate to designing.

In the beginning of this thesis I asked: How may we re-conceptualise new computational technologies for design? The question has been investigated by applying a process of research by design in investigating SR-RFID and by analysing the results in relation to the design activity as it may be interpreted by way of activity theory.

This has resulted in the proposal that we should redefine complex technologies as materials for design activities. I argue that the *conceptual material* is useful for such analysis. Conceptual material is not a material in the usual sense. Rather, conceptual material may be seen as a tool for designing that enables the understanding of form-related systems that emerge within computational technologies.

Conceptual material does not contradict seeing computing as materials or seeing computing as mediated through computational composites. Instead, conceptual materials help us understand selected bits of complex computational composites that are deemed useful for designers' conception of spatial and temporal forms. This enables us to reduce complexity and focus on only those parts of computational composites that may enhance the process of conceptualising new designs. Thus, the conceptual material is created from the perspective of supporting designers' activity of conceptualising forms first. I argue that conceptual materials are useful for designing as a sense-making tool supporting the use of complex technology inside designing. Thus it may be seen as supporting Manzini’s (1986) vision of making the possible thinkable for designers.

The conceptual material does not necessarily exist in a physical form. Rather, it exists as a theoretical concept that provides a clear definition and structure to complex computational technology so as to situate it inside designing as a material. Because of this, the conceptual material may be seen as radically different from traditional physical materials and also computational composites. This is primarily due to how the conceptual material changes the primary use of materials from constructing artefacts to conceptualisation of new designs (e.g. planned artefacts). Overall, my model of the conceptual material offers four advantages over current approaches to digital materials.

1. Conceptual material helps redefine ill-defined technologies so as to make them more relevant for designing.

2. Conceptual material emphasises that the motive for using a material is central to understanding and facilitates materials for particular activities.

3. Conceptual material connects the activity-level knowledge of materials with instrumental and operational levels. This enables a multileveled understanding of materials that connects why-, what- and how-related knowledge.

4. Conceptual material helps structure technologies according to the makeup of human activities first. In this way, we may say it is structured after ways of thinking about computational technology in design, rather than solely about the technology itself.

This thesis argues that by clearly framing technology opportunities considered useful for processes of designing, computational technology can be presented in an abstract yet approachable way, making it easier for designers to shape complex computational technology. The conceptual material supports industrial and interaction design by providing a framework that better maps with the designer’s principal needs of making forms.

4.3 THE ROLE OF MOTIVES IN DESIGNING WITH MATERIALS

I view materials as socially constructed artefacts that serve as carriers of the intentions of other people involved in the making and presentation of them. Materials have histories of use and are shared among people through social communication and culture. Unlike matter (or non-tangible substances like radio waves, light or computing), materials exist only in the socio-cultural context as the elements that may be transformed into artefacts.

For a designer, it is important to be aware of the existence of the agencies held in materials so they may interpret what materials mean in view of the design activity being undertaken, rather than the originally intended use. To do so, designers need to have a critical attitude to any technology presented as a possible material in designing and be prepared to explore the material so as to find what it means for the designer, the design community and the design activity.

In the case of SR-RFID, I have argued that it was an ill-defined design material and carried intentions not necessarily in line with designers' needs. To solve this I proposed that analysing SR-RFID in terms of making forms was useful. This is inspired by authors who have taken up materials' potential in relation to offering opportunities for forming artefacts. Redström (2001) addresses form related to computational technology as dealing with spatial and temporal structures. Such views are further elaborated upon by Mazé and Redström (2005), who discuss the same aspects but as temporal and spatial forms.

The concept of *form-giving* has been presented to interaction design by Smets and colleagues (1994), who suggest the approach could be used in interface design. Later Vallgårda and Sokoler (2010) took up the same term in relation to working with material properties of computers. Form-giving relates to traditional crafts in which people handle physical materials like wood, glass and metals. Smets and colleagues argue that the form-giving merges appearance, functionality and construction. We may say form-giving conveys designers' attitude toward creating artefacts that possess aesthetical as well as functional purposes.

I have previously chosen to use the term form-making qualities in relation to what a material offers to designers. I do so in article 2, in which I describe form-making as one of the principal needs for designers' use of materials (Nordby, 2010). This approach is inspired by Manzini (1986), who saw forming as a central aspect of understanding materials in design. Using the terminology of form-giving, my term could be revised to: qualities *for* form-giving. My choice of using form-making instead is partly related to differentiating the work done with conceptual materials from that of traditional materials shaped in craft.

Form-making positions near-field material within the context of industrial and interaction designers' needs. However, I have not answered how this material functions within the design activity. In moving toward such an understanding, I suggest that the concept of motives may be further explored in relation to materials. To be able to do so, I will first position materials according to design activity using activity theory.

Materials as activity-dependent

One of the central positions of this exegesis is that materials cannot be seen as isolated entities, but must be seen in context of the user or praxis of which they are a part. Thus, an important implication of seeing computational technologies as materials is that the perspectives move from the material itself as the centre of analysis toward the activity with which it is involved. This study extends this and finds it useful to see all materials as dependent on the activity in which it is involved. This enables us to analyse materials as some kind of technology linked to people's activities oriented toward creating artefacts.

By connecting the term material to activities oriented toward making artefacts, we see how materials are not objective absolutes, but are relative to people's activities. After all, the creation of artefacts comprises a vast spectrum of approaches and intentions. What is considered a material by some people may not be addressed as such by others who are not engaged in that type of artefact construction. In addition, materials may be experienced differently according to people's skill, knowledge, objects and motives. This makes materials a useful concept when analysing technology. Firstly, it sees technology from the perspective of making. Secondly, we may further specify the making activity so as to situate the technology inside specific cultural arenas.

In the previous section, material was used to address SR-RFID as a design material. Design materials may be seen as the substance that allows the creation of potential user experiences. From such a perspective, material properties can be seen as a mix of the physical or temporal characteristics of the technology itself (its temporal or spatial 'matter') and subjects' particular approach toward it.

Unwrapping materials in design activity

To be able to address the use of materials inside industrial and interaction designing, I propose that it is useful to apply activity theory so as to see materials from a socio-cultural perspective. I draw inspiration from Engeström's (2006) model that shows how individual designers' activity may be viewed. In his model the subject, the designer, is oriented toward an initial idea or situation (object) that is to be transformed into a designed outcome in the form of a designed artefact. This activity is mediated by external and internal tools and signs that the designer finds relevant to the process.

Tuikka (2002) suggests the design object may be seen as having a 'dual character' and proposes viewing the design object as both future artefact and hypothetical user activity. Kuutti (2005) mirrors this view and shows that the object of the design activity may be seen in relation to two activities: the design activity and the eventual use activity. The object is shared between these in that the object of the design activity is the tool of the eventual use activity. As such, the object is constantly in flux between something to be created and something to be used. This important insight shows designers' orientation toward future possible activities and the experiences they mediate as well as the would-be artefact itself.

Because experiences are the result of the meeting of the produced artefact and people, designers are deeply involved in the technological making of the artefact as well as the human activities of which it will be part. We may see industrial and interaction design as joining anthropocentric and technocentric approaches so as to enable possible experiences mediated by artefacts (Béguin & Rabardel, 2000). Consequently, I see technologies that we use to create an artefact (materials) and people's past, present and possible future activities as important aspects of the object of design activity.

A consequence of this approach to designing is that technology and people must be seen as part of the same problem. These may be developed individually as part of design processes. However, they must sooner or later merge to allow the creation of new designs. Because of this, technology and people as objects in design activity will always influence each other in a dynamic relationship that is destined to merge into a joint outcome.

Such an object of design activity influences our view on materials that must be seen as selected, used and developed from a perspective of potential user experiences, rather than solely the stuff that enables the production of artefacts. Thus, such a design object may well be described in terms of form-giving (or form-making), as this term also reflects the development of an artefact that communicates with people.

The dualism of the design object also points toward seeing design activity as potentially made up of several activities. Activity theory holds that an activity may lose its motive and become an action, and an action may gain importance and become an activity (Leont'ev, 1978). It is not hard to imagine technology-oriented development breaking off into an activity itself propelled by the excitement of exploring technology potentials. Still, such dynamics must eventually converge into the overarching design object of merging people's potential activities and technology's potential representations into artefacts that may mediate experiences.

This analysis of materials in design activity reveals two interesting perspectives. Firstly, in seeing the design objects as joining technocentric and anthropocentric perspectives, designers must consider materials according to people's potential experiences and not just the creation of artefacts. Such, perspectives have been taken up in seeing materials in relation to user experience. However, user experience of materials happens post-design, thus we should not research materials in relation to users, but how materials may be laid out to support designers' conceptualisation of new experiences. Secondly, the role of material in designing may change from mediation design activity to the object of a new activity. In such an activity, material is explored with the purpose of supporting the overarching design activity.

Both phenomena are well known in industrial design, where the exploration of materials has been used as inspiration. Also, a wider interpretation of materials as it relates to people's experience and artefact construction is, for instance, embedded in the term form-giving. However, by analysing these aspects of materials by way of activity theory, we may expand our analysis further. In the following section I will continue the lead from article 2, and see how motives may be used to analyse material use in designing.

Motives as what directs activities

This thesis follows Kaptelinin's (2005) suggestion of separating the object and the multiple motives directing an activity. I see such a move as particularly important as it clarifies the distinction between the object in transformation and the different motives that define the direction the object is moving toward. The reason motive is of particular importance is that in activity theory, motives may be used to explain why an activity exists. Leont’ev (Leont'ev, 1978), who introduced the concept of motive, explained that motive exists in the meeting the objective object of the activity and people’s needs. Motives allow us to see the activity as directed by the social and individual at once.

Motives are not static. They evolve as the subject acts in the world. As such, there is dialectic between the transformation of the environment and the development of motives. Motives are developed through people’s acting in the world. As the source for development, motives are central, as new motives must be generated, merged or removed for development in the design activity to happen. Without the development of motives, creative development will stop, causing the activity to stall. Thus, constant negotiation of motives is necessary for a rich design process to move forward. Thus the conscious (and unconscious) development of motives in situations of great uncertainty is central to designing. One of the major challenges facing designers, therefore, is to make sure the momentum in the design process is achieved through the development of motives driving the design activity itself. Materials play a significant role here as important parts of the environment that designers may use to develop the motives that direct the design activity.

Motives and emotions in activity theory

The concept of motive and its connection to people’s personal makeup (Leont’ev 1973) has been important to activity theory’s initial role as a tool inside psychology. However, it is less elaborated inside HCI or the fields of design. Because motives are linked to people’s personalities and sense of self, we may also address motives as being linked to people’s appreciation systems, aesthetic sense, emotions and sense of ethics. In such a view, activities oriented toward communicating aesthetically pleasing experiences are also oriented toward the motives of people’s potential activities.

This raises the question of whether industrial and interaction design must be seen as predominantly oriented toward those hard-to-grasp motives of people’s activities. If this is so, experience-oriented designers seem to have a fundamentally different orientation than traditional HCI practitioners, oriented to goals and conditions of actions and operations (Nardi, 1996).

On motives, Leont’ev writes:

> Their function, regarded from the standpoint of consciousness, is to ‘evaluate’, as it were, the vital meaning for the subject of the objective circumstances and his actions in these circumstances, in other words, to endow them with personal meaning, which does not directly coincide with their understood objective meaning.
>
> (Leont'ev, 1977, p. 199)

According to Leont’ev, emotions are not reasons for action; rather they are the results of activity. Motives play an important role in this as a mediator between the accomplishment of an object and the emotion (Mäkitalo, 2005). This makes emotional experiences resulting from an activity directly related to the motives that drive the activity itself. Experiences may thus be seen as strictly bound to the activity level and as a direct result of how the activity is enabled to meet different motives.

Leont’ev (1978) noted that people are often unaware of their activities and motives. However, they may be seen as reflected by the emotional colouring of the actions people perform. We may see emotions realised through how the doing of actions fulfils the motives of a person’s activities. Thus, designers engaged in designing artefacts that enable certain emotional experiences need to understand not only people’s potential actions, but also how the accomplishment of actions relates to the motives directing the object of people’s activities. The connection between motives and experiences places motive as of particular interest for designers as other people’s experiences may be seen as the result of designing. Thus, to form specific experiences, designers need to make artefacts that may help realise the motives of other people's potential activities.

In designing with materials, designers continuously evaluate emotional responses to their ongoing creation. Wright (2008) discusses this in the context of a designer creating digital jewellery. He states that the designer engages in an empathic relationship with the material where he shapes the artefact with the user in mind. Such views may be expanded using Leont’ev’s model. Here designers' actions directed toward shaping materials into artefacts are constantly evaluated with regard to the motives directing the activity. The result of the evaluation triggers emotions that may direct designers' further designing.

This example points toward how the very actions involved in the shaping of designs are directly in touch with the motives directing the activity. This helps us see designers' shaping of new expressions as not only an internal fulfilling of their own needs, but directed by the emotions that arise through evaluating the continuous result of designing by way of personal and social motives. Such views help us explain how experience-oriented designing is connected to designers' emotions when designing. However, these emotions mediate the social motive, not only the designer’s personal feelings. Activity theory may in this way help us explain how empathic design functions in a psychological context. Thus, motives play a role in directly guiding designers' actions in shaping expressions using materials.

Another perspective on this is that emotions are used by designers as a tool for gaining access to the motives directing the activity. This dialectic between emotions and motives has important implications for how we understand designing with materials as a social and subjective practice. As emotions are used to evaluate experience in creation, they are also very much in play when using materials. Because these emotions may be seen as reflections of motives, designers' development of motives related to felt life is particularly important in designing. This is what Schön saw when he observed design students developing personal repertories related to design materials (Schön, 1992a). They developed a personal repertoire related to the use of materials. Included in this repertoire were possible motives related to the use of the materials that the student could apply to future design situations. Thus, the students developed their own sense of the material in terms of form-making inside design as an extension of knowledge related to technical construction.

Having elaborated motive development and how emotions matter in material-related practice, we may now turn to placing materials inside the design activity as a tool, sign and possible object.

Materials as tool, sign and object

Tools or signs mediate the design activity and enable designers to transform the objects of their activity into outcomes. This can include tools for thinking or material tools (Kuutti, 1995). Designers use multiple tools in the design process. However, tools are not neutral but have agencies (Kaptelinin & Nardi, 2006) embedded in them and drawn from the intentions of the people who initially developed them.

In realizing that all tools have agency, the question facing the designer is whether this agency is relevant for the future motives the design activity is directed toward. For instance, technology might point toward particular types of transformations that may not make sense for the current motives the design is directed toward. Likewise, it is possible that user research points toward motives not relevant for the artefact types to be created in the design process. This contradiction between inherent agencies in the world and the agencies of possible future activities needs to be resolved through the process of designing.

Vygotsky differentiated between technical tools that help people affect things and psychological tools (signs oriented toward affecting people) (Kaptelinin & Nardi, 2006). He also differentiated between psychological tools as physical (maps, for instance) and symbolic systems that may be internalised by a subject.

It is possible to interpret traditional materials as both physical and psychological tools. They are both used in the production of user-oriented artefacts, and the material may be interpreted as a piece of information describing the material properties. The conceptual material I have presented, however, is only a psychological tool allowing the planning of artefacts and does not have the dual character of traditional materials. It may be considered a sign that can be communicated among designers through social communication or mediated through physical or digital means. Importantly, the conceptual material could be internalised by the designer so as to make it available for the designer when designing.

Bertelsen introduces the concept of design artefacts (2000). These mediate across the many dimensions of design activity, most notably construction, conceptions and collaboration (Bertelsen, 2000, p. 17). He describes construction as the productive relation between the designing subject and the object of design; conception as the dialectical relation between the designing subjects and the historically developing activity and cooperation as the representational relation between subjects involved in design. The conceptual material may be seen as one such design artefact. Thus, the conceptual material mediates production, conception and collaboration of designs. However, the attention in my work is particularly oriented toward the conception dimension of designing because of the importance creative development has in the design of experiences.

Although, particularly in the production of software codes, the gap between producing designs (plans and specifications) and realising them (usable artefacts) is overlapping, there is still a process dealing with conception of forms before production of them. This is the area in which the conceptual material excels. When these forms are to be constructed, the conceptual material as a design artefact is less important than the designs themselves as specifications for the production. At that stage, the conceptual design material loses its meaning in the process and other tools must take over. However, the conceptual material does mediate between construction and representation in that all its properties are based on the properties of the technologies that are used in construction.

Materials as object for exploration

In seeing conceptual materials as design artefacts particularly oriented toward conception (or conceptual development), motives are of interest. Bertelsen (2000) says that the conception dimension of design artefacts helps subjects develop entirely new motives directing design activity. However, this perspective may be extended. When designers engage with materials in designing, they do not only develop motives relevant for the present design activity; they also build long-term relationships between themselves and materials.

When designers use materials, they are objects for learning and development. Schön (1992a) shows how designers, by playing with materials, develop their personal design world from which they develop their design. What Schön describes is a dialectic relationship between the material and designers' interpretation of it. In this relationship, designers may develop personal approaches in the form of skills, appreciation, values and insight into the forming of experiences though the material.

As the design activity is about both transformations and finding the motives driving the transformation, one key aspect of design activity is to address the objects in an instrument-making activity (Kaptelinin & Nardi, 2006). By scrutinising and exploring the objects of an activity, designers can make new tools that open up new possible transformations in the design activity. This could involve both thinking tools and practical tools.

Addressing the objects in an instrument-making activity is absolutely crucial in terms of making internal thinking tools in designing, as it allows for designers to develop a subjectively consistent approach to the objects in an activity. By having internalised tools considering the transformations of the objects, designers can develop their own personal approach to situations that include a personal interpretation of the objects.

This may be expanded upon by drawing on Bèguin and Rabardel's (2000) notion of instrumentalisation. They outline an instrument as an artefact and a subject's scheme for using it. Instrumentalisation shows how a subject's relationship with a particular artefact, for instance materials, may be seen as a learning process. The subject develops a scheme for how to use the artefact through a process of learning. Thus, any artefact that mediates activity consists of both the artefact and the scheme in development. In addition to particular knowledge about using the artefact, this scheme must also be seen as constituting a subject's personal interpretation of the artefact. As such, instrumentalisation may be seen as a relevant concept for describing designers' development of a personal understanding, appreciation and approach to specific materials. Instrumentalisation is useful in directing attention toward how schemes for use are always part of the artefacts that mediate activities.

Instrumentalisation may be seen in relation to the strong material orientation inside the design practices. The transformation of materials, a central issue in most design schools, represents a cornerstone in designers' repertoires. Different design disciplines specialise in particular technology, enabling them to work freely and creatively with the particular material at hand. Graphic artists deal with paper and screens, industrial designers with plastic and metals. Frequently, designers cross borders between technologies, but usually proficiency in material transformation is necessary to excel in designing. This is also true considering computational technologies. However, such technologies are often very complex and hard to grasp. Due to this, the development of material approaches related to computational technologies may be difficult. I suggest, by making the material qualities of such technologies both visible and comprehensible, we may allow designers to engage in processes of material instrumentalisation that allow them to more easily develop material repertoires in the same way design practitioners operate with traditional materials.

Thus, subjective reinterpretations of elements in the world so as to transform them into tools and signs for creative development are a key aspect of design processes. Such instrument-making activities are common in designing, where the main activity might be split into several sub-activities related to developing new approaches to a particular object. These activities are relevant for the particular design activity being pursued. However, they are also important for designers' long-term development of themselves as creative professionals.

Here, my study separates externalised tools and the internal development of personal schemes toward artefacts in the world. As these personal schemes enable the designer to develop unique conceptualisations of the future, activity theory helps us understand designers' need to develop personal and interpersonal approaches toward materials so as to build an internal repertoire of opportunities that enables the development of unique design proposals.

In design activity, materials offer new possible motives that may direct designing. A rich and versatile set of motives is needed to propel the design activity in a new productive direction, and materials may play an important role in this process. In the instrumentalisation process, designers may develop motives related to the use of the material itself. Thus a material may be considered a long-term object of a continuously ongoing instrument-making activity. Such motives reflect a designer's personal appreciation system that is crucial for the designer's ability to provide a unique approach to new design tasks.

Materials and development of designers' motives

I earlier addressed the co-evolution of motive and environment, introduced by Leont'ev (1978), as important in designing (Nordby, 2010). Leont'ev describes that motives are dynamic entities that allow people to change the world, but that is also changed through this interaction. Co-evolution of motive-environment reflects how the developments of designers' motives for designing develop through interaction in and through the world.

Central to these processes are designers' subjective interpretations of the design situation. In situations where the motives and needs of the assumed end users are difficult to obtain or entirely new activities are introduced, designers fill the gap of motives by propelling the design activity by their own motives.

Here, a designer uses his or her own experiences and cultural references as a tool to understand motives relevant for other people. Although these motives may differ from those of the proposed users, they allow development of proposed designs that can be tested at a later stage. As the designs are conceptualised and externalised through the designer, his or her subjective influence in the design will always be present. After all, a designer's or design groups' subjective agency is what drives the activity.

When designing user-oriented functions, such subjective factors might be less obvious because functions are often partly embedded in the given design brief (rethinking functionality remains a major goal in most industrial design). However, considering aesthetic expression, the designer's subjective approach to form is very clear. Here, common design training aims to help aspiring designers find their personal expression and use design judgment to craft expressions that fit particular form traditions. Still, as the designed form is to resemble a new expression, designers' subjective design is essential in the conception of forms.

This separates design practitioners from other participants in shared processes of design, as in specialising in actively probing and using one's own motives regarding the right shaping of end-user experience, to enable conception of new kinds of experiences. They actively and knowingly wrestle with motive-level dilemmas of other people and knowingly use their own personal repertoires, which include preferences and taste, to develop what could be presented in the shared design process.

Designers' subjectivity in designing

As mentioned earlier, interaction and industrial designers deal with creating artefacts that mediate experiences. To be able to create such artefacts, designers need to filter their knowledge of materials through the search for possible experiences, and people’s experiences must be seen in relation to being realised by technology. Thus, designers’ ability to understand potential experiences in relation to possible designs is important. Such a process is not only pursued by objective means but demands personal engagement by the designer.

When looking at a designer’s individual activity, subjective and personal approaches toward designing are important. Such approaches concern situations in which designers evaluate their designs based on their personal interpretation on behalf of the targeted users. Nelson and Stolterman address this as seeing design as service on behalf of the other (Nelson & Stolterman, 2003). One way of seeing this type of approach, as Nelson and Stolterman note, is that the designer engages in an empathic relationship with the potential users. Such a relationship has been described as emphatic design (Segal & Fulton, 1997). Empathic design sees designing as a dialectic relationship between users and designers in which the designers engage subjectively with the user situation.

Empathic design represents a crucial skill designers bring to the design activity. Inside the design community, such personal approaches toward designing are largely accepted and supported. Schön’s (1985) concept of reflection in action applied to design practices accounts for the subjective rigor a designer applies to the situation. Schön shows how designers define a design world through problem setting and the consequent exploration of it. This world can be shared among designers. However, Schön (1992a) claims that the more innovative the design episode, the more likely the episode is unique to the designer. This suggests the importance of a designer’s subjective approach in creating unique results.

Sengers (2006) addresses designers’ subjective approach to designing through the concept of autobiographical design. As such, designers use their own experiences to understand the complex issue of future possible user experiences. This is not seen as a substitute for user-centred design, but rather as an important addition. Schön’s (1992a) work emphasises this where he underlines the importance of educating design practitioners by guiding them through situations in personal ways rather than dictating prescriptive rules.

Thus, we view the designer as skilled in mediating possible user experiences through the self as well as through more objective means. This makes the design activity not only an exploration of the objects of the design activity, but also about using and exploring the designer’s self as a catalysing agency to situations of great uncertainty.

The aforementioned perspectives on designing matter for our understanding of materials. They elaborate on how materials are a tool for inspiration as well as production. They also show how motives are central to this in guiding design processes and also as something the design activity must explore.

Finding motives

Earlier I asked the question: How may we describe the material-related activities of industrial and interaction design? To answer this question I have analysed near-field materials and the conceptual material using activity theory. I propose the conceptual material presented in this thesis may be seen as working in two directions for design. Partly it could be seen as mediating the development of designs in a situated design activity. In addition, conceptual materials may be seen as an object of the activity of designers, who are oriented toward development of their material-oriented repertoires.

Furthermore, the concept of a material's properties related to form-making can be connected to both the conception and the development of a form. In the process of form-making, materials may be seen as contributing in two directions: toward the artefact to be designed and toward the designer as subject. Motives are central in both these directions. Firstly, motives are connected to emotions that may be used in the process of interpreting materials in terms of possible experiences. Secondly, materials may aid the development of new motives that may move the design activity in new directions. In both perspectives, motives are seen as a link to not only conceptual development, but also to conceptual development related to people's feelings and sense-making.

This is why when making design artefacts for industrial and interaction design, interest lies in supporting the development of motives in addition to instrumental support for reaching goals and the offering of conditions for operations. The conceptual material seeks to achieve this by taking up the notion of form-making and introducing motive level support in its structure made up by the form-making qualities.

Based on this study that has highlighted how motives play a role in the use of materials, it is useful to ask whether motives, as used in activity theory, may be positioned as a central concept in the experience-oriented designing of industrial and interaction designers. I propose it may be fruitful in the future to analyse such designing in light of motive development. In doing so we may find that at the core of designing is not problem solving, but the opportunistic processes we may address as *motive finding*. The concept of motive finding directs designers' attention toward developing social motives that may lead their design activity in novel and fruitful directions. Here we might find designers' conscious and unconscious search for the right motives to be considered a core design skill. This highlights designers' ability to generate new designs, rather than reflect upon them when they are generated.

Designers need to develop the very motives driving their own design activity. This involves negotiation of the designer's personal motives, the anthropocentric and technocentric motives and, most importantly, the possible motives of the activities of which the design outcome will be part. Sensibilities toward how to manage, maintain, develop and sort such motives may be considered crucial skill designers bring to complex design situations, especially ones involving technologies such as SR-RFID.

Motive finding may be seen as a supplement to models that explain designing as problem solving, solution oriented or reflection in action. These are all important perspectives, but they may be further extended by seeing motives as a combined personal and social construct that designers engage with in managing their creative agencies. In this way, motive finding as a concept points toward the activity-level subject matter designers engage in when conceptualising new designs.

Having elaborated upon SR-RFID as design material, discussed how the new construct can be considered a special type of conceptual material and discussed how materials in design need to be understood in relation to creative agency and motive finding, we may now see SR-RFID from a design perspective. In doing so, we see that designers' connection to SR-RFID is not only about the objective properties of technology. Rather, a design perspective stresses the meaning of technology as materials inside social design activities. Design materials must be cultivated inside design communities to further strengthen conception, construction and collaborative development of new designs. A design perspective on SR-RFID as design material has been developed through the three journal articles that are part of this study. In the following section, I will present these briefly before summarising the conclusions of this study.

[Inserted page:

Article 1:

Nordby, Kjetil & Andrew Morrison. (2010). Designing tangible interaction using shortrange RFID. *FORMakademisk*, 3 (2): 77-96.

http://www.formakademisk.org/index.php/formakademisk/article/view/78/0

Article 2:

Nordby, Kjetil. (2010). Conceptual designing and technology: Short-range RFID as design material*. International Journal of Design*, 4 (1): [pp]

http://www.ijdesign.org/ojs/index.php/IJDesign/article/view/625/285

Article 3:

This article has been removed from the electronic version of this thesis due to copyright restrictions.

Nordby, Kjetil. (2011). Multi-field relations in designing for short-range RFID. *Personal and Ubiquitous Computing*, 15 (2): 175-185.

Full-text available here:

http://dx.doi.org/10.1007/s00779-010-0296-6

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Chapter 5: The Articles

This thesis is the result of three journal articles developed over the course of four years. Through these articles, an activity-theory-based framework related to interpretation of technology as design materials has been partly revealed. Following is a short summary of the three articles.

ARTICLE 1

Nordby, K., & Morrison, A. (2010). Designing tangible interaction using short-range RFID. *FORM akademisk.*

Figure 4.1. The article took up simple tangible interaction driven by RFID-enabled phones. The image shows one example of such a phone.

In the early investigation of SR-RFID technology, we identified the limitations of the concept of Touch. Early experimentation suggested a move from investigating interfaces using touch to investigating different forms of touch interactions. This was taken up in the first article, ‘Designing tangible interaction using short-range RFID’ (Nordby & Morrison, 2010) (Figure 4.1), which focused on interactions driven by SR-RFID embedded in phones. In the article we asked: What interaction design techniques and features may be developed to further the design of SR-RFID?

The article was co-written by my supervisor, Andrew Morrison, and draws on multiple research domains including HCI, design research and activity theory. As in all the articles, a process of research by design was used to investigate SR-RFID through practical experiments.

The study included an extensive study of the use of SR-RFID in practice and research. In doing so, we found richer use of RFID outside the community related to mobile phones. This led to taking up the perspective of tangible interactions (Hornecker & Buur, 2006).

In an effort to direct the findings related to tangible interactions toward design practitioners’ design process, we used Leont’ev’s activity structure to systematise three different layers of design repertoires related to SR-RFID. Following this, we use the concept of affordance informed by the levels of activity to identify relations between the design and the RFID technology (Bærentsen & Trettvik, 2002). This resulted in the system allowing us to order design-oriented technology knowledge according to operational, instrumental and need-related affordances for designing.

In order to answer the research question, ‘*RFID-based tap and hold*’ was proposed as an alternative to the previous concept of touch to describe tangible interactions driven by SR-RFID. Tap and hold was considered a need-related affordance. Furthermore, the concept was enriched by the presentation of an interaction model describing both key constructs and their relations so as to enable the description and prescription of tap-and-hold-driven interactions using SR-RFID.

Finally, a number of interactions created through experimentation were described using the tap-and-hold model. The interactions represented operational affordances that could be used directly in assembling SR-RFID-driven interfaces. Furthermore, the interactions showed how the instrumental model could be used to describe abstract SR-RFID-tangible interactions.

The article showed that supporting movement between the levels of activity by proposing multiple connected levels of design repertories could be useful in designing. However, the results gravitated toward the instrumental and operational levels of designing. To address this limitation, the next article specifically addressed the higher levels of activities.

ARTICLE 2

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

The article, 'Conceptual designing and technology: Short-range RFID as design material,' took up the perspective of design materials as a core strategy (Nordby, 2010) (Figure 4.2). Method-wise, the analysis spanned a larger set of prototypes and scenario types than the previous article. This was due to a clearer focus on RFID as an abstract technology rather than connected to particular kinds of interfaces. In working with this particular article, the full range of production in the Touch project was more prominent, as the investigation dealt with all aspects of SR-RFID instead of just tangible interaction.

Figure 4.2. The study went beyond phones and included other forms of RFID technologies, here represented by an RFID-equipped toy designed by the author.

The cornerstone of this approach was to focus on the technology as a material used by designers in the conceptual phase of designing. Arguably, the conceptual phase of designing is seen as particularly important in industrial and interaction designing. It is here the big moves are done and where the premises for entirely new artefacts are created. This article explored conceptual designing and what role materials played in the early parts of the design activity. Due to this, the materials' role as a thinking tool was more prominent than its role as condition for the physical production of artefacts.

To investigate the role of SR-RFID as material in processes of conceptual designing, two questions were posed:
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 meet these challenges, the article drew focus to motive as a key concept in designing. Motive, which was described earlier in this text, enables us to address the forces directing the design activity and to connect personal needs to the objects of the design activity.

To support designers' conceptual forming of SR-RFID, the concept of form-making became a central focus of inquiry. That enabled focusing on potential forms as a key factor motivating designers to use a particular material. This is addressed through the concept of form-making qualities, which encompass what different categories of forms can be made with a material.

In addition, the article proposes a process that may be used to appropriate ill-defined technology as a well-framed material for designing. This is done through a process of interpreting a technology in terms of what designers shape in designing. This perspective is used to limit the scope of the technology in question and to produce a specific definition of it as a design material. Further, the new material is explored in the search for form-making qualities.

This study performs this exercise on SR-RFID technology. In doing so, it is reframed as the near-field material. This material is divided further into six form-making qualities representing the dominant categories of forms it offers designers.

The article's main contribution is to completely detach SR-RFID from current approaches and present a framework for understanding it in terms of the creation of forms. Further, it also sharply focused on the form of an intangible phenomenon rather than the radio transmitters or processors enabling it. Such framework makes little sense in the context of implementing the solution. However, as it focuses on aspects in the core for shaping concepts, it helps designers focus on their form-making.

The second article defined the material from a top-down perspective. It also showed how tap and hold might be seen in context with five other kinds of forms. To further populate this model with content, other form-making qualities could be explored in detail.

ARTICLE 3

Nordby, K. (2011). Multi-field relations in designing for short-range RFID. *Personal and Ubiquitous Computing.*

The final article drew on the frameworks created in the first two and applied them to a new form-making quality. The article, called 'Multi-field relations in designing for short-range RFID,' did so by addressing the use of multiple fields as a way of creating forms (Nordby, 2011) (Figure 4.3). The following question was posed: What conceptual framework can be used to support the design of multi-field inputs?

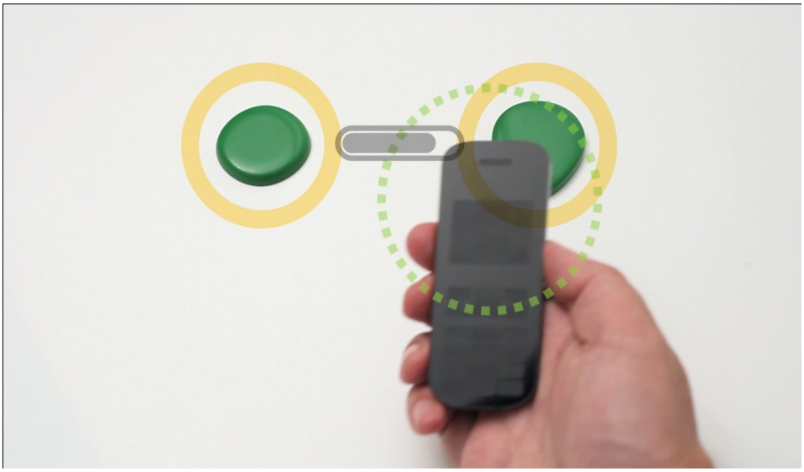

Figure 4.3. The third article used interaction sketches and visualisations to discuss multi-field-driven interactions. The image shows a representation of a gauche interaction component (Nordby, 2011).

The previous articles were taken up by design practice-oriented journals. However, this article was submitted to *Personal and Ubiquitous Computing* (PUC, 2010), because it dealt predominantly with specific interaction techniques and not design theory. PUC is primarily oriented toward computer science, but also accepts more design practice-oriented works (related to views relevant to interaction and industrial design).

This study used two multi-tag-based prototypes and sketches of possible variations of multi-tag systems to develop a conceptual model representing interaction driven by multiple near-fields. The findings addressed the instrumental level of design activity.

In answering the research question, the study introduced *multi-field relations* as a term describing key characteristics of interactions driven by multiple tags and tag readers. The term enables us to look at the logical relationships between multiple tags or readers in a system as a way of providing input.

In the article, I proposed that multi-field relations could be divided into four different relation types:

1. One-way relations concern a field or field group that controls other fields or field groups.

2. Two-way relations deal with fields that mutually control each other.

3. Sequence relations relate to input where making chains of field intersections enables different input.

4. Multiple relations address using multiple simultaneous intersections as input.

The approach taken in this article is in contrast to other works, which usually deal with multiple tags and readers as an asynchronous relationship. It is also one of few studies trying to make sense of multiple aspects of multi-field interactions rather than providing an interaction-technique-centric study. This is important in supporting the design of new multi-field-driven interactions.

The final article is important in the combined work as an example of how the concepts of the first and second article can be used to further investigate additional aspects of a material. When the findings of this article are placed in context with the rest of the near-field material, it reveals a wide array of properties, combinable in many ways that maps an enormous solutions space related to SR-RFID. This counters the common assumption that SR-RFID is a simplifying technology. Together, the findings of the three articles may be seen as a critique to current RFID-oriented practices on touch-driven interactions, by questioning whether touch is sufficient to describe RFID-driven interactions.

Chapter 6: Conclusion

The computational technology designers use as materials is crucial in designing, not only as a means of producing an artefact but also as a tool in creative development itself. This makes knowledge related to such technology a necessity in activities of designing. Still, much computational technology may not be created and presented by technology companies with designers' creative activities in mind. The research reported in this thesis has engaged with this problem through an investigation of SR-RFID technology as a material used by industrial and interaction designers in a research by design approach that connects researching and designing bi-directionally. Industrial and interaction design are sub-fields of designing that share important goals, values and tools. Consequently, the argument is that the two disciplines have similar needs related to the use of SR-RFID in the process of designing.

The title *Between the Tag and the Screen* points toward how this thesis is investigating SR-RFID outside the context of specific interfaces. Instead, I have been interested in how SR-RFID may be understood as a design material in its own right. As SR-RFID is an emerging technology, current use may not offer full insight into the technology's potential in terms of making new forms. In addition, current examples may not be sufficient background for designers seeking to produce new designs, instead directing designers into similar kinds of solutions. Due to this, there is a need to expand the understanding of SR-RFID technology from its current use to potential future use. I have argued that this may be realised by developing a design-oriented understanding of SR-RFID technology as design material. Such a stance may serve as a supplement to the knowledge mediated through existing design exemplars and enable designers to more quickly grasp the potentials of a technology as a material for designing.

The study uses research by design as a principal method to interrogate technology through designing. This has been conducted in collaboration within an interdisciplinary design team consisting of engineers and designers from graphic, interaction and industrial design. The designing has been carried out through a series of design processes, each illuminating different aspects related to SR-RFID and designing.

To analyse the results, the study used research from a wide area of fields, including design, HCI and psychology. In particular, the use of activity theory has helped me develop a theoretical approach that has made it possible to analyse technology in relation to designing as an activity. The joint practical and theoretical procedure has resulted in a better understanding of SR-RFID and a stronger theoretical framework concerning materials in design practices. The dominant insights are summarised in the following sections structured with reference to the initial three research questions:

1. How may SR-RFID be presented to support industrial and interaction designing?

2. In what way may we re-conceptualise new computational technologies as material for design?

3. How may we better understand the use of materials in industrial and interaction design?

1. NEAR-FIELD MATERIAL DESCRIBES DESIGN-RELATED ASPECTS OF SR-RFID

To answer the first research question, I have proposed near-field material as a new conceptualisation of SR-RFID geared toward supporting design activities. Near-field material offers a large set of form-making motivational, instrumental and operational affordances. Together, the affordances make up a new understanding of key properties unique to SR-RFID-related form-making.

Through this study, it became evident that SR-RFID consists of multiple different components, each individually formable. For instance, SR-RFID covers radio transmitters, various output modules and different casings for antennae. Due to this, we may consider SR-RFID as a design material with an unclear boundary. This makes it hard to analyse the technology as a material with specific properties.

To overcome this problem, RFID material was reduced to the essential parts designers shape into their designs. This led to the definition of near-field material, which consists of radio fields generated by SR-RFID technology and their interaction. These fields are the basis for SR-RFID-driven interactions and a cornerstone for designer conceptualisation of SR-RFID-related forms.

Near-field material is expressed further through a set of operational, instrumental and motivational affordances. The motivational affordances provide a top-level overview of the different forms offered by near-field material. The instrumental affordances provide models that explain the workings of each form-making quality. Finally, operational affordances show a wide range of different examples of forms. Together the affordances make up a hierarchy of elements that can be combined in any way, offering a vast range of design opportunities.

The near-field conceptual material has three main advantages. Firstly, it allows designers to efficiently understand the opportunities of design-related attributes unique to SR-RFID technology. Secondly, it offers multiple levels of understanding of the material, which may suit all three levels of activity. Thirdly, it provides an abstract view of the material, which may guide designer form-giving without prescribing possible solutions.

The near-field material differs significantly from the current understanding of SR-RFID. In essence, it involves a material that does not exist alone outside other materials. For instance, to shape the near-fields we must ultimately transform radio antennae, computer code and distribution of radios. However, the near-field material allows us to transcend these elements and instead conceptually shape the effect of them in the form of interactive opportunities offered by the near-fields. The near-fields may in this way be seen as a container of properties that, although shaped by other means, can help focus designer attention on essential features of SR-RFID-related designing.

2. CONCEPTUAL MATERIALS ARE USEFUL FOR DESIGNING AS SENSE-MAKING TOOLS SUPPORTING COMPLEX MATERIAL PRACTICE

To answer the second question I claimed that material as a concept may be tied to particular activities. Thus the meanings of materials changes according to the praxis and even the activities of individual people. Furthermore, I used activity theory to develop a method for reinterpreting complex technologies as design materials. Central to this process is the introduction of conceptual material. Such material is constructed so as to specifically support the conceptual development of a design rather than the eventual production of an artefact. Conceptual materials may be considered tools aimed at supporting form-oriented thinking. The conceptual material differs from traditional conceptions of materials in that it concerns a material made to support conceptualisation of new designs rather than the physical production of them.

A conceptual material consists of a clear description of the boundaries of a material. The boundaries are created to bring forward characteristics of a technology directly influencing designers' conceptualisation of form. The material framing is further populated by affordances directed to the motivational, instrumental and operational levels of the design activity.

Conceptual material allows the transformation of loosely framed technology to well-defined design materials. This enables us to present complex technology in an abstract yet approachable way, making it easier for designers to include it in their designing. Conceptual material helps us to focus on the aspects of complex technologies that are particularly useful in designers’ form-giving. As such, the material is derived from designers' needs first, rather than the technology itself.

3. MOTIVES ARE CENTRAL FOR UNDERSTANDING USE OF MATERIALS IN INDUSTRIAL AND INTERACTION DESIGN

In answering the third question, I have analysed the use of materials inside interaction and industrial design using activity theory. These are early attempts of an activity-theory model centred on the designers’ personal and social activity. This proved useful in understanding the relationships between technology as material and designers. Having applied activity theory I argue that although materials need to be seen in relation to the full activity, including actions and operations, we need to pay particular attention to the role of motives.

The reason for this is that the object of designers' activity is to create artefacts that mediate experiences. The implications of such a view are that the focus on materials expands from what constructs artefacts to what materials means in context of further experiences. Form-making (or form-giving) directs attention toward the communicational aspects of material forming as well as the functional and structural.

Motives are useful for understanding designing in two central ways. Firstly, motives represent an intermediary link between people’s objective items in the world and their needs and feelings, including his or her personal self, aesthetical sense, preferences and values. Thus, motives mediate important aspects designers face in making novel experiences. Secondly, because motives direct all activities, they are also the source of designers’ creative development. In such light, the generation of new designs is enabled through negotiation of the multiple motives involved in the design process. This makes the combined collective and subjective rationale for making a design one of the principal concerns of the designer’s practice. This highlights designers’ need to identify, generate, negotiate and modify their own and other peoples’ motives in the process of conceptualising new designs using materials.

Motives mediate important aspects of a designer’s problem spaces. For instance, one can argue that industrial and interaction designers are particularly bent toward motive-level issues in their designing. At this level, people’s desires, cultural belonging and personal sense are principal concerns. Bødker (2006) addresses this as the third wave of HCI where the first and second correspondingly dealt with the operational and instrumental level of activity.

I argue that the development of motives in using materials is important in two ways. Firstly, materials are important in designers' development of the design activity itself. In exploring materials in relation to a specific design activity, a designer may generate new motives that may be used to move the design activity in new and innovative directions. Secondly, when exploring materials, designers may develop their own repertoire of potential motives directly related to the material itself. Such subjective understanding of materials is important for designers in that it allows them to bring particular material approaches to new design situations, thus infusing future activities with personal meaning related to materials use.

The near-field material and the conceptual material are generated from the perspectives of supporting motive development in design activities from the go. As such, they point toward how design research should orient attention toward supporting designers' development of motives in designing in addition to the important goals and conditions.

NOTES ON ACTIVITY THEORY AND RESEARCH BY DESIGN

In earlier works, activity theory has predominantly been used to analyse designing as a multidisciplinary process or to study user activities. The current study has shown how activity theory may also be useful for analysing industrial and interaction designers' individual and collective designing with materials. It also allows us insights into how designers grapple with new technologies in industrial and interaction design frames. This is important because designing, in essence, is dependent both on the individual agency of a designer and his or her ability to act in a larger socio-cultural context.

Activity theory allows us to bridge the personal and the social by providing a rich set of analytical tools that enables us to see the personal and the cultural as a unified system, rather than as separated worlds. Although activity theory has been useful in this study, it has not been without difficulty. As most of the research related to activity theory and design has been oriented toward other aspects of designing than the ones pursued in this study, it has been a testing process to adapt it for my use. I suggest further research is needed to better position activity theory inside an industrial and interaction design praxis perspective. I suggest three avenues for such research:

Firstly, the self, motives and emotions are aspects of particular importance for design. However, these are not extensively covered in activity theoretical studies oriented toward design activity. It would be useful to study these aspects further so as to help us tackle them more robustly and to strengthen our understanding of these immensely important areas of design knowledge.

Secondly, although activity theory may be used as I have done, to show the overarching structure of the design activity, the presented structure does not cover the full complexity of the design activity. Such conceptualisations of design should be used cautiously, as they hide the complexity involved in creative activity, making the activity seem more straightforward than it is. By seeing design activity as a dynamic structure of multiple overlapping and merging activities, this may be resolved. Yet, I argue that activity theory needs to develop better tools to be able to fully deal with the ambiguity, complexity and uncertainties of the design activity.

Thirdly, most of the activity theory-driven studies are oriented toward studying other people in their context. This is not so in my study, which takes the stance of research by design in which I as an author take an active role in a design-driven investigation. Such a design-driven approach is not to my knowledge described within activity theory. It is likely that by doing further research we may use activity theory to further develop a theoretical understanding of research by design. If we can achieve this we will have extended the use of activity theory from mostly being about understanding users from a third-person perspective to understanding design interventions as analytical, generative and explorative tools from the perspectives of designers, design activity and design professions.

According to Sevaldson (2010), research by design uses designing as a way to further develop design praxis. Such processes shift between design interventions and research-oriented reflection in a dialectic relationship. In such processes it is important to develop alternative frameworks that show how a design activity may be used to develop signs and tools in support of design praxis and research. In processes of research by design, methods and traditions related to designing itself are well understood. However, theories and frameworks that may guide the research side of research by design are less elaborated. I suggest that activity theory should be considered as a fruitful approach to the further development of research by design.

NEAR-FIELD MATERIAL AND BEYOND

Manzini called for minimising the differences between what is possible and what is thinkable (Manzini, 1986). To do so I have shown that materials should be analysed in relation to designers' needs. These needs concern knowledge related to construction of the artefact and also related to the development of possible experiences.

Materials are a prime concern in traditional design practices. However, inside interaction design, materials approaches have been less developed. Instead, the focus has shifted toward users and their cultural and cognitive understanding of interfaces. Such knowledge is important. However, when striving to generate entirely new experiences, deep knowledge of the technologies that mediate experiences is necessary. My analysis of SR-RFID technology, a seemingly simple technology, have uncovered a rich set of concepts that may inspire new kinds of solutions. They support motive finding in opening up an entirely new way of interpreting SR-RFID.

The results shown here may be seen as a call for maintaining and further developing a rich discourse related to technology interpretation inside the design practices. This discourse does not necessarily overlap with engineering or other design-discipline discourse, but must adapt to the tools, knowledge and motives specifically relevant for the discipline in question. By doing so, we may produce tools that not only make technologies easier to understand but also specifically help designers use them in conceptual development.

Special attention needs to be paid to how we understand computational technology as materials. This is due to how such technologies may be both hard to grasp and possibly interpreted in many ways. My approach to SR-RFID is only one of many possibilities. Thus, materials discourse related to computational technology is not merely a question of material properties, but also a question of what constitutes a material. In this way, computational technology may direct our attention to the differences between digital and physical ‘matter’ and materials as signs in processes of design. I suggest that these are areas that may benefit from further theoretical developments in design research.

Bringing the results of this thesis back to the origin of the project and the study of interactions on RFID-embedded mobiles, I now make a suggestion. As SR-RFID is released in wider marketplaces and embedded in mobiles, it is likely that the technology will be used in the creation of a large range of innovative services not foreseen when specifying NFC. In the further development of such standards, it seems useful to develop and present SR-RFID as a design material. In doing so, the technology may be presented to designers with documentation and tools that may expand and accelerate the future creative potential of the technology in addition to the creation of specialised tools that support the already anticipated application areas. In this way, standards may be directly oriented to support designers’ creative form-making. This benefits designers’ need to develop innovative services. In addition, it may benefit technology providers by opening new unforeseen market niches.

This thesis has added to research seeking to support creative use of SR-RFID technology. Reflecting on the title of the thesis, I argue that by exploring the design space between RFID tags and the screens of RFID reader devices, I have been able to develop the near-field material. This material is defined specifically to support innovative use of SR-RFID by presenting information that may help the formation of motives as well as the carrying out of actions and operations.

Research will continue to play an important part in the further exploration and clarification of SR-RFID as material, pragmatically and conceptually. It is important that research oriented toward making sense of technologies for design practice and research also considers how the research may be taken up into an ongoing design discourse. Such research-informed materials-oriented discourses should include attention to motives for using SR-RFID as well as goals and conditions. I hope that by doing so, researchers can develop new technologies in such a way that designers may more easily find their own voice within them as design materials.

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Appendix

Article 1

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Article 2

CONCEPTUAL DESIGNING AND TECHNOLOGY: SHORT-RANGE RFID AS DESIGN MATERIAL

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Article 3

MULTI-FIELD RELATIONS IN DESIGNING FOR SHORT-RANGE RFID

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