Design Research & Tangible Interaction

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ABSTRACT
The research on Tangible Interaction (TI) has been inspired by many different disciplines, including psychology, sociology, engineering and human-computer interaction (HCI). Now that the field is getting more mature, in the sense that basic technologies and interaction paradigms have been explored, we observe a growing potential for a more design-oriented research approach. We suggest that there are several arguments for this proposed broadening of the TI-perspective: 1) the need for designing products within contexts-of-use that are much more challenging and diverse than the task-oriented desktop (or tabletop) systems that mostly inspire us today, 2) the interest to also design TI starting from existing physical activities instead of only as add-ons to digital applications, 3) the need for iterative design and evaluation of prototypes in order to develop applications that are grounded within daily practice over prolonged periods of time, and 4) the need to extend ease-of-use to more hedonic aspects of interaction such as fun and engagement

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Design, tangible interaction, action research, design research, embodied interaction, product design.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces – *Haptic I/O, Input devices and strategies (e.g., mouse, touch screen), User-centered design.*

INTRODUCTION
In our Industrial Design department we believe that the engineering approach and the human sciences approach can benefit from the addition of design. Design has the potential to integrate engineering knowledge, knowledge from the human sciences and design knowledge in one coherent process. In this paper we want to show how the design research approach can realize this integration of different fields in the research context of Tangible Interaction (TI).

Tangible Interaction or Tangible User Interfaces, denotes a recent and fast-growing research field that is inspired by many different disciplines. Consequently, many different approaches and paradigms have been proposed to further this field (see the next section "from tangible interaction to design research" for more detail). The HCI field, which combines knowledge from the human sciences with technology, has for example promoted the importance of ease-of-use and the need to let HCI profit from the well-developed skills that people possess for handling physical tools and managing social relationships [7]. In this sense, TI is seen as the next step, beyond graphical user interfaces, towards a more direct manipulation [27] of virtual information by human operators. Engineers on the other hand have addressed the technological challenges posed by Tangible Interaction by developing advanced input technologies, such as optical, electromagnetic and acoustic tracking, and new ways for combining real and virtual worlds, such as virtual and augmented reality [21]. The authors of this paper, who have a mixed background in design, engineering and human factors, think that TI is now advanced enough to form an important inspiration for product design, especially for the design of ICT (Information and Communication Technology) based products that are the core interest of our Industrial Design department. We are also convinced that, in order for TI to develop beyond the laboratory setting that it is mostly in today, it should be increasingly inspired by design activities that are aimed at providing more insight into the opportunities offered by different contexts-of-use. Both in general terms (in the section on "a design research approach") and through specific examples (in the case studies section) we intend to make clear how TI could, in our view, benefit from such a proposed Design Research approach. We will round off the paper with a short discussion on other visions supporting our broadening of the TI-perspective.

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FROM TANGIBLE INTERACTION TO DESIGN RESEARCH

Tangible Interaction

Early user interfaces (UI) employed indirect command line interaction that was nevertheless quite efficient in the hands of computer specialists. Later on, graphical user interfaces (GUIs) became increasingly widespread and provided a much wider audience with access to computers. These GUIs were inspired by the concept of direct manipulation that was formulated by Shneiderman [27]. His proposal was to make objects and actions in interactive systems visible to the user so that they could be more easily recognized, manipulated and remembered. The ultimate goal of direct manipulation was to give users the impression that they were directly interacting with the information presented on-screen. Such a degree of engagement in the interaction would imply that the user was "interacting through, instead of with, the computer".

At approximately the same time the notion of seamless design was proposed by Ishii et al. [17]. They argued that continuity with existing work practice and everyday skills was essential for interactive systems. It allows the reduction of workload, improves user acceptance and makes systems easy to learn and use. The idea of the DigitalDesk, designed by Wellner [31], was based on this notion of seamless integration of physical and digital worlds. However, such systems were still somewhat removed from manipulating digital data in a direct and physical way. In 1995 Fitzmaurice et al. [10] introduced Graspable User Interfaces that allowed direct control of digital objects through physical handles. This concept offered an even more tight and seamless connection between physical and virtual worlds. The main motivation was that the affordances offered by physical handles (such as the possibility of two-handed manipulation, spatial caching, simultaneous control over position and orientation, etc.) were much richer than the affordances offered by virtual handles. A new name and a more general definition of Graspable user interfaces were introduced in 1997 by Ishii and Ulmer [28]. They called this new interface paradigm: Tangible User Interfaces (TUI). In short they defined the goal of TUI as augmenting the real physical world by coupling digital information to everyday physical objects and environments. Their key observation was that tangible objects should not only be considered as input devices, but that the observable state of these devices should be more closely linked to the state of the digital applications that these devices are interacting with. Up to this point in history physical objects used in tangible interfaces were usually passive. The (mostly fairly simple) physical shapes of the objects were fixed and often did not reflect the function of the objects (for example, many systems used brick-like shapes [3], [10], [25] etc.). The output displayed by the digital system was usually needed to reflect the properties and functions of these physical objects.

It was shown that in terms of usability and natural interaction TUIs clearly outperformed standard mouse- and keyboard-based interfaces (e.g. [9], [22]).

Tangible Interaction and Design

Although one of the first and best-known examples of tangible interaction, the marble answering machine of Bishop [23], explored an alternative interaction style in a product context, preciously few other examples of consumer products with tangible interfaces can be found. Yet, we believe that tangible interaction has value in an industrial design context. The area of industrial design is shifting towards the design of interactive products and these products increasingly gain complex behavior. This increasing complexity of interactive products might be made easier to grasp using tangible interaction techniques as was also argued in the introduction. However, we also think that the concept of tangible interaction will change in a product context. Let us first briefly compare the area of tangible interaction with the area of product design.

Tangible interaction (TI) builds on a base of HCI knowledge. This HCI background is the cause of several differences when we compare the TI approach with a traditional product design approach. We point at two important differences.

Firstly, there is a difference in the way that the concept of usability is approached. A definition of usability that is often used and quoted in the HCI context is the ISO/DIS 9241-11 standard: 'The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.' (quoted from [26] p. 72). This definition of usability demonstrates the influence of the origin of HCI: the work environment with its focus on efficiency and effectiveness within specified tasks and contexts. Product design on the other hand has a much broader area of application. It ranges from the professional work environment to the home environment and from goal-oriented activities to leisure-oriented activities. Empathizing with such diverse contexts and identifying opportunities for new products within them, is a core activity within product design. Products are hence designed to provide added value, i.e., to address a specific design problem. They aim at providing solutions for human needs. The focus is not only on usability aspects, but also on user experience goals, such as fun, emotionally fulfilling, being supportive of creativity and aesthetically pleasing [24].

Secondly, there is a difference in how interaction itself is approached. Where TUIs are concerned with physicalizing functions or flows of digital information, product design is concerned with physicalizing interaction while expressing functionality. That is, the form of products mediates both the interaction and the expression of functionality. Products are 'packages' where form, interaction, and function are integrated. TUIs mostly offer physical handles for (streams of) digital information. In line with Jensen et al. [18] we think that tangible interfaces are generally designed to control and manipulate digital information inside a computer while products are generally designed to monitor or control something in the physical world.

Summarizing, we have argued that the TI approach of today differs from the product design approach. Yet, we feel that tangible interaction has potential for the design of interactive products. However, few examples of such interactive products with tangible interfaces exist. Product reality today seems very much unrelated to the tangible interaction prototypes that have been developed within diverse laboratories. The only way to change that is to provide compelling products that employ tangible interfacing techniques. In the next section we propose a design-research approach suited to explore this new type of interactive products.

A DESIGN RESEARCH APPROACH

In his influential paper on the nature of research Archer [4] defines scientific research as a 'systematic enquiry whose goal is communicable knowledge'. He identifies five widely accepted categories of research: (1) Fundamental research, (2) Strategic research, (3) Applied research, (4) Action research, and (5) Option research. In this context we are interested in research of the fourth category: action research, defined as 'a systematic investigation through practical action calculated to devise or test new information, ideas, forms or procedures and to produce communicable knowledge' ([4] p. 6). Research through design is similar to Archers' 'research through practice' [4], which is a form of action research. Archer warns that since action research is situation-specific it is 'difficult and dangerous to generalize from Action Research findings' ([4] p. 12). What is important in this statement is the word: 'situation-specific'. For us this implies two things. First, the skills of the designer play an important role. It is through the designerly skills that the problem area unfolds. The problem definition and solution go much more hand-in-hand than is usual in engineering and research. Second, the knowledge gained through a research through practice project is applicable to a specific situation. Or as Hummels states, it leads 'to conditional laws instead of general laws' ([16] p. 1.27). In the case of product design it is applicable to a specific class of products and their design processes. Archer states that a practitioner should position himself in opinion and theory to identify the domain in which the knowledge from his research is applicable.

Knowledge on two levels can be gathered when researching product design. One can research aspects of products themselves, like form or interface, but one can also research the process of how these products came into existence. When conducting research through design, both types of knowledge are intertwined. Knowledge on products and knowledge on the process of designing these products is generated. Products are designed to explore implications of theory in context. Usually, such theories are not specific enough to provide reliable predictions in concrete and complex contexts; they merely serve as inspiration. Turning these inspirations into concrete products that can be experienced is an essential contribution for design. The resulting products can subsequently be subjected to experimentation in real life situations to understand the complex relationship of man with designed reality. The assumption underlying the research through design approach is that knowledge gained from these products, through experimentation, can be generalized in the form of design specifications for future products and in new theory or frameworks. Here lies the essential difference between the research through design approach and the design practice. The first is initiated by a research question and leads to communicable knowledge, the latter starts from user needs and leads to new products. Design skills are instrumental in conducting research through design but it would be a mistake to equate the two. In line with Fallman [8] we distinguish between the two in their aim: knowledge or artifacts.

Why Design Research is useful

To implement the concept of tangible interaction into interactive products it is necessary to integrate it into the design process. In that way tangible interaction can also profit from the knowledge and skills that are part of designing products.

We identify two sets of design skills. On the one side, designers are sensitive to the subtlety of human experience in the broadest sense. That is, they are sensitive to the natural world, but certainly also to the man-made world, and the combination of the two, as they are inseparable. The designers are aware of the diversity of people, how they differ, how they are the same, how they are an individual in a society and in different societies, and how their needs contrast. This sensitivity constitutes one set of skills: it feeds their ideas and concepts. To get subtle ideas, you need subtle sensitivity.

The other set of skills is about making, about converting ideas into physical (observable) artifacts. This is about drawing, mechanics, form giving, materials and how to combine them, electronics and how to program them, and so on. Making constitutes the second set of skills: it feeds the transformation of the world. For creating subtlety, you need subtle skills.

A designer is trained in these skills; they manifest themselves in their use of tools for visualization and physicalization. Designers are trained in the integration of different areas of knowledge (e.g. engineering, production-technology, sustainability, human-factors or marketing strategy) into coherent, subtle, and innovative product solutions. It is in exploiting this power for integration that design offers value for the area of tangible interaction. It means that tangible interaction will not be an add-on to product design but part of it. Design as instrument in a research-through-design approach can be used to explore and validate the knowledge from the field of tangible interaction in a product context. It will yield compelling prototypes and knowledge. It is important to realize that design does not only apply knowledge, it also transforms knowledge. Our understanding of tangible interaction will change.

We see five application areas of the research-through-design approach that are relevant for our search for new knowledge on tangible interaction in a product context:

[A] The design-research approach stimulates you to investigate theory in context while designing your tangible solution, thereby embedding your product in real life.

[B] Since the design-research approach investigates theory in context, it facilitates the creation of a new design based on existing physical activities or products. Traditional TI-work is often based on improving digital activities by adding physical interaction. Turning the perspective around often makes it easier to establish added value for tangible interaction.

[C] The design-research approach encourages the creation of several models/prototypes or demonstrators: learning by doing. Related to the initial research question, during the evaluation phase the most suitable model is selected and later developed further. Such iterative processes are very seldom observed in current TI research.

[D] Once your design is worked out into a demonstrator or prototype (could be quick & dirty, but also full-fledged), it has to be evaluated with potential users of the design. Such prototypes are not only tested in order to improve their usability, but are ways of letting users experience new functionalities. Such experiences often lead to discussions that can inspire re-design or provide ideas for new, related, products.

[E] More mature designs that are sufficiently advanced in terms of usability, robustness and design (on aspects such as material, shape, etc.) may be deployed in situations that allow for a more longitudinal study of their potential impact. Deploying such products in existing contexts allows for gaining insights that cannot be acquired within laboratory experiments.

CASE STUDIES IN DESIGN RESEARCH

In this section we mention some examples and case studies that illustrate aspects of the Design Research approach in our Tangible Interaction studies.

[A] For the creation of a system that can support everyday recollecting [13], extensive studies into the context of use were done, including the way human memory works by investigating Autobiographical Memory theory. This study revealed that memories need to be cued, so that people can reconstruct them on the basis of current knowledge. This opposes the often-believed theory that all events are stored completely in memory and moved the design of the interaction from a focus on database query towards cuing [15]. After studying diverse types of cues that people could use for relating to their memories [13], such as digital photos and videos, smells and souvenirs, it was decided to use souvenirs as physical cues to memories (see Figure 1). The reasons were threefold: 1 - people already have souvenirs in their environment, 2 - they have a mental map of the memories related to these souvenirs and 3 - these physical objects can be used as shortcuts to digital media in a Tangible User Interface for a media browser.

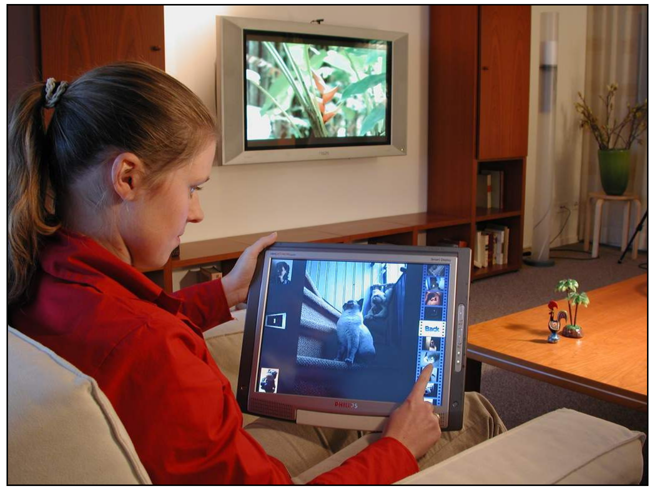

Figure 1. Everyday recollecting support with tangible interaction (Elise van den Hoven).

[B] The example mentioned above is also relevant for supporting claim B. Since recollecting memories, including showing photos, videos and objects to friends and family is in itself a physical activity, which was revealed by studying the context of use, the creation of a support system including Tangible Interaction, expanded on this highly-valued activity.

Another case where the design of a TI started from a physical activity was a student project that aimed at augmenting exercises for young patients with degenerative muscle disease. The exercises that these patients have to perform on a daily basis are repetitive and uninteresting, and hence boring. In order to improve the motivation of the children, the exercises were incorporated within a digital game activity that was displayed during the exercises.

[C] An example of how tangible interaction principles can be incorporated into product design can be found in the PhD research of Joep Frens [11]. Frens explored an alternative interaction paradigm for photo-camera’s to the menus-on-screens-with-navigation-buttons that are paramount today by means of a research-through-design approach. He first created a number of low-fidelity (cardboard) prototypes to explore the solution domain for the new interaction paradigm. This resulted in a new digital camera concept (high-fidelity prototype) that integrates form, interaction, and function, see figure 2. This novel interaction style was named rich interaction, and incorporates concepts from the area of tangible interaction and the theory of direct perception. In contrast with conventional products a user of this new camera does not need to read labels, menus, or icons on generic buttons. Instead it offers its functionality directly by means of expressive form and behavior.

The role of tangible interaction concepts in this new camera can best be demonstrated by an example. To take a picture the trigger next to the screen is pushed (Figure 2a). As can be seen the trigger fastens the screen to the lens. If the trigger is pushed the screen flips away from the lens (Figure 2b), the connection between lens and screen is broken, and the image on the screen freezes; a picture is taken. To save this picture the screen is pushed towards the memory card on the left side of the camera (Figure 2c). The picture will visibly flow into the memory card and is then saved, see also Figure 2. The camera is part of a set of four cameras that span a range of interaction styles from rich to conventional. Those cameras were experimentally compared [11].

This project yielded knowledge on different levels. First, the prototypes themselves provide compelling examples of how products with TI principles could take form. Second, the experiments with the cameras provide insight into the value of TI principles when they are applied to products. Third, it offers a new framework for designing TI-products where the interaction itself is the focal interest.

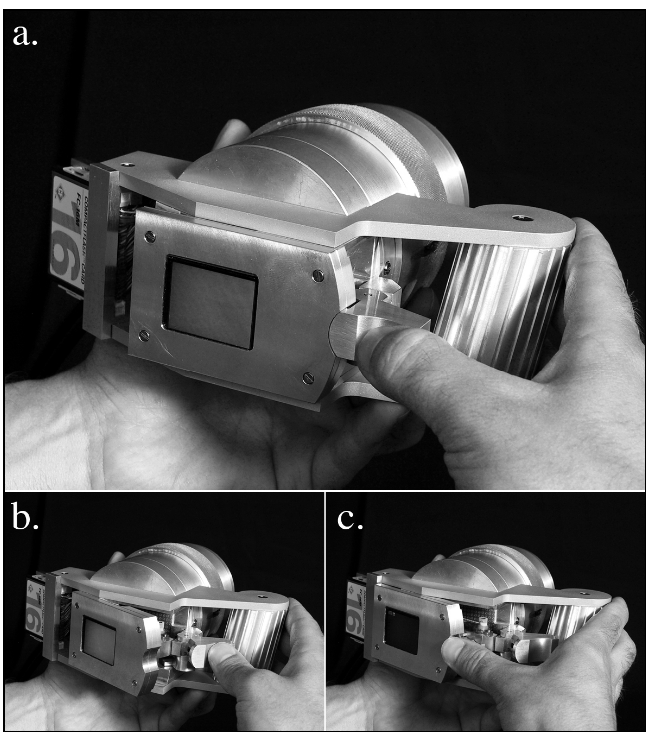

Figure 2. A photo camera developed with a design research approach (Joep Frens) a, b) taking a picture, c) saving picture.

[D] An example illustrating how TI can be evaluated is a study done on the design of tangible objects in digital tabletop gaming [5]. This case study focused on comparing the designs of two sets of playing pieces, each fully operational sets of tangible objects that could be used to interact with the digital game. One set of playing pieces was designed to be iconic, meaning that the physical appearance represented the link with the related digital information, while the other set was symbolic, where the physical appearance did not have a direct link with the digital information. In short this resulted in the iconic set fitting the theme of the game, and the symbolic set possessing a more abstract look. Using the design research approach made it possible to test whether or not both novice and expert gamers preferred any of the two sets of objects.

Figure 3. Electronic paper prototype on the Visual Interaction Platform [2].

[E] The Electronic Paper prototype [2] is an example of a TI that has undergone several iterations in terms of improvements on technology, usability and graphical layout. Based on these iterations the prototype resulted in a mature design. It has been used to probe a particular target user group (in this case architects and designers) into thinking about alternative uses of augmented reality, beyond the sketching activities for which the Electronic Paper prototype was originally designed [20]. Such qualitative user feedback inspires new ideas for potentially useful functionalities. Additional work on the physical form design and on the ease of deployment of the system (which requires robustness, easy calibration, etc.) are currently undertaken in order to make it possible to incorporate the prototype into existing contexts, such as the work environment of the students and staff of our department. This sort of deployment should provide more inside into the longitudinal effects of such a TI system.

In addition to the implementation of this Design Research approach into Tangible Interaction, this new approach will also create possibilities for new Tangible Interaction frameworks or taxonomies. The current taxonomies (e.g., [29], [12], [14]) only mention the actual design of TI objects implicitly, e.g. by distinguishing iconic and symbolic representations (the physical represents the digital, or not for symbolic). In addition to the taxonomy extension by Koleva et al. [19], which adds information about the link between the physical and digital objects, we believe that new taxonomies should focus on the design of physical representations (e.g. form, color and material) and the interaction with both the physical as well as digital objects of tangible interaction systems (e.g. [32]).

DISCUSSION

A trend that seems to support our proposal, for introducing design research into the Tangible Interaction field, is the increasing interest in Ambient Intelligence [1]. Ambient Intelligence, or related visions such as Ubiquitous Computing [30], Pervasive Computing, Calm Technology, Intelligent Environments, Aware Computing, all have one thing in common. They give a vision on the future of consumer products starting from the miniaturization trend, which predicts a development away from large stand-alone components towards tiny ones that are integrated in everyday objects. We already see it happening today: sensors, processors, RFID tags, all kinds of electronics (some even claiming to be “intelligent”) are being miniaturized and are invading our surroundings, i.e., electronics become increasingly embedded in everyday objects.

Of course, this miniaturization creates ample opportunities for Tangible Interaction as we already see happening now, e.g. these tiny electronics can realize tangibles that push back [19], meaning that these objects can react, e.g. by movement (such as the ambient display Pinwheels [6]), to a change in digital, rather than physical, information. In the near future we might expect tangible objects that can give physical feedback, e.g. by changing shape, color or tactile qualities, in response to user actions or other external influences (such as a student project that resulted in a bridge in a game, that can be opened or closed by the digital tabletop it is standing on).

In the actual Ambient Intelligence vision [1], groups of these objects will create networks, and these objects could, for example, recognize people and their situational context, to be able to anticipate the user’s needs in an optimal way. This could mean that TI will be around us wherever and whenever. Therefore the integration of these objects into our everyday world gets more important and prominent, which asks for a design research approach.

CONCLUSIONS

In a research through design process where design methodology meets research methodology, both contribute. Design has the power to integrate knowledge from different areas of research into relevant, highly experiential prototypes. Research offers the methods to conduct experiments and to draw knowledge from these prototypes. It would be a mistake to think that the prototypes that result from a research through design process are products that are production ready. Instead, the prototypes can be seen as ‘physical hypotheses’ that have sufficient product qualities to draw valid and relevant conclusions from.

From traditional psychological, later engineering and HCI approaches, we observed the increasing use of the design research approach in the Tangible Interaction field. In this paper we tried to confirm this observation and show you what the use can be of design research for future tangible interaction studies.

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