Encountering the Digital: Representational and Experiential Embodiment in Tangible User Interfaces

A »Research Through Design« Approach
to the Concept of »Embodiment« in Human-Computer Interaction

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Dedicated to those
who also find themselves in the middle of a
seemingly endless, painful, and impossible
academic journey.

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Abstract

This dissertation is concerned with the concept of »embodiment« in the field of Human-Computer Interaction (HCI). It investigates the issue by the means of Research Through Design (RTD).

The notion of »embodiment« has many meanings in HCI. It is therefore the aim of this work to contribute to its clarification. I propose a distinction between two major meanings: »embodiment« in the sense of »representation« and »embodiment« in the sense of how the experience of one's socio-physical world is fundamentally grounded in having a living body. I propose to name these two meanings »representational embodiment« and »experiential embodiment«.

Having separated the two meanings, I then look at those moments in which they *encounter*: I investigate moments in which »embodied« users face »embodiments« of digital information. These moments of encounter appear to be a central aspect of Tangible User Interfaces (TUIs), which are often concerned with making digital information graspable. Therefore, I focus on TUIs, pursuing the question of how the design of the »representational embodiments« of digital information affects the user's experience of the interaction.

RTD is a research concept that promises to offer a new, »designerly« perspective on a subject matter. There are different approaches to RTD, of which I have chosen Findeli's model of Project-Grounded Research (PGR). I introduce RTD and PGR, contextualising them in their historical context. I underline the central roles of the prototype and the »project« in PGR. I also relate RTD to its academic reference points: action research and grounded theory. Afterwards, I transform my research question into a design question, namely how the »embodiments« of digital information could be designed in a way that is oriented to the users' »embodiment«.

In everyday language, physical (e. g. »disk *size*«, »data *mining*«) and social metaphors (»*smart* phone«, »battery *life*«) are often used to describe concepts of interacting with digital information. These metaphors form the starting point of my investigation into TUIs that make digital information graspable through socio-physical manifestations – through shape change, weight shift, and life-like signals. I describe the prototypes and report several previous studies that were conducted with them. These assess, for example, the accuracy at which users could feel the shifted weight on the phone's inside, or the experiences of users carrying the »living mobile« for a weekend.

I then report a comparative study of the three prototypes and three vibration-based comparison prototypes. In this study, I make use of the Repertory Grid Technique (RGT). RGT is based on so-called »personal constructs«, which the users name themselves, as to describe the prototypes (e. g. »knowledge required – easy to understand«, »biological – technical«, »exciting – boring«). The users then use their own personal constructs to rate the prototypes. The findings of the RGT study indicate that the interaction with the *Shape-Changing Mobile*, *Weight-Shifting Mobile*, and *Ambient Life* prototypes was experienced by the users as novel and interesting, but at times also as irritating, and even annoying. The mixed results from this study can be described as three »two-sided coins«: the interaction with the prototypes was rated as *rich in associations*, but *requiring prior knowledge* and, at times, *disappointing*. It was rated as *permanent*, but at times *annoying*. Lastly, it was described as *cute*, but sometimes *creepy*.

I conclude that the encounter of »representational embodiment« and »experiential embodiment« can open a conceptual space for interaction design that is rich in opportunities, but also rich in challenges. It is this space that I set out to explore with this dissertation.

In summary, the main contributions of this dissertation are a separation of different meanings of »embodiment« in HCI and a study of TUI prototypes that explore the encounter of these meanings.

Zusammenfassung

Diese Dissertation behandelt das Konzept des »Embodiments« in der Mensch-Computer-Interaktion (»Human-Computer Interaction«, HCI) und folgt dabei dem Forschungsansatz der »Forschung durch Design« (»Research Through Design«, RTD).

Der »Embodiment«-Begriff hat mehrere Bedeutungen in der HCI-Literatur. So ist es das Ziel der vorliegenden Arbeit, zur Klärung dieses Begriffs beizutragen. Ich schlage vor, zwei wesentliche Bedeutungen des »Embodiment«-Begriffs zu trennen: Einerseits wird »Embodiment« im Sinne von Repräsentation verwendet, andererseits im Sinne der fundamentalen Bedeutung des lebendigen Körpers für das Erleben der sozialen, physischen Welt. Es erscheint daher hilfreich, diese beiden Bedeutungen getrennt zu behandeln und zu benennen: »Embodiment als Repräsentation« (»representational embodiment«) und »Embodiment als Grundlage des Erlebens« (»experiential embodiment«).

Die Trennung dieser zwei Bedeutungen ermöglicht es, die Momente zu untersuchen, in denen sie aufeinander treffen und einander begegnen. Dies ist beispielsweise der Fall, wenn der, insbesondere als »körperlich« begriffene, Benutzer auf »verkörperte« digitale Informationen trifft. Diese Begegnung erscheint ein zentrales Moment von Tangible User Interfaces (TUIs) zu sein, die oft das Ziel verfolgen, digitale Informationen greifbar zu machen. Ich konzentriere mich in meiner Arbeit deshalb auf TUIs und gehe der Frage nach, welchen Einfluss die Gestaltung der »Verkörperungen« (des »Embodiments«) der digitalen Informationen auf das Erlebnis der Interaktion hat.

Die »Forschung durch Design« (RTD) ist ein Forschungsansatz, der eine »designspezifische« Perspektive auf einen Untersuchungsgegenstand verspricht. Es gibt mehrere Modelle, die dem RTD-Ansatz folgen. Eines davon ist Findelis Modell der »projektgeleiteten Forschung« (»Project-Grounded Research«, PGR), auf das ich mich in meiner Arbeit vorrangig beziehe. Ich stelle den RTD-Ansatz in seinem historischen Kontext vor und gehe dabei insbesondere auf die zentralen Rollen des Prototypen und des Projektbe-

griffs ein. Des Weiteren widme ich mich zwei wichtigen akademischen Bezugspunkten der »Forschung durch Design«: Aktionsforschung und Grounded Theory.

Im Anschluss daran entwickle ich eine gestalterische Fragestellung, die zur weiteren Klärung meiner Grundfrage dienen soll: Wie können die »Verkörperungen« (»Embodiments«) digitaler Informationen gestaltet werden, sodass sie der fundamentalen Bedeutung des lebendigen Körpers für das Erleben der sozialen, physischen Welt (dem »Embodiment« des Nutzers) gerecht werden?

In der Alltagssprache werden häufig physische (»Festplatten*größe*«, »Daten*flut*«) und soziale (»*Smart*phone«, »Batterie*lebens*dauer«) Metaphern verwendet, um Konzepte des Umgangs mit digitalen Informationen zu beschreiben. Diese Metaphern sind der Ausgangspunkt für meine Untersuchung von TUIs, die digitale Informationen durch soziale und physische Metaphern greifbar machen sollen – durch Formveränderung, Gewichtsverlagerung und lebensähnliche Signale. Ich beschreibe die entstandenen Prototypen und fasse die Ergebnisse vorheriger Studien zusammen. Diese sind beispielsweise mit der Genauigkeit befasst, mit der Nutzer die Verlagerung des Gewichts, das sich im Inneren des Geräts verschiebt, erfühlen können, oder aber mit den Erfahrungen von Nutzern, die das »lebendige Handy« ein Wochenende lang bei sich trugen.

In einer weiteren Studie habe ich die drei Prototypen und drei auf Vibration basierende Vergleichsprototypen miteinander verglichen. Hier bediene ich mich der Methode der Repertory Grid Technique (RGT). RGT basiert auf sogenannten »persönlichen Konstrukten« (»personal constructs«), welche die Teilnehmer der Studie selbst benennen, um die Prototypen zu charakterisieren (z. B. »Wissen erforderlich – einfaches Verständnis«, »biologisch – technisch«, »spannend – langweilig«). Die Teilnehmer verwenden ihre selbstbenannten Konstrukte dann, um die Prototypen, jeweils zwischen den beiden Polen des Konstrukts, zu bewerten. Die Ergebnisse der RGT-Studie weisen darauf hin, dass die Interaktion mit den Prototypen von den Teilnehmern als neuartig und interessant erlebt wurde, jedoch teilweise auch als irritierend und sogar nervend. Meine Interpretation dieser durchaus gemischten Ergebnisse fasse ich in Form dreier »zweiseitiger Medaillen« zusammen: Die Interaktion mit den Prototypen wurde als *reichhaltig an Assoziationen* aber *Vorwissen erfordernd* und teilweise *enttäuschend* empfunden. Sie wurde als *permanent* aber teilweise *nervend* bewertet. Letztlich scheint sie als *niedlich*, teilweise aber auch als *abschreckend* erlebt worden zu sein.

Ich ziehe daraus folgende Schlussfolgerung: Die Begegnung von »verkörperter« digitaler Information und dem als »körperlich« begriffenen Nutzer spannt einen konzeptionellen Raum für das Interaktionsdesign auf, der viele Potenziale, aber auch neue Herausforderungen beinhaltet. Es ist dieser Raum, den meine Dissertation in Ansätzen erforscht.

Zusammengefasst liegt der Beitrag der vorliegenden Arbeit in der Aufzeigung zweier verschiedener Bedeutungen von »Embodiment« in der HCI, deren Begegnung dann, anhand von TUI-Prototypen, untersucht wird.

Contents

CHAPTER 1

The Structure of this Book

In this chapter, I provide an overview of the structure of this book. This dissertation is concerned with the concept of »embodiment« in Human-Computer Interaction (HCI). »Embodiment« is a concept that appears to be used ambiguously in the HCI literature. I investigate this issue by the means of Research Through Design (RTD). In the RTD project, I explore the concept of »embodiment« through the design of haptics-enhanced interaction with hand-held devices. Thereby, I pursue the following research question: *What is the potential contribution of design research to a clarification of the concept of »embodiment« in HCI?*

In the second chapter (p. 5), I outline the historical development of the role of the body in HCI. Over the course of this development, the body can be observed to be of growing importance. Besides new ways of interaction, also theoretical accounts of HCI (e. g. »Third-Wave HCI« and »Embodied Interaction«) seem to have increasingly focused on the body. This development was accompanied by a growing concern with the concept of »embodiment« in HCI. However, in the HCI literature, the concept of »embodiment« appears to be used in different meanings.

In the third chapter (p. 33), I propose that »embodiment« in the HCI literature is used both in a sense of *»representational embodiment«* and in a sense of *»experiential embodiment«*. By »representational embodiment«, I mean the signifying relationship of one entity to another in which one stands for (i. e. »embodies«) the other. By »experiential embodiment«, I mean the fundamentality of having a living body for experiencing one's socio-physical world.

Both meanings are used in the HCI literature. For example, Ishii (2008, p. xvi) refers to Tangible User Interfaces (TUIs) as *embodying digital information*: »TUI makes digital information directly manipulatable with our hands, and perceptible through our peripheral senses by physically embodying it.« This is what I mean by »representational embodiment«. Differently, Dourish (2001) understands »embodiment« as a way of being in the world. Dourish (ibid., p. 125) defines it as »the property of our engagement with the world that allows us to make it meaningful«, denoting a »participative status« (ibid., p. 100). This is what I mean by »experiential embodiment«. Both can be argued to be valid usages of the term »embodiment«, but without explicit differentiation, their ambiguity may lead to misunderstanding. Hence, I propose to treat – and label – them separately. Then, after separating these two meanings of »embodiment«, I look at the moments when the »embodied« digital information and the »embodied« user encounter.

For example, avatar-based interaction in a virtual world uses a »representational embodiment« of a user's body, manifested within a »representational embodiment« of a socio-physical world, in order to leverage on the user's skills from the real socio-physical world (which is founded in the user's »experiential embodiment«). Likewise, TUIs can be described as providing »representational embodiments« of digital information that are manifest in the socio-physical world, and thus also as leveraging on skills founded in the user's »experiential embodiment«. Thus, both avatar-based interaction and TUIs follow the same approach of putting the digital information into an environment which the user is familiar with, through their »experiential embodiment«. In both cases, »representational embodiment« and »experiential embodiment« encounter each other.

I suggest that design research can explore this conceptual space. Especially those areas in which the two meanings of »embodiment« encounter seem to be of interest. Through prototypes, I explore the encounter of »representational embodiment« and »experiential embodiment«. In particular, I investigate new forms of »representational embodiment«

of digital information in TUIs, designed in orientation to the user's »experiential embodiment«. In this investigation, I follow the RTD approach. RTD proposes the pursuit of a research project *through* a design project. RTD is presented and contextualized in a larger debate about design's role in research in the fourth chapter (p. 57).

In the fifth chapter (p. 75), following the previously outlined approach, I assess the following design question: »*How can haptic actuations (i. e. »representational embodiments« of digital information) in TUIs be designed based on socio-physical metaphors (i. e. assumedly in a way that suits the users' »experiential embodiment« in their socio-physical world)?*«

Functional prototypes, exploring novel ways of haptic actuation (i. e. »representational embodiments«), are presented as case studies. These »representational embodiments« of digital information in the prototypes are based on the principles of shape change, weight shift, and life-like signals (i. e. breathing and heartbeat) – they are based on socio-physical metaphors. Thus, they are designed to make digital information graspable and experienceable, in orientation to the user's »experiential embodiment«. These prototypes are then compared to vibration-based prototypes in a Repertory Grid Technique (RGT) study (p. 120).

The results of the RGT study indicate that the proposed haptic actuations may, at times, be perceived as richer in metaphors, more permanent, and more life-like than others – but these advantages seem to come at a price: the proposed styles of actuation may be metaphorically rich, but the employed metaphors can also remain unfulfilled, and may also require prior knowledge. The permanence of the proposed styles of actuation can make them easier to ignore, but it may also be perceived as annoying. Some of the life-like aspects of the prototypes can be perceived as cute, but, at times, also as creepy.

In the sixth chapter (p. 147), I close with a reflection on these findings. For HCI's concept of »embodiment«, the findings of this work mean that socio-physical metaphors may offer a way to improve the »fit« of the »representational embodiment« to the »experiential embodiment«, but not without entailing new challenges. The proposed distinction between the two notions of »embodiment« was helpful in the design and description of the prototypes. It may also be helpful for future researchers in the TUI field. Design served as a helpful means to explore, in practice, the conceptual space that the proposed distinction opens up.

In that, this dissertation contributes to general knowledge on different levels. On a theoretical level, it contributes a new distinction between »representational embodiment« and »experiential embodiment« in HCI. On a practical level, it contributes exploratory prototypes of haptic actuation in TUIs, based on socio-physical metaphors, which explore the proposed distinction. In that, design research can contribute a new, design-specific perspective to the concept of »embodiment« in HCI. It can help to explore the conceptual space that is opened by distinguishing between the two notions of »embodiment« in HCI, through experimental prototypes.

CHAPTER 2

The Increasing Importance of the Body and »Embodiment« in HCI

In this introduction, I discuss the current state of Human-Computer Interaction (HCI) in its historical context, emphasizing the growing importance of the body and of the notion of »embodiment«. This serves as the context for my later argument that, despite its growing importance, »embodiment« is used ambiguously in the HCI literature.

The advent of the »personal computer« in the 1980s and 1990s marked a change in who typically operated computers. Bannon (1991) notes, for instance, that while previously only trained computer operators were the typical users, computers were increasingly used by common people. Originally, the creation of – partly mechanic – calculating machines was mainly motivated by the intent to automate laborious tasks. At first, these were physical tasks (e. g. weaving), later they were predominantly mathematical (e. g. cryptography). The »Jacquard Loom«, for example, has recently been discussed by Fernaeus et al. (2012) as an early predecessor of the computer, containing a programmable logic machine. The mechanic era of computers was followed by the transistor-based, electronic era. Thus, regarding the role of the body, it could be argued that operating a computer used to be a bodily activity, when they were mainly mechanical devices. Then, the body's role diminished when computers became primarily electronic devices, which may have been necessary for them in order to become mainstream products.

The rise of the »personal computer« entailed that, for example, office tasks were increasingly fulfilled using computers. This development is conceptualised as a shift from a focus on »human factors« (i. e. humans as sources of errors, which was especially of interest in the military context) to »human actors« (i. e. people in their everyday context) , as noted by Bannon (1991, p. 25).[1] At this point, computers were used mainly in work environments. Mouse and keyboard were the predominant input devices, while screen and printer were the predominant output devices – the body played no major role. As prices for software and hardware lowered, though, computers increasingly became a part of people's everyday lives. In these *everyday interactions* with computers, the body played a role of growing importance.

2.1 Developments in HCI Practice

The development towards the integration of computers into people's everyday lives brought along new forms of input and output. Because people who were not trained to operate computers were now the typical users, it was often sought to make the interaction easier to understand. Furthermore, computers were no longer only used for work, so it was also sought to make the interaction more entertaining. At the same time, the complexity of the applications increased – alongside computational power and memory. In the course of these developments, the body grew in its importance for HCI. Some particular areas of research, in which the body may be of special importance, are touch input,

[1] Bannon (2011) argues that both the notions of »Human Factors« and »Human-Computer Interaction« may be outdated and should be replaced with »Human-Centric Computing« or »Human-Centric Design«.

gestural interaction, gaze-based interaction, Augmented Reality (AR), projection-based interfaces, ambient displays, and Tangible User Interfaces (TUIs). In the following, I give an overview of some developments in these areas. To underline that the body's increasing involvement in the interaction can be observed on different scales, I begin with smaller-scale interaction techniques (e. g. touch, gestures, and gaze), and then move to larger-scale ones (e. g. projection-based interfaces, ambient displays, and TUIs). I chose these examples because they illustrate how the body's importance increases on different scale levels, as well as for both input and output.

2.1.1 Touch Input

Touch input can be considered to be one of the early developments that emphasised the role of the body in HCI. Its origins date back to the early days of electronic computers. One of the earliest touch screen-based interfaces is proposed by Johnson (1965) (cf. Buxton (2013)). A related development is pen-based input, which leverages on bodily dexterity, as well.[2]

Overcoming initial technical limitations of touch input (i. e. being limited to one finger or one pen), different approaches to multi-touch were explored (e. g. by Krueger et al. (1985), cf. Buxton (2013)). Recently, different technical approaches for multi-touch input have been proposed, including pressure-based (e. g. as proposed by Rosenberg et al. (2009)) and optics-based solutions (e. g. as proposed by Han (2005)).

Also, such interactions can be found in combination with tokens, which emphasises the role of bodily skills even more (Kaltenbrunner and Bencina, 2007) (Fig. 2.1). Besides

[2] For a detailed overview of the history of pen-based input, see Ward (2013).

FIGURE 2.1: »ReacTable« (Kaltenbrunner and Bencina, 2007) employs a token-based approach for digital music creation.
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planar tables, also different shapes of touch-responsive surfaces have been explored: for example, Benko et al. (2008) propose a spherical interactive surface at the size of a model globe (Fig. 2.2). Also the bottom surface of tables has been included in multi-touch interactions (Wigdor et al., 2006). Such interactions leverage on bodily skills like grasping, pointing, and moving. They often encourage the collaboration of multiple users, as well.

Fostering the integration of such interactions into people's everyday lives, touch interfaces have also been integrated into everyday objects. Projects in this area include, for instance, »ScratchInput« (Harrison and Hudson, 2008), which recognises gestures from the sound of rubbing (e. g. with a fingernail) over any surface. Furthermore, textiles and cloth are increasingly turned into interactive surfaces (Lepinski and Vertegaal, 2011).

Such approaches leverage on bodily skills that go beyond interacting with a screen through indirect means (e. g. via mouse and keyboard), but often lack haptic feedback. At times, objects on the touch surface are included in the interaction. For example, Izadi et al. (2008) propose a system that simultaneously projects on the surface and through it. This allows for a second projection on a sheet of paper placed on the interactive table, e. g.

FIGURE 2.2: »Sphere« (Benko et al., 2008) explores multi-touch interaction on a spherical surface.
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as a second »layer« of information that can be moved around freely. The lack of haptic feedback in multi-touch surfaces has been addressed through passive objects placed on the table, e. g. by Weiß et al. (2009) in the »SLAP Widgets« project. In this project, they explore passive, transparent, physical widgets for haptics-enhanced interaction with a multi-touch table. In the follow-up project, »Madgets« (Weiß et al., 2010a), the physical widgets are actuated through electromagnets, thus allowing for active haptic feedback and dynamic repositioning on the surface. Exploring the applications of large multi-touch surfaces in everyday use, also interactive desks have been proposed, e. g. by Wimmer et al. (2010) and Weiß et al. (2010b) (Fig. 2.3).

In touch input, the increasing involvement of the body can be observed on different scale levels, ranging from small-scale to large-scale interactions. Computer mice are being augmented with multi-touch input, allowing for multi-finger gestures on the mice's surfaces (Villar et al., 2009). Electromyography (i. e. sensing muscle activity) is proposed by Benko et al. (2009) to assess *which* finger is used to touch the screen, estimate the exerted pressure, and allow gestures outside of the system's sensing area. Multi-touch in-

FIGURE 2.3: »BendDesk« by Weiss et al. (2010) integrates multi-touch interaction into a curved desk.
© 2010 Malte Weiß. Included here by permission.

teractions are being integrated into floors, allowing for foot-based interactions (Augsten et al., 2010) (Fig. 2.4). Such »full-body involvement« can lead to interactions that are not only drawing on bodily skills, but, by design, bodily exhausting. For example, Mueller et al. (2011) explore »exertion interfaces«, which integrate HCI and sports.

Notably, the notion of »embodiment« is rarely used in this part of the literature. No mention of the notion was found in the articles cited in this section – even though the proposed styles of interaction do involve the body. This may be the case because of the rather technical focus of these works.

2.1.2 Gestural Interaction

Improvements in motion sensing technology increasingly allow for the inclusion of gestures in the interaction. These gestures may include hand gestures, which are recognised, for example, by a camera, as well as gestures performed with the device while holding it.

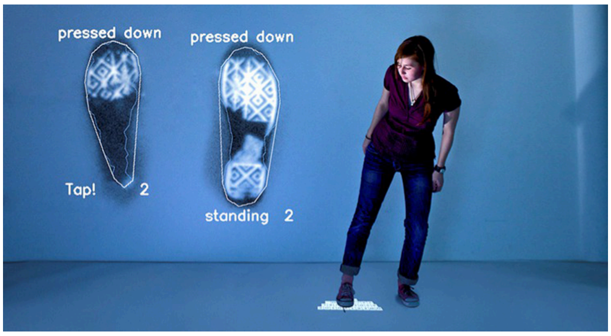

FIGURE 2.4: »MultiToe« (Augsten et al., 2010) integrates multi-touch interaction into a floor.
© 2010 Thomas Augsten. Included here by permission.

For example, gestural interaction while holding portable projectors is explored by Willis et al. (2012) in the »SideBySide« project. Also, gestural interactions are explored for the space behind hand-held devices, e. g. by Caballero et al. (2010) in the »Behand« project. Gesture tracking systems increasingly become cheaper. Olwal et al. (2012), for example, propose the »SpeckleEye« sensor, which offers low-cost gesture recognition at a small form factor. Such systems help to integrate gesture recognition into everyday objects. Providing another example for this development, Bailly et al. (2012) propose the placement of a gesture-recognizing camera on the user's shoe. To make gestures easier to use, Bennett et al. (2011) propose a system that offers prediction and »auto-completion« for gestures. Gestural interaction is also proposed in the context of 3D displays, in order to make the interaction with their virtual contents more »natural« (Grossman et al., 2004).

Gestural interfaces do not necessarily require physical contact. Therefore, they are explored for usage in public spaces, e. g. in shopping window applications (Perry et al., 2010). Furthermore, gestures, which often can be performed without looking at one's hands, are of growing interest for in-car interactions, mostly for the purpose of reducing driver distraction (Döring et al., 2011) (Fig. 2.5).

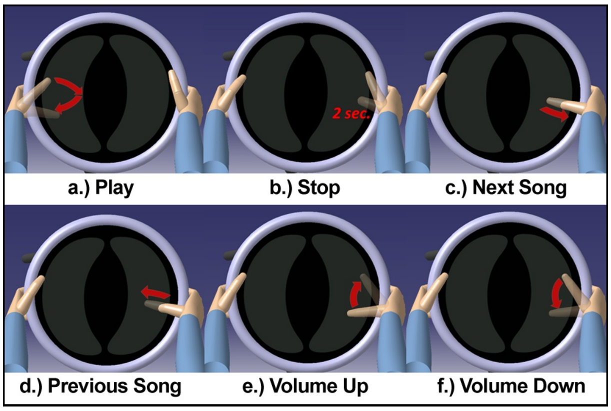

FIGURE 2.5: Döring et al. (2011) propose a set of gestures for music player control from a car's steering wheel.
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Gestural interfaces are currently under active research, and heavily draw upon bodily skills – here, mostly the hands are included in the interaction. In this part of the literature, »embodiment« is occasionally used, yet not extensively.[3]

Critiques of gesture-based interactions include the argument that such interactions are, at times, considered inappropriate, because of their obtrusiveness (Norman, 2010). In contrast, a more subtle way of involving the body in HCI is gaze tracking.

[3] Most of the works mentioned in this section (Willis et al., 2012; Caballero et al., 2010; Olwal et al., 2012; Bailly et al., 2012; Wu and Balakrishnan, 2003; Grossman et al., 2004; Perry et al., 2010) do not mention »embodiment«. Bennett et al. (2011), in turn, mention »embodiment« as follows: »The proposed method of controlling time is to [...] encapsulate time within an object (control through containment or embodiment) [...].« It appears that »embodiment« is used in the sense of »representation« in the interface here.

2.1.3 Gaze Interaction

Gaze-based interactions often use camera systems (sometimes head-mounted, sometimes in the environment) to determine the direction of a user's gaze. Gaze has been proposed as an input for video games (Smith and Graham, 2006), but also as a means of augmenting text reading, e. g. through the activation of a dictionary look-up upon dwelling on a word (Biedert et al., 2010). Smith et al. (2005) propose a system to augment everyday objects with eye-contact sensing capabilities through small infrared tags. One frequently-mentioned issue with gaze-based interactions is the so-called »Midas touch«. It denotes the ambiguity of gaze in such a system – one may look at an object to find out more about it, and one may look at an object to activate it.[4] Also in this part of the literature, »embodiment« is used sparsely. It does not appear to be a central concept for gaze-based interaction. Still, given its strong dependence on the bodily action of looking, gaze interaction can be considered another example for the increasing importance of the body in HCI.

Touch input, gesture-based interfaces and gaze interaction involve the user's body on a rather small, often more input-oriented, scale. Other approaches tend to do so on a larger scale, involving more of the user's environment in the interaction. Furthermore, these approaches tend to intertwine input and output.

2.1.4 Augmented Reality

Augmented Reality (AR) can be described as the overlay of one's perception using digital information. Often, this is achieved visually, through a screen in a head-mounted

[4] For a discussion of the »Midas touch« issue, see Velichkovsky et al. (1997) and Huckauf et al. (2005).

FIGURE 2.6: Cheok et al. (2002) propose an augmented reality user interface for their »Touch Space« project.
© 2002 Adrian Cheok. Included here by permission.

display (Fig. 2.6). Originally proposed to help maintenance engineers to repair complex machinery, AR is now increasingly being used in applications for entertainment and navigation (Bolter et al., 2013). AR applications heavily draw upon bodily skills (e. g. looking around, and walking) in the interaction. Hence, AR can be considered to be another example for the body's increasing role in the interaction.

The notion of »embodiment« is used in this part of the literature, as well. For example, Cheok et al. (2002, p. 433) state that they understand »embodiment« as »presence and interaction in the world in terms of real-time and real-space«, citing Dourish (2001). Bolter et al. (2013, p. 44) also make use of »embodiment«, noting that users experience AR as a »mixed and hybrid reality of information on the one hand and physical location and embodiment on the other«. Cheok et al.'s and Bolter et al.'s notions of »embodiment« both seem to emphasise the interaction's situatedness in a socio-physical context. Notably, Bolter et al. (ibid.) *oppose* »information« and »embodiment«. While the two are etymologically similar (i. e. »em-bodi-ment« and »in-form-ation« both denote a momentum of manifestation), they may be understood as pointing towards a cognitivist (i. e. information-, or representation-centric) and a pragmatic (i. e. experience-centric) approach to the interaction.[5]

Besides through AR, the overlay of real-world objects through digital information is, at times, achieved by projecting on them. Projection-based interfaces do not rely on head-mounted displays, and can, thus, be considered to be more suitable for more casual interactions.

2.1.5 Projection-Based Interfaces

This development enables the interaction with digital content on any surface, by the means of projectors. »OmniTouch« by Harrison et al. (2011), for instance, employs its wearer's body as an interactive surface and proposes various interaction styles (Fig. 2.7). Projection-based interfaces are also explored in dome-like architectures, e. g. by Benko and Wilson (2010). Relatedly, motorised projectors are explored as a means of augmenting rooms with interactivity (Wilson et al., 2012).

Combining projection-based interfaces and everyday furniture, Benko et al. (2012) present »MirageTable«, which blends digital content and the physical desktop into one interactive space. The body is not only used for orientation and movement in such spaces; also the user's familiarity with real-world physics is leveraged upon. In the »HoloDesk« project, for example, Hilliges et al. (2012) propose to apply simulated real-world physics to digital content, using 3D tracking and a see-through display. These developments can be interpreted as supporting the »Luminous Room« vision that Underkoffler et al.

[5] Fernaeus et al. (2008) also discuss this issue, pointing to a »conceptual shift from an information-centric to an action-centric perspective on tangible interactive technology«.

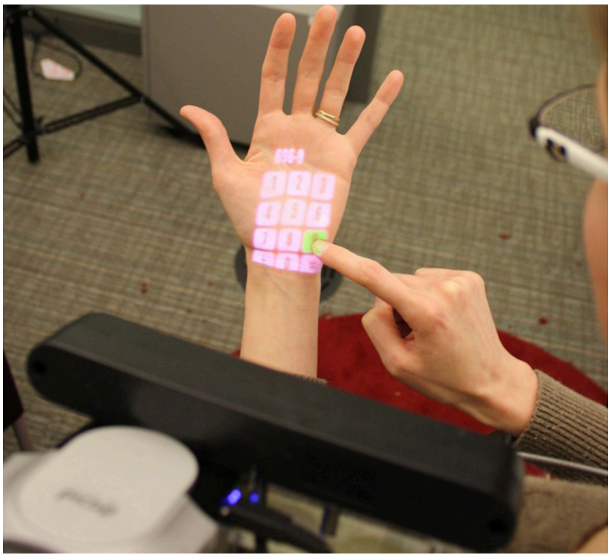

FIGURE 2.7: »OmniTouch« (Harrison et al., 2011) integrates projection and touch on various surfaces, also on the user's skin.
© 2011 Chris Harrison and Microsoft Research. Included here by permission.

(1999) propose. In this vision, real-world surfaces are augmented with digital content. Endeavours to make interactive spaces omnipresent are accompanied by developments that transfer pointing interactions from the desk into mid-air (Winkler et al., 2012). In a similar, yet surface-oriented effort, the »MagicFinger« project, Yang et al. (2012) describe a wearable sensor that turns any surface into an input area. In these works on projection-based interaction, the term »embodiment« is used only rarely. Similar to the aforementioned literature on »touch input«, the focus of these works is rather technical. Conceptually, though, the body plays a central role here.

Projection-based interfaces integrate the interaction into the user's environment. This is also the case in ambient displays, which attempt to blend in with the environment, making it easy for users to ignore them.

2.1.6 Ambient Displays

Ambient displays are interactive systems that are often designed to operate not in the centre of the user's attention, but in its periphery (Fig. 2.8). Such an integration of digital technology into the users' environment, as proposed by Ishii et al. (1998), is pursued by an active research field. The shapes taken by these interfaces are various. One of the early examples for an ambient display is the »Information Percolator« (Heiner et al., 1999), using water flow as a display. Originally proposed for the office context, ambient displays are also explored for home applications (Consolvo and Towle, 2005) and public spaces (Vogel and Balakrishnan, 2004). Recent explorations propose ambient displays to support a sustainable lifestyle (Kim et al., 2010). Other recent advancements in this field include proposals to use ambient displays to increase presence awareness in group collaboration (Brewer et al., 2007). Ambient displays make use of the ability of people to turn away from parts of their surrounding, and ignore them. Hence, they can be considered another example for the increasing role of the body in HCI.

FIGURE 2.8: Van Mensvoort's »Datafountain«. Currency strength is ambiently displayed as fountain height.
© Koert van Mensvoort. Included here by permission.

Besides the body, also the notion of »embodiment« appears to be of interest in the literature concerned with ambient displays. Vogel and Balakrishnan (2004, p. 137) use »embodiment« as follows: »A prototype system implementation that embodies these design principles is described.« This meaning of »embodiment« appears to describe the manifestation of principles in an object. Brewer et al. (2007, p. 9) seem to mean something else when they mention »embodiment«: »An activity monitor could be implemented as a traditional PC application [...]. The physical embodiment that we have chosen, though, [...] allows the device to occupy the edge of the desk, alongside toys and personal items, negotiating between the spheres of work and play.« They describe the »physical embodiment« of their device. This seems to be another meaning of »embodiment« in the HCI literature. It is used in other occurrences, as well – Fällman (2003b, p. 126), for example, describes »the physical embodiment of the software systems [in] mobile information technology«. The two usages of the term »embodiment«, as the *manifestation of principles*, and as an object's *physical presence*, underline the term's diversity of meanings in the HCI literature.

2.1.7 Tangible User Interfaces

One aspect of bringing digital information into the physical world is to make it »tangible« – representing digital information through graspable objects. This is one core aspect of TUIs. Proposals of TUIs have been made since the early 1990s. At this time, increasing computing power had brought along increasing realism in user interfaces, and also a trend towards virtualisation (e. g. early explorations of Virtual Reality (VR) and AR). Wellner et al. (1993, p. 24) pose the question of how we can »escape« from the computer screen. They provide two possible answers: we can escape into a virtual reality, or into the real world. They argue that both approaches are opposite to each other. Also Hornecker (2004, p. 1) notes that TUIs are an »opposite trend, compared to developments towards virtualisation« (transl.). TUI research is an active field of research, and strongly builds upon bodily aspects in the interaction – Wellner et al. (1993, p. 26) refer to this as the »the primacy of the physical world«. The »Tangible Bits« paper by Ishii and Ullmer (1997), which is often cited as the »original« TUI vision paper, describes two »parallel, but disjoint spaces«: the world of bits, and the world of atoms – both of which are to be coupled in TUIs.[6]

The »Marble Answering Machine« (Bishop, 1992) (Fig. 2.9) is frequently cited as the early prime example for a TUI. Each message left on the answering machine is represented through a marble, which rolls out of the machine's marble reservoir. A message can be played by placing the respective marble on a »play« spot; it can be deleted by putting the marble back into the machine's marble reservoir. Thus, it makes use of bodily skills, and enables the integration of the interface into the user's socio-physical environment (e. g. one can keep a particularly important message in a special place on one's desk).

[6] For a discussion of different definitions of TUIs, see Hornecker (2004, p. 87).

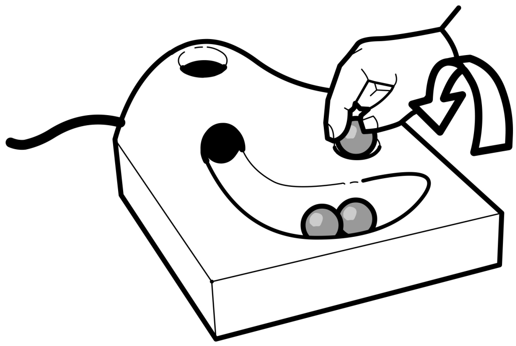

FIGURE 2.9: The »Marble Answering Machine« by Bishop (1992) provides physical representations for voice messages.
© 1992 Durrell Bishop. Included here by permission.

The »United Pulse« project (Werner et al., 2008) is a tangible communication device which can be described as based on the metaphor of touching one's partner, through a simulation of her or his heartbeat. Here, a bodily aspect of the remote person is simulated. Differently, »inTouch« (Brave and Dahley, 1997) is a tangible communication device based on manipulating a pair of connected objects – a board of three »rollers«. Each roller's movement on the one device resembles the movements of its counterpart on the other side. An *indirect* touch is simulated – both communication partners touch an object, and their manipulations are resembled on the other device (Fig. 2.10). This simulates that both communication partners interact with the same object, even though they

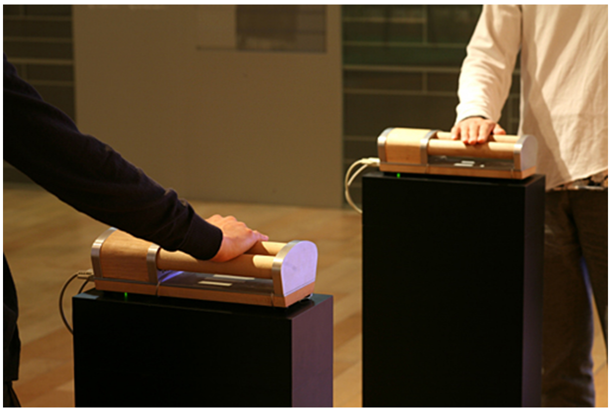

FIGURE 2.10: »inTouch« (Brave and Dahley, 1997) explores mediated remote touch in telecommunication .
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are not in the same room (ibid., p. 363). In these two examples, TUIs are used for bodily telecommunication.[7]

The types of actuation used in TUIs are various, and cover most of the skin's receptors. For example, Hribar and Pawluk (2011) propose a thermal interface, based on the symbolic mapping of »warm« and »cold« colours, displayed through actual warm and cold temperature. »TeslaTouch« (Bau et al., 2010) proposes a friction-simulating mechanism for touch screens in mobile devices (Fig. 2.11).

»Shoogle« (Williamson et al., 2007) is a vibration-based system that simulates virtual objects in a mobile, hand-held device. For it, Williamson et al. (ibid., pp. 121-122) point

[7] In such interfaces, immediacy is often desired. Immediacy can be described as the perceived disappearance of the medium, when the beholder solely pays attention to its content. For a discussion of this topic, see O'Neill (2008) and Bolter and Grusin (2000).

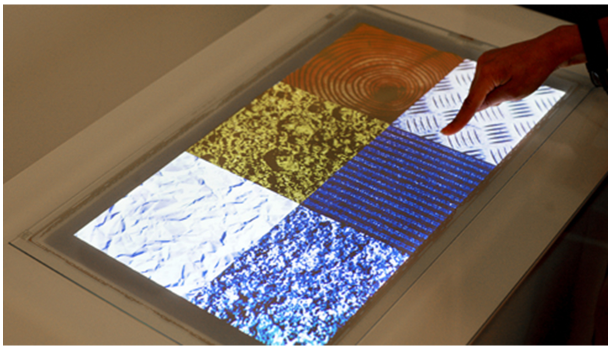


FIGURE 2.11: »TeslaTouch« (Bau et al., 2010) allows for different frictional simulations on a multi-touch screen.
© 2010 Olivier Bau. Included here by permission.

to different scenarios: the »eyes-free message box«, »keys in a pocket« and »liquid battery life«. Besides that, other TUIs use vibration for tactile output. The »Cybertouch« glove (Immersion, 1999) can be described as based on a 3D virtual representation of a physical object, which is made perceivable for the user through vibration on the fingertips, once she or he moves his hand »into« the object. »FeelSpace« (Nagel et al., 2005) is a belt which always vibrates into the direction of north (Fig. 2.12). »Tactons« (Brewster and Brown, 2004; Kildal and Brewster, 2007) are tactile codes, based on vibrotactile, rhythmic representations of digital information.

The notion of »embodiment« is used frequently in this part of the HCI literature.[8] For example, Williamson et al. (2007, p. 121) summarise their project as transforming the device »from a sizeless portal through which information flows to an *embodied*

[8] Notably, also the name of the TEI conference, the major conference on TUI research, was changed from »International Conference on Tangible and Embedded Interaction« (2009) to »International Conference on Tangible, Embedded, *and Embodied* Interaction« (emphasis added) (2010) (Hornecker, 2011, p. 23). As to avoid confusion, it should be noted that »TEI« appears to be used in reference to the conference, but also in reference to the research field itself (e. g. by Shaer et al. (2013)).

Figure 2.12: »FeelSpace« (Nagel et al., 2005) implements a permanent vibrotactile stimulation into the direction of north.

container, with physically meaningful characteristics« (emphasis added). The expression »embodied« appears to be ambiguous here, as it could mean »physical«, but also »representational«. This ambiguity may be a speciality of TUIs.

In their 1997 paper, Ishii and Ullmer (1997, p. 238) describe the »activeLENS« (a tangible user interface on a smart desk) as a »physically embodied window«. Ishii and Ullmer (ibid., p. 236) note, regarding the »Marble Answering Machine« (Bishop, 1992): »This physical embodiment of incoming phone messages as marbles demonstrated the great potential of making digital information graspable by coupling bits and atoms.« But these two mentions of »embodiment« seem to mean different things. In the first case, the window is physically *present*, in the second case, the messages are not physically present (i. e. their sound is absent), but they are physically *represented*. As I argue below, »representation« is an often-used meaning of »embodiment« in HCI. The notion of »presence« is also strong in HCI, but mostly in the sense of being the basis for a user's (who is »present«) *experience*. TUIs can be described as the attempt to provide bodily »perceptible« manifestations of digital information (Ishii, 2008, p. xvi).

Arguments in favour of such tangibility (also in reference to the term »embodiment«) can be found in the early HCI literature, at times in critique of »virtual reality«. Referring to Weiser (1991), Klemmer et al. (2006, p. 146) point to »Weiser's exhortation to design for ›embodied virtuality‹ rather than virtual reality«. It is not clear, however, what Weiser means by »embodied virtuality«. Some sense of manifestation, or relationship to a context, may be meant, but it is not clear. Potentially in relation to this, Dourish (2001, p. 38) points to a notion of »physical virtuality«, citing Weiser (1991), as a synonym for »Ubiquitous Computing«. Regarding another meaning of »embodiment« in the context of TUIs, Fishkin's framework should be mentioned. Fishkin (2004) proposes a classification framework for TUIs, in which »embodiment« is one of two major properties – the other one is »metaphor« (ibid., p. 347). Here, the usage of the term »embodiment« is, again, different. Fishkin proposes different *levels* of »embodiment« in his taxonomy, whereas »full embodiment« is a condition in which »the output device is the input device« (ibid., p. 349). It appears to be related to what Ishii and Ullmer (1997, p. 236) call »seamless integration of input and output« (cf. Hornecker (2004, p. 74)). Later, this concept is more often called »input/output coincidence« (Ishii et al., 2012, p. 44).

Fishkin et al. (2000) mention a paradigm »embodied devices« (cf. Fishkin et al. (1998)). The paradigm they propose is based upon the concept of »treating the *body of the handheld device* as part of its user interface« (emphasis added) (Fishkin et al., 2000). The examples for this Fishkin et al. (ibid.) outline are TUIs that leverage on paper metaphors (i. e. flipping pages, rolling through a Rolodex™, and annotating a document), which are then translated rather directly into the proposed devices' interaction design.

Fishkin et al. (1998, p. 3) note that in this paradigm the »task is embodied in a device«, which may indicate that such devices are highly specialised.[9] Thus, Fishkin's understanding of »embodiment« appears to be much concerned with the relationship of a device's physical properties and the implied manifestation of its *functionality*. In that, it is related to, but not identical to the understanding of »embodiment« as the manifestation of *digital information* proposed Ishii and Ullmer (1997). In the understanding of Fishkin et al. (1998), »embodiment« means how a device's hardware manifests its functionality (i. e. the »task«), in the understanding of Ishii and Ullmer (1997), it means how a TUI manifests »digital information«. In the following, I rather focus on the latter of the two understandings.

In most of the aforementioned examples, TUIs are described as drawing on the user's bodily experience with the socio-physical world – thus, TUIs can be considered another example of the increasing role of the body in HCI.

In summary, many developments in HCI practice indicate a growing interest in the body and »embodiment«.

[9] Also Hornecker (2004, p. 122) discusses how specialisation is a key characteristic of TUIs.

2.2 Developments in HCI Theory

Also in theoretical perspectives on HCI, the body and »embodiment« seem to have been of increasing interest. Increasing private computer use, for games, multimedia, desktop publishing, and communication, supported interactions outside of the office, in users' everyday lives.[10] This development is described as »Third-Wave HCI« (Bødker, 2006, p. 1). In »Third-Wave HCI«, the body is of greater importance than in »Second-Wave HCI«, too. »Second-Wave HCI« considers the interaction with the computer as an act of »communication« (Quek et al., 2006, p. 388).[11] Bødker (2006) suggests that to address issues from users' everyday lives, »Third-Wave HCI« might be more appropriate than its predecessors.

One example for the diminished role of the body in »Second-Wave HCI« is the »human information processor model« (originally named the »Model Human Processor«). In it, the user is described in a cognition-oriented, computer-like fashion (Card et al., 1983). This concept separates the body (i. e. input and output) from the mind (i. e. information processing). The dichotomy of body and mind is often considered a central

[10] Rogers et al. (2011, p. 55) note that in the mid-1990s, the aim of going »beyond the desktop« established itself in the HCI community. This notion may be primarily denote the changing context of computer usage (i. e. leaving the desktop behind), but it may, at the same time, point to the growing spectrum of metaphors used in user interfaces (i. e. leaving the desktop *metaphor* behind).

[11] »First-Wave HCI«, in contrast to »Second-Wave HCI« and »Third-Wave HCI«, considers interacting with a computer as »tool usage« (Quek et al., 2006, p. 388). »First-Wave HCI«, especially because it is rooted in ergonomics, may be seen as rather bodily. Thus, one may speak not of a continuous rise of the body throughout HCI history, but rather of its »renaissance« in »Third-Wave HCI«.

concept of Cartesian philosophy.[12] »Second-Wave HCI« is, at times, called »Cartesian HCI« (Dourish, 2001, p. 189).[13]

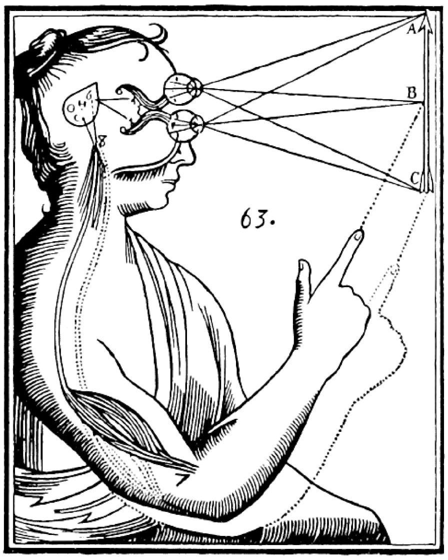
This theoretical development towards the everyday, bodily engagement of users has been accompanied by the technological development towards smaller devices, which have been increasingly integrated into the users' environment. This can be seen as fulfilling the vision of »Ubiquitous Computing«, as formulated by Weiser (1991). In this vision, Weiser describes the 21st century as a world of omnipresent computation, in which architecture, everyday objects and clothing are integrated with »calm« computer technology.[14] In this vision, the body, situated in a computationally enhanced socio-physical environment, plays a major role: interacting with computers becomes a part of people's everyday, lived experience.

Relatedly, Harper et al. (2008, pp. 14-15) point to a historical development of four computing eras: »one computer per many users« in the »mainframe era«, »one computer per user« in the »personal computer era«, »several computers per user« in the »mobility era«,

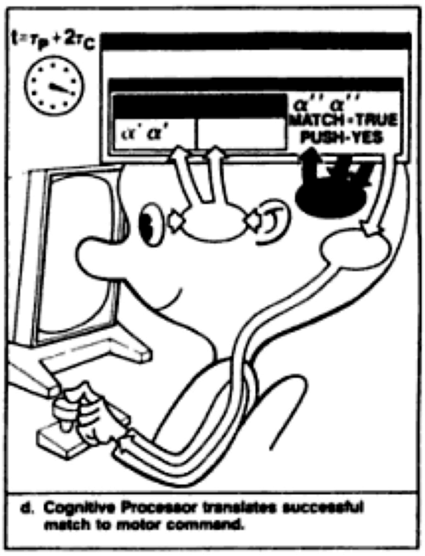
[12] Descartes' illustration of the relationship of body, mind, and environment and Card et al.'s illustration (Fig. 2.13) of the user's input, processing, and output appear, from this point of view, strikingly similar.

[13] It may appear notable that, similar to »computer-like« conceptualisations of the user, also »human-like« conceptualisations of the computer have been proposed. Tripathi (2005), for example, argues that through multimodal input, »computers can hope to share some of the phenomenological experience«. In the reviewed literature, these seem to be rather the exception, though.

[14] Regarding Weiser's notion of »calm technology«, Rogers (2006) recently proposed that the HCI field may have taken another direction than the one proposed by Weiser and Seely Brown (1997), aiming at »engaging rather than calming people«. For a detailed historical discussion of HCI history, also see Jørgensen (2008).



(a) The mind-body dualism, as illustrated by Descartes.



(b) Illustration of the »Model Human Processor« (Card et al., 1983, p. 68).
© 1983 Stuart Card. Included here by permission.

FIGURE 2.13: Illustrations of the relationships of body, mind and environment by Descartes (a), and user input, processing, and output by Card et al. (1983) (b).

and »thousands of computers per user« in the »ubiquity era«. This development implies a growing importance of the body, as well.[15]

Another theoretical model which is proposed for this development is that the »computer reaches out« (Grudin, 1990). This »outreach« can be seen as an increase in the body's importance in HCI, as the environment, in which the user is *bodily situated*, is increasingly involved in the interaction.

Some theoretical frameworks in HCI explicitly pick up the term »embodiment«. For example, both Reality-Based Interaction (RBI) (Jacob et al., 2008) and Natural User Interfaces (NUIs) (Wigdor and Wixon, 2011) can be regarded as based on »embodiment«, as they make use of the user's familiarity with their socio-physical everyday world. RBI integrates the interaction into the everyday world, and thereby draws on the user's already existent experience with it. This experience is not only mental, but rather social, bodily, and mental, at the same time, and without clear separation (i. e. it is not »Cartesian HCI«). NUIs follow a similar approach, but seem to be focussed more on gestures. Making gestures is often considered an inherent part of users' everyday experience. Such styles of interaction may thereby be considered as building on users' »embodied« skills (Oliveira et al., 2010). Also »embodied interaction« (as coined by Dourish (2001)) focuses on the physical and social embeddedness of the interaction: Dourish (ibid., p. 17) notes that his understanding of »embodied interaction« serves as an overarching concept for tangible computing and social computing.

Second-Wave HCI, in contrast, is argued to be a model based on *disembodiment* (Fig. 2.14), due to its reliance on the conception of the user as an information processor

[15] Interacting with a computer in the »mainframe era« is likely to have drawn heavily upon bodily aspects: using the same computer together with other people makes it necessary to socially and, thereby, bodily interact with one another. The later »renaissance« of the body's role in the »mobility era«, after being diminished in the »personal computer era«, is similar to its »renaissance« in »Third-Wave HCI«, after being diminished in »Second-Wave HCI«.

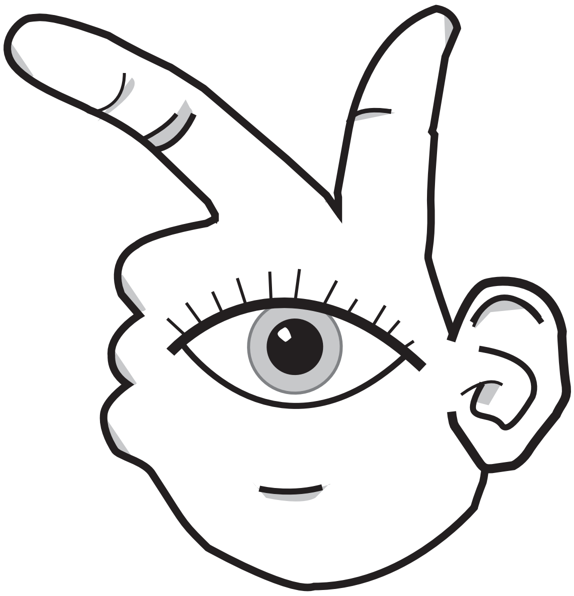


FIGURE 2.14: Illustration of »how the computer sees us«, showing an almost disembodied view of the user. Modified version with two fingers, inspired by O'Sullivan and Igoe (2004, p. xvii)).

(Bardzell, 2010, p. 1307). Other approaches to HCI that are argued to be based on »disembodiment« include language-based approaches, virtual environments, and also desktop computing in general.[16]

The complicated and meaning-rich issue of »embodiment« in HCI can be observed well when analysing a paper by Fällman (2002), which features several meanings of »em-

[16] Tripathi (2005) argues that »natural language technologies [...] fail to take into account the embodied aspects of communication«. Cuddihy and Walters (2000, p. 183) point to a problematic »disembodiment of action« in virtual environments. Fällman (2003b, p. 347) argues that desktop computing follows an »ideal of disembodiment«.

bodiment«: Fällman (ibid., p. 300) describes an »embodiment relation [...] between the user and the system«, which indicates a rather relational meaning, denoting skilled use. He also describes »devices [...] embodying their interfaces« (ibid., p. 301), which may be a meaning in the »functionality-embodying« sense proposed by Fishkin et al. (1998). By calling the proposed device a »contextually aware embodied system« (Fällman, 2002, p. 297), the mutual influence of the (physical) device and its environment may be meant. But also the mere physical inclusion of a sensor in the device is a possible meaning of »embodiment«, e. g. when Fällman notes that »the glove also embodies a custom made tilt sensor device« (ibid., p. 297). Lastly, when it is noted (ibid., p. 302) that »the system itself is embodied in a literal sense on the user, as it is arm worn as opposed to handheld«, a meaning of being closely connected with one's own body is apparent. In conclusion, it can be said that the notion of »embodiment« has many meanings in HCI, and that some clarification may be helpful.

2.3 »Embodiment« in HCI: A Complicated Case

In this chapter, I have outlined the growing importance of the body in HCI. As examples, touch-based interaction, gestural interaction, projection-based interfaces, AR and TUIs were named. Accompanying this rise, the notion of »embodiment« has gained a diverse set of meanings in the HCI literature. For example, the notion of »embodiment« is used in the sense of being present in »real time and real space« (Cheok et al., 2002, p. 433). It can mean the manifestation of »design principles« in a prototype (Vogel and Balakrishnan, 2004, p. 137). It can denote an object's capability to be placed on a desk (Brewer et al., 2007, p. 9). It may describe how one is familiar with gestures and metaphors as »embodied« skills and knowledge (Lakoff and Johnson, 1980). It can serve to metaphorically »encapsulate time« in a user interface (Bennett et al., 2011). Another meaning of it is that the input and the output of a system are simultaneous and co-located (Fishkin, 2004). It can state that a device is connected closely to the user's body (Fällman, 2002), or that its form corresponds to its function (Fishkin et al., 1998).

Considering all these possible meanings, the case of »embodiment« in the HCI literature shows to be complicated. Therefore, I took the question of »Who or what is embodied here?« to the HCI literature.

CHAPTER 3

»Representational« and »Experiential Embodiment« in HCI

In this chapter, I analyse the concept of »embodiment« in Human-Computer Interaction (HCI), differentiating between two major meanings of the term: between »representational embodiment« and »experiential embodiment«. This explicit distinction may be helpful, simply as to avoid confusion. More importantly, though, distinguishing between the two meanings of »embodiment« exposes the moments in HCI in which they »encounter« one another. This »encounter« of the two meanings, as I argue at the end of this chapter, opens a conceptual space. It is this conceptual space that I then set out to explore through design.

Etymologically, the term »embodiment« means the incorporation of one entity in another.[1] The prefix »em-« stems from »in-« and means an inward movement. The stem

[1] According to Harper (2010a), the term is composed from (to) »embody« and »-ment«. The term »(to) embody«, in turn, is, according to Harper (2010b), composed from »en-« (i. e. »in«) and »body«.

»body« points to a meaning of containment.[2] In its earliest usages, in the 1540s, the word was used in a spiritual sense, in reference to a spirit, »embodied« in a physical form (Harper, 2010b). Later, from the 1660s, it had also been used to denote the manifestation of principles and ideas (ibid.).

In the HCI literature, »embodiment« also seems to be used in different meanings. One meaning denotes, for example, an avatar that »embodies« (i. e. represents) a user, or a Tangible User Interface (TUI) that »embodies« (i. e. represents) digital information. A different meaning seems to be at hand when an »embodied« user is meant: a user in a socio-physical context, which influences her or him, and which is, at the same time, influenced by her or him.

In the following, I propose a distinction between these two meanings.[3] The first meaning conceives »embodiment« as »representation« – I refer to it as *»representational embodiment«*. The second meaning denotes the mutual influence of having a living body and experiencing one's socio-physical environment. I refer to this meaning as *»experiential embodiment«*.

[2] Barnhart and Steinmetz (1988, p. 103) describe »body« as being used as »bodi« before 1200, originating from the Old English term »bodig«. They point out that the Old English term is cognate with the Old High German word »botah, potach, botch« (English: »body«), and Middle High German »botech, botich« (ibid., p. 103). According to *Duden 07. Das Herkunftswörterbuch* (2006), also the German word »Bottich« (English: »keg«) descends from the Middle High German »botech[e], botige«. This underlines the meaning of »container«. Noteworthily, the suffix »-ly« stems from the Proto-Indo-European word »lik«, which also means »body« (Harper, 2010c). It is of the same origin as »like« and the German words »Leiche« (English: »corpse«), »Leib« (English: »living body«), »-lich« (English: »-ly«), »gleich« (English: »same«), »solch« (English: »such«) and »welch« (English: »which«) (ibid.).

[3] Distinguishing between »representational embodiment« and »experiential embodiment«, I do not claim to provide an exhaustive list of meanings of »embodiment« in the HCI literature.

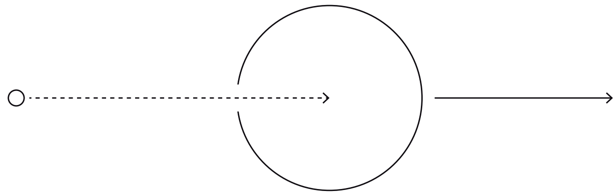


FIGURE 3.1: Schematic illustration of »representational embodiment«: one entity is represented (»embodied«) by another. The »embodied« entity continues to exist independently of its representation.

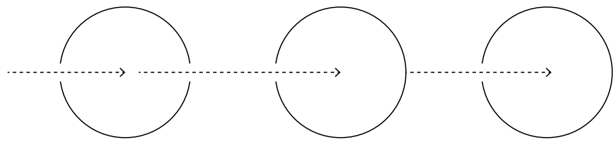


FIGURE 3.2: Schematic illustration of »representational embodiments«, one representing (»embodying«) another.

3.1 »Representational Embodiment«

In general, »representation« is a concept of signification. It denotes the sign relationship in which one entity stands for another (Fig. 3.1). In Peirceian semiotics, representation is the *relationship* between the »sign« and the »signified« (Peirce, 1931-58, Vol. 1, § 540) (cf. Nöth (2000, p. 163)).[4] According to Peirce (1931-58, Vol. 1, § 339), representations can also represent one another (Fig. 3.2). The triad of »icon«, »index«, and »symbol«, as proposed by Peirce (ibid., Vol. 2, § 274) (cf. Nöth (2000, p. 66)), includes three different types of

[4] In Peirce's writings, according to Atkin (2010), »representation« is at times also used for the »signifying element«.

representation. This typology describes different relations between sign (or »representamen«), object, and interpretant. In this context, »representation« is used to describe the relationship between object and sign.[5] An *icon*, in this typology, is a representation that is based on similarity. Nöth (2000, p. 193) points out that in Peirce's terminology, similarity is the secondary criterion – primarily, an icon is a »sign that refers to the object through its own properties« (transl.) (cf. Peirce (1931-58, Vol. 2, § 247)). An *index*, in turn, is described as a representation of an object by which it is »affected« (Nöth, 2000, p. 185) (cf. Peirce (1931-58, Vol. 2, § 248)). It is not based on similarity, but on natural connection. It does not add something new, rather it points to something that the interpretant had already known. A *symbol*, in Peirce's typology, has been argued to be a representation that is primarily based on regularity and habit, and secondarily on arbitrariness and conventionality, according to Nöth (2000, p. 179).

Adhering to Peirce's understanding of representation, I propose the following definition for »representational embodiment« in the HCI literature:

> By »representational embodiment«, I mean the signifying relationship of one entity to another in which one stands for (i. e. »embodies«) the other.

In computer science, representation appears to be a commonly used concept (Dourish, 2001, p. 20). Firstly, this appears to be due to the possibility of viewing computers as structured into »levels« of representation (Winograd and Flores, 1987, p. 86). Regarding this »representation stack«, Winograd and Flores (ibid., p. 86-87) name, as examples,

[5] For a detailed discussion, see Nöth (2000, p. 178; p. 185; p. 193).

the »physical machine«, the »logical machine«, and the »abstract machine«. They also point out that it is possible for a user to operate on one layer of representation without having an understanding of the layer below (i. e. working as a programmer does not require knowledge of the computer's electronics) (ibid., p. 86-87). Secondly, they argue that a computer programme often represents entities from the physical world (i. e. they are programmes »about« something) (ibid., p. 84). In HCI, both »representational« perspectives on computers seem to occur, too. Firstly, user interfaces can be regarded as offering users access to the lower levels of the »representation stack«. For example, an operating system may offer a linguistic or graphical representation of the underlying binary operations. Secondly, user interfaces often resemble the programme's »aboutness«. For example, most messaging applications include the recipients' names, or pictures. Also, the employed interaction principles often represent actions that users are familiar with from their everyday lives. Especially in Graphical User Interfaces (GUIs), the concept of *interface metaphors* seems to be commonly used. This may include, for example, building on representations of things that users are familiar with (e. g. the desktop, or quasi-physical manipulations as in »drag and drop« (Hutchins et al., 1985)).

At times, representations in HCI are meant by the word »embodiment«. For these cases, I propose the more precise term »representational embodiment«.

For example, »embodiment« appears to be used for *body-like representations of computer software*: graphical agents and physical robots. In this context, the word »embodied« is sometimes used to describe user interfaces that look like humans or animals. This is the case in Tomlinson et al.'s definition of »Embodied Mobile Agents«. Tomlinson et al. (2006, p. 969) define »Embodied Mobile Agents« as »graphically animated, autonomous or semiautonomous software systems«. It is also visible in the description of »Rea« as an »embodied, multi-modal conversational interface agent [...] a computer generated [*sic*] humanoid that has an articulated graphical body« by Cassell et al. (1999, pp. 521-523) (cf. Cassell et al. (2000)). Similarly, Marti and Schmandt (2005, p. 239) describe animatronic dolls as »physical embodiments for mobile communication agents«. Also Stiehl et al. (2006, p. 317) point to »embodiment« as a property of robots. In these examples, *body-shaped* interfaces are called »embodied«.

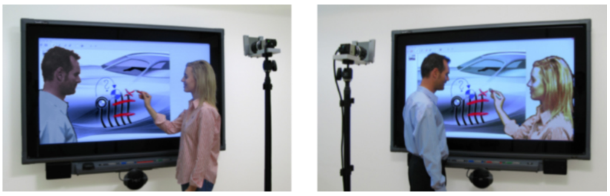


FIGURE 3.3: Kuechler and Kunz (2010) describe a workspace with »embodiments of remote collaborators«.
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Furthermore, »embodiment« is used for *virtual representations of users*: avatars. For example, Ducheneaut et al. (2009, p. 1151) note that »an avatar [...] is also a visual representation of the user, a ›tangible‹ embodiment of their identity«. Similarly, Ries et al. (2008, p. 167) describe a virtual avatar as a »self-embodiment« of a user. Pinelle et al. (2008, p. 2) define »embodiments« as »visual representations of users«. Mazalek and Davenport (2002, p. 255) describe a project on »tangible embodiments of different character perspectives in a multiple point-of-view interactive narrative«. In their work on a telepresence-augmented whiteboard, Kuechler and Kunz (2010) write about »embodiments« of remote collaborators (Fig. 3.3). In all of these examples, the user is »embodied« (i. e. represented) *by* something else.

Furthermore, »embodiment« is used in the context of TUIs – in the sense that a TUI »embodies« (i. e. represents) digital information. For example, Edge and Blackwell (2009, p. 69) describe TUIs as objects that »[embody] digital system state«. Likewise, Ullmer et al. (2010, p. 93), in their work on »Cartouches«, point to »paper and graspable artifacts as interactive embodiments of digital information«. Also Tungare et al. (2006, p. 359) write about »embodied tangible representations of abstract computer data«. In these examples, »embodiment« seems to stand for the physical *manifestation* of digital information.[6] This meaning of »embodiment« in TUIs appears to be representational. However, also the *interaction* with TUIs is often labelled as »embodied interaction« (Dourish, 2001, p. 16), and it conceptually builds upon an understanding of the user as an *embodied being* (Klemmer et al., 2006, p. 142). This may indicate that TUIs draw on *both* »representational embodiment« and »experiential embodiment«. I discuss this thought in depth at the end of this chapter.

For now, in conclusion, »representational embodiment« is a concept that has different meanings in HCI, including body-like representations of computer software (i. e. agents and robots), virtual representations of computer users (i. e. avatars), and physical manifestations of digital information (i. e. in TUIs).

3.2 »Experiential Embodiment«

In contrast to »representational embodiment«, which denotes a sign relationship between one entity and another, what I mean by »experiential embodiment« is a concept that describes how the body influences one's experience of the socio-physical context, and vice-versa (Fig. 3.4).

This notion goes back to phenomenology and is based on Merleau-Ponty's conception of the living body. According to Bermes (2012, p. 39), the living body is a core concept of Merleau-Pontyian phenomenology. It originates in the question of »how sense and sensuality can occur together« (transl.) (ibid., p. 50).

[6] Hornecker and Buur (2006, p. 438) distinguish three different »views« on tangible interaction: a »data-centered view«, an »expressive-movement-centered view«, and a »space-centered view«. References to »representational embodiment« in TUIs (as in »embodied« digital information) seem to occur mostly in research that adheres to the »data-centered« view.

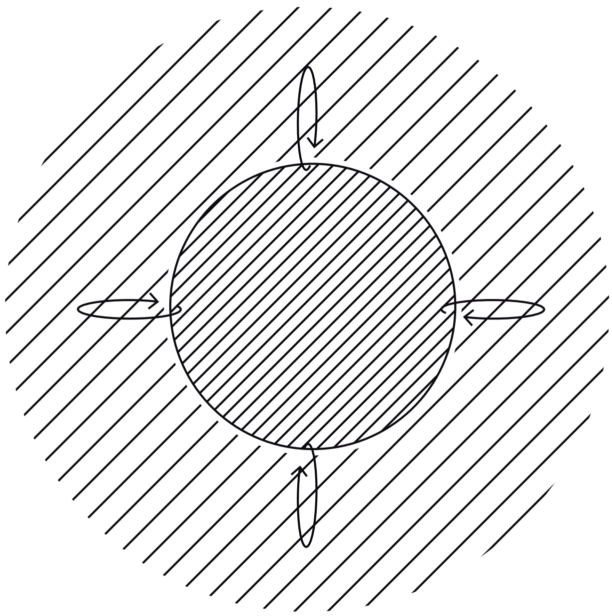

FIGURE 3.4: Schematic illustration of »experiential embodiment«: mutual constitution of a living being and its surrounding world (i. e. a socio-physical world).

According to Bermes (2012, p. 61), the living body is ambiguous in Merleau-Ponty's works: it is a »sensual object of the world« (transl.) on the one hand, and it is »sense-giving« (transl.) on the other. It is, ambiguously, object and subject at the same time (ibid., p. 73) (cf. Robertson (1997)). This way of bodily being appears to be what Merleau-Ponty (1962, p. 236) means by being »embodied«. Merleau-Ponty's phenomenology of the living body is summarised by Bermes (2012, p. 87) as a »a phenomenology of the unconscious, anonymous, sense-giving existence, mediated through the living body, continued in conscious, personal experience« (transl.).[7] Merleau-Ponty's conception of embodiment entails several further aspects. These are discussed in other disciplines, as well. Social aspects, e. g. how one's embodiment enables the relation to »other embodied subjects« (Merleau-Ponty, 1962, p. 229) are discussed in sociology. Cognitive aspects, e. g. how a »a movement is learned when the body has understood it« (ibid., p. 160), are discussed in cognitive science.[8] Variations of these are observable in HCI, as well. Thus, before exploring the usage of this meaning of »embodiment« in HCI, I will briefly examine the usage of »embodiment« in sociology and cognitive science.

Sociology is argued to have shown interest in »embodiment« since the early 1990s (Crossley, 2006, p. 21). Here, »embodiment« means one's *bodily embeddedness into one's socio-physical space*: social interactions are shaped through »embodied being«, while »embodied being« is shaped through social interaction (Cregan, 2006, p. 5). Thus, this kind of »embodiment« is often considered to be inseparable from its social context (Shilling, 1997). Positions within sociology that are concerned with »embodiment« have been categorised as belonging to the sub-field of »carnal« sociology (i. e. as in relation to the »flesh«) (Wacquant, 2005). These positions, often citing the writings of Merleau-Ponty, mostly criticise the Cartesian body-mind dualism (Turner, 1992).[9]

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[7] For a detailed introduction, see Bermes (2012).

[8] Robertson (1997) refers to the term »lived cognition« for this concept.

[9] For an overview of this debate, see Csordas (1995), Wacquant (2005), and Turner (1992).

This notion of »embodiment« is often associated with the constitution of *experience*. For instance, Cregan (2006, p. 3) defines »embodiment« as »the physical and mental experience of existence [...] the condition of possibility for our relation to other people and the world«. Here, experience and »embodiment« in a socio-physical context are seen as closely related. Similarly, Csordas (1995) describes »embodiment« as a »standpoint in which bodily experience is understood to be the existential ground of culture and self«. Also in this case, body, experience, and socio-physical embeddedness are viewed as closely related. Varela et al. (1992, p. xv) seem to understand the body as a lived, »experiential«, »phenomenological« structure, which underlines this relationship, too. They oppose this notion with the »physical«, »biological« view of the body (ibid., p. xv). In a similar argument, Waskul and Vannini (2006, p. 3) argue that a body is both object and subject, one being emergent from the other (cf. Waskul and Riet (2002, p. 510)). They define »embodiment« as »the process by which the object-body is actively experienced, produced, sustained, and/or transformed as a subject-body« (Waskul and Vannini, 2006, p. 3).

In conclusion, many sociological positions conceptualise the experiencing, »embodied« subject and their socio-physical environment as interwoven and mutually constituted.

In cognitive science, »embodiment« can mean the foundation of *thinking* in bodily presence and acting. Gibbs (2005, p. 9), for example, points out that recent developments in cognitive science have increasingly regarded »embodiment« to be the basis of »perception, concepts, mental imagery, memory, reasoning, cognitive development, language, emotion, and consciousness« (cf. Dreyfus and Dreyfus (1999)).

Phenomena which were originally conceptualised as primarily mental are increasingly viewed as founded in bodily presence in a socio-physical context – i. e. they are viewed as founded in »embodiment«.[10]

This concept is often denoted by the term »embodied cognition«. Wilson (2002) defines it as follows: »Embodied cognition holds that cognitive processes are deeply rooted in the body's interactions with the world.« Note that not only the body is emphasised here, but also the surrounding world. »Embodied cognition« can be interpreted as a counter-movement to previous developments in cognitive science. These were less focused on the body – and, thus, less focused on »embodiment«. Rather than that, they modelled thought processes as the manipulation of symbolic representations of the world in the mind. Often, such theories are meant by the umbrella term »cognitivism« (Varela et al., 1992, p. 40). In the literature concerned with »embodied cognition«, cognitivism is often criticised.[11] All these are examples for embodied cognition, and, thus, examples for the predominant meaning of »embodiment« in cognitive science.

Up to this point, I have shown that, in sociology, the notion of »embodiment« can describe the mutual constitution of oneself and one's socio-physical context. Furthermore, I have shown that, in cognitive science, it can be understood as the foundation of thought processes in the body's interactions with the world. Both are closely related to one's experience of the world.

I therefore propose »experiential embodiment« as an umbrella term for these notions of »embodiment«. I propose the following definition:

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[10] For a detailed discussion of the debate on »embodiment« in cognitive science, see Gibbs (2005).

[11] For a recent Research Through Design (RTD) project on »embodied cognition«, see Van Dijk (2013).

> By »experiential embodiment«, I mean the fundamentality of having a living body for experiencing one's socio-physical world.

In HCI, this notion of »embodiment« is also observable. Often, it points to a conceptualisation of the »embodied« user. This conceptualisation stands in sharp contrast to the previously dominant conception of the user as an »information processor«. In this previous conception, much in relation to cognitivism, thinking is conceived as the manipulation of mental representations (i. e. »information processing«) (Card et al., 1983). It tends to conceptualise body and mind as separate (Klemmer et al., 2006, p. 141), whereas the approaches that I propose to be grouped as concerned with »experiential embodiment« tend to conceptualise body and mind as *intertwined*.

This concept is visible in some definitions of »embodiment« within the HCI literature. For example, Antle (2009, p. 27) defines »embodiment« as follows: »Embodiment means how the nature of a living entity's cognition is shaped by the form of its physical manifestation in the world.« Her definition appears to conceptualise thinking and having a body (a »physical manifestation in the world«) as intertwined. Similarly, Fogtmann et al. (2008, p. 90) point to »bodily presence in the world and the *intertwining of the body and the mind*« (emphasis added) in relation to their notion of »embodiment« in HCI. It is similarly defined by Hurtienne and Israel (2007, p. 129): »[embodiment] has to do with how much human thinking and knowledge is shaped by our direct sensory-motor (embodied) interaction with the world«. Dourish (2001, p. 189) bases the notion of »embodied interaction« on the duality of body and mind, too.

Furthermore, this notion of »embodiment« in HCI conceptualises the user and her or his socio-physical environment as intertwined. This is, for example, visible when Dourish (ibid., p. 18) defines »embodiment« as follows: »Embodiment [...] denotes a form of *participative status*. Embodiment is about the fact that things are embedded in the world, and the ways in which their reality depends on being embedded.« (emphasis added) Dourish points to a »participative status« and to being »embedded in the world«, which underlines the influence of the *context* on the »embodied« being. Citing Dreyfus (1990), also Bidwell and Browning (2006, p. 229) point to an intertwined understanding of body, mind, and environment.

In the following, I expose three views on »experiential embodiment« that appear to be prominent in the HCI literature: »embodiment« as the sensorimotor foundation of cognition, »embodiment« as situatedness in a context and »embodiment« as the basis and result of skill acquisition.

Regarding the first view, which conceives *embodiment as the sensorimotor foundation of cognition*, Merleau-Ponty's concept of the body as »a primordial ground of all of our experiences« (Tripathi, 2005) appears to be central. Merleau-Ponty's concept presumes that one can only have experience of the world when one also has a body (Merleau-Ponty, 1962, p. 171). In Cartesian philosophy, which is often contrasted to Merleau-Ponty's works, the mind is conceptualised as being able to exist without the body: »It is certain that I, [that is, my mind, by which I am what I am], is entirely and truly distinct from my body, and may exist without it« (Descartes, 1901, § 9). Merleau-Ponty's concept, in contrast, puts the foundation of experience in having a body. Furthermore, Merleau-Ponty appears to criticise abstract representations of the experiential body: »[The] experience of the body *degenerated* into a ›representation‹ of the body; it was not a phenomenon but a fact of the psyche.« (emphasis added) (Merleau-Ponty, 1962, p. 108) Also HCI research adhering to this view appears to conceptualise body and mind as interrelated.

One example for this is learning-oriented HCI research. Because it emphasises »the role of the body, physical activity, and lived experience in cognition«, »embodiment« is proposed as a conceptual starting point for the design of child-friendly interfaces (Antle et al., 2009, p. 306). Price (2008), similarly, notes that TUIs offer new ways to support learning, as they allow leveraging on children's familiarity with interactions in the physical world. Hashagen et al. (2009) propose a full-body interaction environment for children that facilitates the understanding of algorithmic concepts. They draw upon the notion of »embodiment« as they assume that children learn about algorithmic concepts

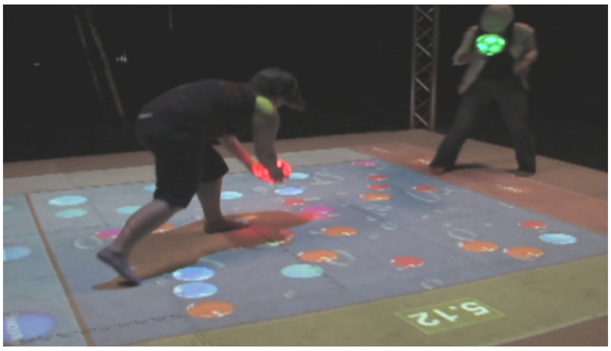

Figure 3.5: The »SMALLab« environment by Kelliher et al. (2009).
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more easily when bodily interacting with them. Relatedly, Quek et al. (2006, p. 388) point out that even learning mathematics, which is usually considered a mental activity, is »embodied«.

Putting more emphasis on the socio-physical context, Kelliher et al. (2009, p. 1029) propose the SMALLab, an environment for »embodied, multimodal, collaborative learning« (Fig. 3.5). It is a projection-based environment that allows for full-body interaction, and covers learning topics from chemistry, physics, geography, and poetry (ibid., p. 1030). Like the previously mentioned works, their project draws on the experiential notion of »embodiment« as it assumes that bodily action – and interaction – helps children to understand abstract concepts more easily.

A related concept that is concerned with the understanding of abstract ideas through concrete bodily experience, is that of »embodied metaphors« (Lakoff and Johnson, 1980). For example, Lakoff and Johnson (ibid.) mention the metaphors »argument is war« and »love is a journey«. They note that when we talk about verbal arguments, we often use metaphors that borrow vocabulary from the context of war (e. g. »He attacked every weak point in my argument.« (ibid., p. 4)). Similarly, when talking about love, we often borrow metaphors from the context of journeys (e. g. »Look how far we've come.« (ibid.,

p. 44)). Both metaphors explain abstract concepts (»argument« and »love«) through bodily experiences (»war« and »journey«). Lakoff and Johnson also coin the term »entity and substance metaphors« (ibid., p. 24). It denotes metaphors that conceptualise abstract concepts (e. g. feelings and thoughts) as tangible *things* (which can, for example, be »shared«, have different »sides«, etc.) (ibid., pp. 24-26).

In the HCI literature, »embodied metaphors« are also being drawn upon. For instance, Bakker et al. (2009, p. 142) base their work on learning and sound on »embodied metaphors«. In their project, children learn the musical concepts of volume, pitch, and tempo through interactive objects and full-body movement (ibid., p. 143). Again, the authors assume that children understand abstract concepts more easily through bodily movement and action.

But, notably, the term »embodied metaphors« seems to suggest that it is the *metaphor* that is »embodied«. This meaning of »embodied« seems to be a different one than what could be derived from my working definition of »experiential embodiment« (i. e. the metaphor is not having a living body and an experience of its socio-physical context). Also, it seems to be different from just »representational« (which would be a tautology, as metaphors are representational by definition). Rather, it appears that »embodied« is meant in the sense of *»body-learnt«* here – a meaning of »embodied« which I did not cover up to this point. This meaning of »embodied« is also observable in the HCI literature. HCI researchers often use the terms »embodied skills« and »embodied knowledge«. For example, Harrison et al. (2007, p. 3) contrast »embodied skills« with »abstract skills«. This contrast shows the opposition of learning »with the body« and learning »with the mind«. Relatedly, Jensen et al. (2005, p. 11) point to Farnell (1999), regarding the concept of »embodied knowledge«, emphasising that »knowledge is not only in the mind, but also in the body«. Conceptions of »embodied knowledge« and »embodied skills« are argued to not only be shaped through everyday experience, but also stand in a mutually constitutive relationship to it. For example, Fällman (2003b, p. 58) points out that »embodied skills« are not only gained through everyday life, but also shape how everyday life's »things and situations show up for us«.

In conclusion, the idea of body and mind being intertwined, and not separate, is a strong and emerging one in HCI. It is one view of the HCI literature on »experiential embodiment«.

A second view on »experiential embodiment« in the HCI literature seems to regard »embodiment« as situatedness in an environment. HCI literature concerned with this view appears to conceptualise body, mind, and the user's environment (i. e. the socio-physical context) as interconnected. At times, individual and context are argued to be inseparable (Dourish, 2001, p. 17). HCI research that adheres to this view is often concerned with *collaboration*. For example, Nadeau and Williams (2009, p. 147) mention the »embodied basis of collaborative practice«. Thus, HCI research adherent to this view often belongs to HCI's sub-field of Computer-Supported Collaborative Work (CSCW).[12] Fällman (2003a), for instance, proposes a context-sensitive, arm-worn device that emphasises the worker's mobility in their real working context. It can be considered to be an example for an interface that does not separate the interaction with the computer from the interaction with the socio-physical world, rather intertwining the two. Similar proposals are made for office environments. For example, Brewer et al. (2007) propose »Nimio«, a physical ambient display for work groups in separate workplaces. It allows workers to maintain contact over a distance, and get a feeling for the activity in the remote workplace. It is intended to be placed on the worker's desk, and thus emphasises the aspect of being situated in the workplace's socio-physical context.

In conclusion, viewing users and their socio-physical context as intertwined is an emerging theme in HCI research, and another view on the notion of »experiential embodiment«.

[12] Button and Dourish (1996) coined the term »technomethodology« (citing Garfinkel (1967) regarding the term »ethnomethodology«) for research concerned with how people use technology to get work done. See Button and Dourish (1996) for a detailed discussion.

A third view on »experiential embodiment« in the HCI literature concerns »embodiment« as the foundation and result of skill acquisition. In Merleau-Ponty's works, »embodiment« means, according to Dreyfus (1996), how the body enables the acquisition of skills. Dreyfus (ibid.) points out that Merleau-Ponty (1962) distinguishes »innate structures, basic general skills, and cultural skills« and that »by embodiment, Merleau-Ponty intends to include all three ways the body opens up a world«. Moreover, Dreyfus (1996) argues that »flow« (i. e. the feeling of being absorbed in an activity, cf. Csikszentmihalyi (1992)) does not involve mental representations of abstract concepts, but is rather based on bodily, skilful action. He cites Merleau-Ponty (1962, pp. 160-161), who argues that »a movement is learned *when the body has understood it*, that is, when it has *incorporated* it into its ›world‹, and to move one's body [...] *independently of any representation*« (emphasis added). These aspects of »embodiment« are also observable in the HCI literature. For example, Svanæs (2000, p. 231) proposes that in order to support the inclusion of kinaesthetic skills in the interaction, user interfaces should avoid abstract representations.

Also in this context, »embodied« is, at times, used in a sense of »body-learnt« – describing, for example, how activities are »embodied« into one's habitus. In this context, »embodiment« can mean different things: some sources describe that the *state* of »embodiment« (i. e. being experientially present in one's socio-physical world) provides the *basis* for acquiring skills (e. g. Quek et al. (2006)). Other sources describe the »extension« of the body (i. e. the integration of an activity or a tool into one's perception of the body) as a *process* of »embodiment«. Regarding this, Iwakuma (2002, p. 78) points out: »This ›extension of the bodily synthesis‹ is a *process* of embodiment.« (emphasis added) A frequently mentioned example for this »extension of the body« through an object is that of a visually impaired person learning to use a cane (»[...] it literally becomes part of the body« (ibid., p. 78)). Haraway (1988, p. 588) describes »prosthesis« as a kind of »embodiment«, and also Fels (2000, p. 14) points to situations in which a person »embodies an object« (e. g. in skilled use), feeling »that the object is an extension of himself«. Here, »embodiment« means a relationship between the object and its user, and thus the *result* of skill acquisition. This notion can also be found in Ihde's works. Ihde (1990, p. 73) defines the »embodiment relation« as occurring when »technology becomes maximally ›transparent‹ «. At a later point (p. 152), I refer to this meaning (»body-learnt«) of »embodiment« as *»skilful embodiment«*. It appears to be a third important meaning of »embodiment« in HCI, closely related to the concept of immediacy. In this concept, the medium steps into the background, and the user focuses solely on the content (O'Neill, 2008; Bolter and Grusin, 2000).

In conclusion, the notion of »embodiment« can have several meanings in the context of skill acquisition:

- It can denote the *foundation* of skill acquisition: because of its »embodiment« in the socio-physical world, the living being can acquire skills (Quek et al., 2006).
- It can describe the *process* of skill acquisition: it is possible for a living being to engage in the »process of embodiment« of an activity (Iwakuma, 2002).
- It can be the *result* of skill acquisition: the »embodiment« relation can describe the feeling that an object (e. g. a tool in use) has become an extension of one's own body (Fels, 2000).

In the light of this, it appears that the term »embodied interaction« can also be interpreted in different ways. It could mean a kind of interaction that one is highly familiar with and absorbed in (i. e. one has »embodied« the interaction into one's habitus), but it could also mean a kind of interaction that one engages in as an embodied being (i. e. the person interacting is »embodied«, and thus the interaction is also »embodied« in a socio-physical context).[13] A third interpretation could be (and has been) that also the *computer* is embodied in »embodied interaction«. For example, Lyons et al. (2012, p. 77)

[13] The similarly ambiguous term Natural User Interface (NUI) is helpfully disambiguated by Wigdor and Wixon (2011, p. 14), who point out that it should be pronounced »*natural user* interface«, and not »*natural* user interface« (emphasis in original). This emphasises that they understand the user as natural, not the interface.

seem to understand »embodied interaction« as »expressive interaction with an *embodied system*«. Dourish (who is often cited as the author who coined the phrase »embodied interaction«) rather adheres to the second way of interpreting the notion. Dourish (2001, p. 2) defines »embodied interaction« as »interaction with computer systems that occupy our world, a world of physical and social reality, and that exploit this fact in how they interact with us«.

Only few authors contributing to the HCI literature do distinguish between »embodied« and »bodily«. Matthews (2006), in a discussion of gestural interfaces, makes such a distinction. Matthews (ibid., p. 406) argues that gestural interfaces are operated *bodily*, but that the skills they leverage upon are not always *»embodied«*: »This is a situation that does not maximise the ›embodied‹ potential of movement for interaction design, particularly as it would require users to learn another (bodily) language to interact with the system.« He makes this distinction even clearer when he points out that such a gesture-controlled system employs »our capacity for movement and skill building, and not our embodied familiarity with the physical world« (ibid., p. 406). It appears that »embodied familiarity« is meant in the sense of »body-learnt« here. Distinctions like these appear to be helpful, as they help to avoid confusion among seemingly similar terms. Unfortunately, they can be found only rarely.

3.3 Encounters of »Representational« and »Experiential Embodiment«

This chapter has shown two different meanings of »embodiment« in the HCI literature: »representational embodiment« and »experiential embodiment«. It may be argued that any experience can be conceived as a mental representation (Johnson-Laird, 1986). At the same time, it may be argued that every representation needs to be experienced (Pollio et al., 1997). Such conceptions may be valuable in certain cases, but they blur the boundary between the two meanings of »embodiment« in HCI. For now, I therefore propose to focus on their differences.

I am also aware that this distinction is primarily valuable for the English language – other languages, including German and French, in which many of the »embodiment«-related phenomenological concepts originate, have more distinct terms for »representational embodiment« and »experiential embodiment«.[14] Nonetheless, the manifold meaning of »embodiment« in English appears striking, and worth investigating further. Viewing the two notions of »embodiment« as both distinct and related entails the opportunity to investigate those situations in which they *encounter*. Some approaches to HCI may be understood as seeking such situations. In these, it is attempted to suit the computer's »representational embodiment« to the user's »experiential embodiment«.

One example for this is the use of *avatars* in user interfaces. Interfaces based on avatars attempt to place a »representational embodiment« of the user's body in the »digital world«. The underlying assumption here may be that once the (virtually represented) user and the digital information are in the same (i. e. digital) »world«, the interaction can leverage on »embodied knowledge« from the user's socio-physical world (because of the user's »experiential embodiment« in the socio-physical world). Following this assumption, it appears plausible that navigation in a virtual world, with an avatar, is easily understandable for everyone who knows how to navigate the »real« socio-physical world. Recent HCI research is concerned with this concept. For example, McManus et al. (2011) investigate how users estimate distances in virtual worlds, depending on different aspects of their avatars' bodies. The visual appearance of their avatars has been

[14] In German, for example, the terms »Verkörperung« (»an embodiment of something«) and »Körperlichkeit« (»having a body«) could be used to point to the different meanings of »embodiment«. Being not a philosopher myself, I am reluctant to use »Leib« (»living body«) and »Leiblichkeit« (»having a living body«), which may be tempting, but appear to stand in a too large philosophical discussion that I do not feel confident enough to handle adequately in this thesis. For an introduction into the German term »Leib«, see Ritter and Gründer (1980, p. 173).

found to be an influential factor for how users perceive »themselves« in virtual worlds (Neustaedter and Fedorovskaya, 2009; Boberg et al., 2008). This makes avatar-based interfaces one example for the encounter of »experiential embodiment« and »representational embodiment«. Creating a representation of the user in the »digital« world can be seen as the attempt of putting both, the digital information and the user, into the same »world«.[15]

TUIs seem to follow a similar approach. As described above, these user interfaces provide physical representations of digital information. In that, they also attempt to put users and digital information into the same »world« – like avatar-based systems. Differently, though, they attempt to put the two into the *socio-physical world*. The »Marble Answering Machine« by Bishop (1992), for example, puts »representational embodiments« of digital information (i. e. messages left on the answering machine) into the user's socio-physical world. It is thus assumed to be possible for users to »encounter« digital information in ways that suit their »experiential embodiment«: the messages can be easily sorted, disposed, kept, and shared. They are also visible to other people.[16] Users are assumed to be familiar with the interaction with marbles. In the »Marble Answering Machine«, this familiarity is assumed to be transferrable to the interaction with marbles that are »representational embodiments« of digital messages. It puts the digital information and the user into the same (i. e. the socio-physical) world.[17]

[15] A similar argument could be made for Virtual Reality (VR) – a »representational embodiment« of the user's body is placed »inside« a »representational embodiment« of a virtual world. The assumption that such an interaction would be intuitively understandable for users is based on the underlying assumption that such an »encounter« can leverage upon »embodied knowledge« from the user's everyday experience.

[16] For a detailed discussion of the role of openly visible actions and objects in collaborative HCI (i. e. CSCW), see Robertson (2002).

[17] The assumption that the user's knowledge about how to interact with objects in the socio-physical world can be seamlessly transferred to interactions with digitally augmented objects has recently been scrutinised. See Hornecker (2012) for a detailed discussion.

In principle, any computer hardware could be conceptualised as an »embodiment« that the user encounters. Winograd et al. (1996, p. xviii), for instance, describe computer hardware as the »embodiment of the software«. Also, all HCI could be argued to be based on some bodily activity. Matthews (2006, p. 405), for instance, points out that »virtually all interaction with technology makes use of human movement«.

Nonetheless, TUIs appear to take a more radical position, making the digital *graspable*. Often, they co-locate input and output, and thus create the illusion of direct interaction with the digital content (Ishii, 2008). Hornecker (2004, p. 83) names this principle »haptic directness« (transl.), in reference to Shneiderman (1983) (»direct manipulation« in GUIs). Another term that is associated with this aspect of TUIs is that of »physicality«. Hornecker (2006, p. 3) notes that physicality means the interrelation of »physical bodies (users)« and »the physical world« – a concept on which many aspects of TUIs rely, as Hornecker (ibid.) argues.

Hornecker (2011, p. 21) notes that different »physicalities intersect in interaction« (e. g. the physicality of the user's body and the physicality of the objects that are interacted with). This moment, the intersection of physicalities, appears to be similar to the moment that I mean by the »encounter« of »representational embodiment« and »experiential embodiment« in TUIs. In these moments, a central role is played by *touch*. Bermes (2012, p. 158) notes that, according to Merleau-Ponty (1986), active and passive, as well as inside and outside, »intersect in the flesh« (transl.). Touching something, as Hornecker (2006, p. 3) notes, »brings us in close (and potentially dangerous) encounter«. It is this encounter of users and digital information that I seek to investigate further.

A related concept, which I shall mention at this point, is that of *simulated physical properties*. In many cases, GUIs contain visual simulations of physical properties.[18] For instance, the Apple iOS Human Interface Guidelines (2013) encourage developers to add »physicality« to their GUIs. Such »pseudo-physical« interaction principles may seem beneficial: they can offer the flexibility of a GUI and may, at the same time, leverage upon users' knowledge from the physical world.[19] Furthermore, they avoid many technical challenges of »real« physical interfaces. Nonetheless, it seems that some aspects of physicality may get lost in simulation. Hornecker (2011) discusses several aspects of physicality, including the material properties of objects, and the social aspects of space. Such aspects may easily fall short when they are only simulated.

But »real« physicality in HCI is not unproblematic, either. Compared to the large body of existing research concerned with the design of GUIs, many questions regarding the design of TUIs are still unanswered (and, perhaps, even yet to be asked).

This includes the central question of how physical representations of digital information in TUIs should be designed. Hornecker and Buur (2006, p. 441) argue that the representations in a TUI should be designed in a way that is familiar to the user. They note that the representation (they coin the term »tailored representation« for this) should build upon the user's previous experience to be in support of a TUI's »embodied facilitation«. Dourish (2001, p. 20) notes that attention should be paid to »the duality of representation and participation«. This »duality« may come into play in especially

[18] See Barr (2003) and Barr et al. (2005), as well as Rogers et al. (2011, p. 44), for a detailed discussion of physical metaphors in GUIs.

[19] Research on »mirror neurons« (Rizzolatti and Craighero, 2004) suggests that some neural structures in the human brain behave similarly when one performs an action and when one only observes the action being performed. Related research, concerned with »embodied simulation«, (Gallese, 2005; Gallese and Sinigaglia, 2011), underlines parallels in »mirror neuron« research and Merleau-Ponty's philosophical positions (Merleau-Ponty, 1962): to understand the actions and intentions of others, we depend on our own body. Such research may advocate a sufficiency of »observed action« – of *simulated* physicality in GUIs.

those situations in which the »representational embodiment« and the »experiential embodiment« encounter.

But up to this point, it appears to be rather unclear how the »representational embodiments« of digital information *should* be designed in order to »suit« the user's »experiential embodiment«. Specifically, the effect of the »representational embodiments'« »fit« (or »tailoring«, in Hornecker and Buur's terms) to the user's »experiential embodiment« on how the interaction is experienced seems to be studied only rudimentarily. This may be reasoned in the limited comparability of different TUI projects. Many TUI projects exist, but all of them have different applications, different shapes, and different styles of actuation. This makes it hard to compare them in a study. To assess this issue, I propose different, but comparable, haptics-enhanced TUIs, providing »representational embodiments« of digital information, designed in orientation to the user's »experiential embodiment«. These prototypes draw on socio-physical metaphors for digital information. I also propose a set of comparison prototypes (employing vibration-based haptic actuation). Consequently, the design question that I seek to pursue is the following:

> How can haptic actuations (i. e. »representational embodiments« of digital information) in TUIs be designed based on socio-physical metaphors (i. e. assumedly in a way that suits the users' »experiential embodiment« in their socio-physical world)?

I propose to pursue this design question in order to explore the conceptual space that is opened by the distinction between »representational embodiment« and »experiential embodiment«. Thereby, I follow the approach of Research Through Design (RTD). I give a methodological overview in the next chapter.

CHAPTER 4

Research Through Design

In the previous chapter, I have exposed a conceptual space that is opened by distinguishing between »representational embodiment« and »experiential embodiment« in Human-Computer Interaction (HCI). To explore this space, I propose to follow a Research Through Design (RTD) approach. In particular, I propose to follow Findeli's model of Project-Grounded Research (PGR). In this chapter, I present Findeli's model and contextualise it in a larger debate about design's role in research. My goal in this chapter is to justify my method, showing that the »designerly« approach to the issue of »embodiment« in HCI is possible and worthwhile.

Findeli's model of PGR builds upon Frayling's differentiation between research »for«, »about«, and »through« design, which is discussed below. It also builds upon Cross' argument regarding »designerly ways of knowing« and Archer's early definitions of design research. Both Cross' argument and Archer's definitions are also discussed below, each in its respective historical context. Findeli defines design research as follows:

> »Design research is a systematic search for and acquisition of knowledge related to general human ecology considered from a designerly way of thinking, i. e. a project-oriented perspective.« (Findeli, 2010, p. 287)

The model that he proposes, PGR, seeks to answer a research question *through* the pursuit of a design question (Findeli et al., 2008, p. 86). In Findeli's works, two different methodological descriptions of PGR can be found. In one description, a design question is transformed into a research question as a first step (Fig. 4.1). The other description starts with the research question, which is then transformed into a design question (Fig. 4.2). In both descriptions, the third step is the finding of a design answer, from which, in the fourth step, a research answer is extracted. Hence, it may be assumed that one may start with either a design question or a research question – depending on the starting conditions – as long as a design answer is found, which can then contribute to a research answer. Thus, Findeli's model can be viewed as belonging to the general field of RTD, which is concerned with »designerly« ways of research (Saikaly, 2005, p. 15). According to Bardzell et al. (2012, p. 288), designing is often considered to be a central activity within such »constructive design research« endeavours. Findeli's model emphasises the interplay of practice and theory, and the interplay of design and research. These interplays are emphasised in other models of RTD, too. For example, Dalsgaard (2009), in reference to Binder and Redström (2006), proposes a model similar to Findeli's PGR. Dalsgaard's model is also based on a dynamic interplay of research and design (cf. Basballe and Halskov (2012, p. 59)).

These models are located in a historical context of debates around the topic of how and why one should combine (or separate) design and research. An overview is given in the following.

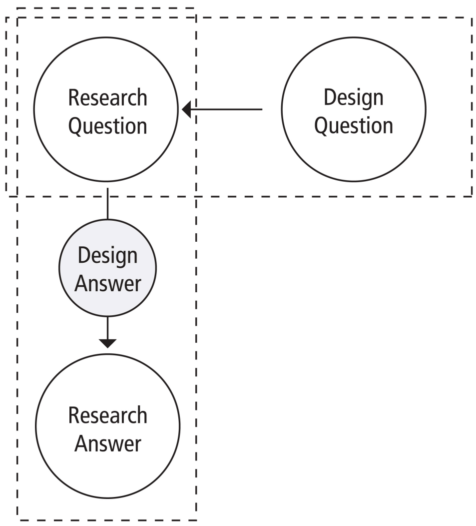

FIGURE 4.1: Findeli's model of RTD (starting with the design question), adapted from his article in the publication that followed the 2010 *Questions and Hypotheses* conference. (Findeli, 2010, p. 288)

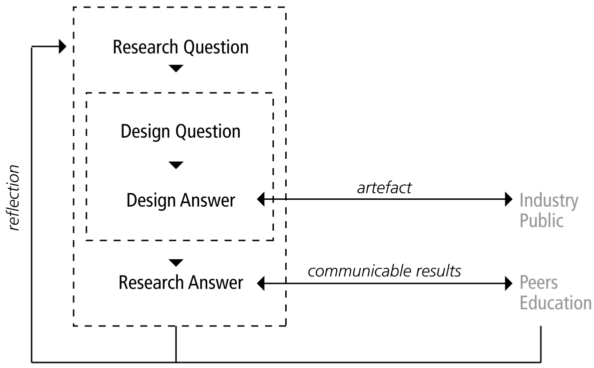

FIGURE 4.2: Findeli's model of RTD, adapted from his presentation at the 2010 *Questions and Hypotheses* conference, with added »outcome channels«.

4.1 Historical Context

Findeli's model stands in a context of other advancements in design research. Firstly, his definition of design research extends Archer's preliminary definitions of design research from 1981. These definitions are based on combinations of individual definitions of »design« and »research«. Archer proposed several different definitions. One of his definitions of design research is a combination of the individual definitions of »Design« and »Research« (i. e. both without articles, and both spelled with a capital »D« and a capital »R«):

> »Design Research is systematic enquiry whose goal is knowledge of, or in, the area of human experience, skill and understanding that reflects man's concern with the enhancement of order, utility, value and meaning in his habitat.« (Archer, 1981, p. 31)

According to Archer (ibid., p. 31), this definition is not precise at all. His second preliminary definition integrates the individual definitions of »design« and »Research« (i. e. »design« without an article and spelled with a lower-case »d«):

> »Design Research is systematic enquiry whose goal is knowledge of, or in, the embodiment of configuration, composition, structure, purpose, value and meaning in man-made things and systems.« (ibid., p. 31)

This definition is, according to Archer (ibid., p. 31), too vague, as well. The third alternative he proposes he finds too narrow and outdated (ibid., p. 31):

> »Design Research is systematic enquiry *into* the nature of design activity.« (emphasis added) (ibid., p. 31)

Findeli's definition integrates Archer's conception of »research« as a »systematic search for and acquisition of knowledge«. Differently, though, the role of design is not that of the object or field of investigation (»knowledge of, or in [design]«), nor is it the direction of the inquiry (»into the nature of design«), it is rather the researcher's starting point (»considered from a designerly way of thinking«) from where an inquiry is undertaken, *outwards* the design field (»related to general human ecology«).

Secondly, Findeli's model also integrates an extension of the concept of »designerly ways of thinking«, as proposed by Cross (1982). This concept regards artefacts as knowledge, and emphasises the designer's ability to »read« and »write« this knowledge (ibid., p. 225). Cross (ibid., p. 225) provides the example of an axe, which »offers (or ›explains‹) a very effective way of splitting wood«.[1] Findeli's model extends upon Cross' concept as it transfers the »designerly ways of thinking« to the context of *research* (Findeli, 2008).[2]

[1] Taking Cross' concept further, a designed artefact has later been called a »theory nexus«. See Carroll and Kellogg (1989) and Collins (1994) for a detailed discussion.

[2] Similarly, Dalsgaard and Halskov (2012, p. 428) point out that RTD is concerned not only with design problems, but also with *research* problems.

4.1.1 Research For, Into, and Through Design

The notion of »research through design« goes back to the differentiation between research »for«, »into«, and »through« art and design, as proposed by Frayling (1993, pp. 4-5). Similarly, also Archer (1995, p. 11) differentiates research »for«, »about« and »through« practice. Unlike Frayling (1993), Archer (1995) refers to »practice« in general, and not only to »art and design«. The general distinction is similar, though. Another, slightly different distinction is proposed by Ludvigsen (2006) . Ludvigsen (ibid.) distinguishes between research »in«, »on« and »through« design (cf. Dalsgaard (2010, p. 201)). All three differentiations are similar in that they differentiate one relationship of design and research in which research is conducted to prepare a design project (»for« and »in«), one relationship in which research is concerned with design (»on«, »into«, and »about«), and one relationship in which design is considered a *means* of research (»through«).

According to these differentiations, »research *for* design« (»research *in* design«) is part of a design project's preparation. Rarely, research degrees are awarded for this type of research, as the acquired knowledge in this type of research is seldom made explicit. Box (2007, p. 13) notes that this type of research is mostly undertaken as a means of *preparation* for a design project. Frayling (1993, p. 5) argues that, in the end, it is often only the artefact that is explicitly displayed. Archer (1995, p. 7) describes research for design as »option research« – research undertaken to enable a decision on what to do. He argues that this type of research is specific to the given situation, which limits the acquired knowledge's transferability to other contexts. Box (2007), Frayling (1993), and Archer (1995) all note that research for design is commonly limited in its transferability to other contexts. Its findings are, as they argue, mostly specific to the situations they arose in. Thus, such research is often considered not suitable for acquiring a research degree.

»Research *about* design« (»research *on* design«, »research *into* design«) tries to *understand design* from an outside perspective. It is rather seldom conducted by designers, and more often by researchers from other disciplines (Box, 2007, p. 13). It is usually considered the least controversial, as the disciplines that conduct such research do already have their own epistemological and methodological traditions (Frayling, 1993, p. 5). This type of research is described as mostly conducted within the humanities (Archer, 1995, p. 11). Box (2007), Frayling (1993), and Archer (1995) consistently locate research about design outside the design discipline. All three argue that it is straightforward research, but that it is usually not the designer who engages in it. It does, as they claim, not require or emphasise a designer-specific skill or perspective.

»Research *through* design« (»research *by* design«), in contrast, is argued to be a design-specific perspective on research: here, design is regarded as a means of knowledge production. It is, according to Frayling (1993, p. 5), the second largest category, and not as standardised as research about design. One example for RTD is doing something new with an already existing technology, documenting the effort, and communicating the findings (ibid., p. 5). It is considered the most controversial type of the three, but, at same time, the most promising one (Box, 2007, p. 13).

> »It is when research activity is carried out through the medium of practitioner activity that the case becomes interesting. [...] There are circumstances where the best or only way to shed light on a proposition, a principle, a material, a process or a function is to attempt to construct something.« (Archer, 1995, p. 11)

Findeli et al. (2008, p. 70) describe PGR as a research approach, based on RTD, that *criticises* and *integrates* the two other types of design research distinguished by Frayling (i. e. research »for« and »about« design). The first critique is that »research for design« is generally considered as insufficiently scientific for academia (as also argued by Frayling (1993)). The second critique is that »research about design« is often irrelevant for design. RTD, in turn, attempts to integrate both approaches, being *rigorous and relevant*, according to Findeli et al. (2008, p. 71). The aim of achieving both rigour and relevance at the same time is a dominant one in the design research literature. Zimmerman et al. (2010, pp. 316-317) argue for a need of »rigorous and relevant« theory, while Dalsgaard (2010, p. 202) points to a need for »discipline and rigor«. Also in the research field of Information Systems (IS), which is related to HCI, a debate about the commensurability of rigour and relevance arose (Robey and Markus, 1998). Here, rigour and relevance are argued to create a dilemma (Ross, 1981, p. 318). Robey and Markus (1998, p. 7), in contrast, argue that the two are not contradictory. In this context, action research is proposed as a means to achieve both rigour and relevance (Avison et al., 1999, p. 94). This could be considered to be a noteworthy parallel, as Findeli et al. (2008, p. 72) refer to PGR as »action research in design«.

4.1.2 A »Designerly« Mode of Inquiry

Archer's and Cross' thoughts can be regarded as early advancements of design's slowly establishing recognition as a knowledge-producing discipline. These advancements include arguments for a designerly mode of inquiry and the possibility of design-specific contributions to general knowledge, based on design-specific skills. The Design Research Society (DRS) conference in 1980, »Design: Science: Method«, is described as an important turning point in this development. Archer (1981) asks: »What is Design Research that It Is Different from Other Forms of Research?« Here, he mentions a »designerly mode of enquiry«, which can be counted as research, but differs from other forms of research (ibid., p. 34). According to Archer (ibid., p. 35), the similarity between the designerly and scholarly modes is that both look at and impose structure upon the world. The difference, he argues, is the process of how this structure is imposed. Similarly, Cross (1982, pp. 221-222) argues that the »designerly way« differs from the »scientific way« in its methods and values. These statements stand in the context of a wider discussion on how to combine science (or, at least, research) and design.

In this discussion, it is generally argued that the sciences are concerned with how things *are*, while design is concerned with how things *should* or *could* be – even though different terms are used for this difference. Alexander (1964), for instance, contrasts science's concern with »existing structures« with design's concern with »new structures« (cf. Cross (2001)). Frayling (1993, p. 1) takes a similar position when he contrasts research, concerned with »going over old territory«, with art, craft and design – which are »concerned with the new«. Relatedly, Simon (1969, pp. 4-5) contrasts the natural sciences as concerned with »how things are« and design as concerned with »how things ought to be«. Further juxtapositions of science's and design's concerns include »analytic« – »constructive« (Gregory, 1966) (cf. Cross (2001)), »natural« – »artificial« (Willem, 1990) and »what is going on« – »what is going wrong« (Findeli, 2010, p. 286). The basic argument is similar among these positions: science is concerned with the existent, while design is concerned with the not-yet-existent.[3]

Another area in which design and science are argued to be particularly different is that of *evaluation*; design is often evaluated in terms of its creativity, science – to the contrary – in terms of its repeatability (Cross, 2001, p. 51). Relatedly, Forlizzi et al. (2008, p. 28) argue that even under the same starting conditions, two designers given the same problem are likely to produce different results. Zimmerman et al. (2007) point out that this may be the reason why some HCI research conferences were initially reluctant to accept papers reporting on design research projects without a formal user study.

Regarding the question of what an appropriate evaluation for a design research project is, Findeli et al. (2008, p. 72) propose three areas of evaluation: »an original and significant contribution to [design] knowledge«, »an expected improvement of design practice« and »some fruitful consequences for design education«. It appears that these evaluation criteria are initially located *inside* the design discipline, but may have an outward impact (i. e. he places »design« in brackets). Also Forlizzi et al. (2008, p. 27) propose a set of criteria

[3] Besides these bipolar contrasts, also triadic models are proposed. Nelson and Stolterman (2002) propose a triadic model of design, science, and art, in connection with the »real«, the »true«, and the »ideal«. For a detailed discussion of several triadic models of design, research, and art, see Fällman (2008).

to evaluate interaction design research contributions in HCI: »process, invention, relevance, and extensibility«. They point out that while repeatability is not considered a core element of the contribution, a documentation of the design process should be provided.

In conclusion, many differences of science and design are discussed. Nonetheless, combining the two is often considered to be potentially fruitful. Endeavours to combine the two despite their differences have thus sparked debates around the question of when an activity counts as »research« at all.

Frayling (1993, p. 1) points out that, even though research is a careful and searching activity, it is not an activity limited to laboratories. He argues that it is about *searching*, that it must include an *external position* of the researcher and that it must lead to *communicable results*. Also Archer (1995, p. 6) has provided criteria for practitioner activity to count as research. According to him, it should be directed towards knowledge, be conducted systematically, and express its data, methods, and results clearly. Archer (ibid., p. 11) furthermore underlines that research should aim to produce *communicable knowledge*. Basballe and Halskov (2012, p. 59) underline that the findings of an RTD project should be communicated in *written form*. It therefore appears that one important aspect for an activity to count as research is the *communicability* of the acquired knowledge.[4]

Explicit documentation of the design process is argued to be mandatory, especially in RTD (cf. Agnew (1993); Dalsgaard and Halskov (2012); Binder et al. (2009)). Also the criterion of »extensibility« (i. e. that the knowledge gained in a design research project can be built upon by others), as proposed by Forlizzi et al. (2008, p. 28), appears to emphasise this aspect. Zimmerman et al. (2010, p. 316) mention a need for a *standardised* documentation process for RTD projects, as to enable the generation of theory. Gaver

[4] Archer (1995, p. 6) also adds »communicable« to his definition of research to his 1981 definition (»systematic enquiry whose goal is knowledge« (Archer, 1981, p. 30)): »systematic enquiry whose goal is *communicable* knowledge« (emphasis added). This may emphasise the importance of the knowledge's communicability.

(2012) criticises this approach, finding it too restrictive. Brandt and Binder (2007, p. 3) argue that a design research project's documentation should include an articulated argument, so that other researchers are able to engage with it (cf. Dalsgaard (2010, p. 202)). In conclusion, the importance of documentation during the design process, as to allow for a »genealogy« (Brandt and Binder, 2007, p. 3) of the produced knowledge and artefacts, is often underlined.[5]

Related discussions regard the adequate ratio of text and artefact in a thesis, in order for it to be suitable for the award of a research degree. A written thesis appears to be mandatory in almost every institution awarding doctoral degrees in relation to design, while some may allow for submitting an artefact *accompanying* the thesis (Douglas et al., 2000).[6]

Methodologically, it is mostly argued that design should maintain (or develop) its own methods, and not adopt other disciplines' procedures of inquiry. It is, for example, argued to be so different from other disciplines that the use of its own, design-specific research methods is not only justified, but also necessary (Findeli, 2000b, p. 56) (cf. Box (2007, p. 12)). Furthermore, it is argued that importing methods from other disciplines would harm the discipline of design research – it should, as Seago and Dunne (1999, pp. 11-12) argue, not lose its »originality, iconoclasm, energy, style, and wit«, just to, scientifically, »play it safe«. Also Krippendorff (1995, p. 145) warns about design's »colonization« by other disciplines. Similarly, Jonas (2004, p. 6) argues that relying on methods from other disciplines does, on the long term, harm the discipline of design research.

[5] The term »design rationale« is commonly used for the justification and documentation of decisions made during the design process (Lee and Lai, 1991; Shipman and McCall, 1997). Bagalkot et al. (2010, p. 42), for instance, engage in an RTD project, after which they reflect their design rationales, but do not provide a formal evaluation.

[6] For a review of PhD theses »by project« at the Royal College of Arts in London in the 1990s, see Seago and Dunne (1999). For a related discussion of PhD research projects at the Politecnico di Milano, see Guerrini (2010).

Furthermore, Jonas (2006) notes that scientific respect sometimes comes at the »price« of having to adapt to other disciplines' methods.[7]

4.1.3 Project Orientation and the Role of Prototypes

A widely used concept in the field of RTD appears to be that of *project orientation*. Regarding this, Findeli (2000a) describes the *project* as design's »most original and specific feature«. Findeli (2010, p. 287) defines the »designerly way of thinking« as a »project-oriented perspective«. This underlines the centrality of the »project« for RTD. Also Jonas (2004, p. 1) mentions an »overarching project« (transl.) as a means of combining design and research. Torka (2009) argues that research is, by itself, »project-shaped« (transl.). Likewise, Forlizzi et al. (2008, p. 22) point to »project research« as one of five models of design research in HCI, yet not in reference to Findeli.

One aspect that is closely associated with project-orientation is the central role of the *prototype*. The role of the prototype appears to be understood as a means of communication, both internally (i. e. within the project team, or to the designer herself/himself) and externally (i. e. to clients and peers) (cf. Zimmerman et al. (2007); Buchenau and Fulton Suri (2000)). Also, prototypes are considered as helpful in thinking, as they can act like a sparring partner for the designer (Klemmer et al., 2006, p. 142). They are argued to be a means of testing implicit hypotheses (Keyson and Alonso, 2009, p. 4550). Some methods, including the Repertory Grid Technique (RGT) (that I discuss and apply below), also rely strongly on prototypes (Fällman, 2003b, p. 299). In that, the prototype is often considered to be the connecting element of research and design (Basballe and Halskov, 2012, p. 58). However, according to Findeli et al. (2008, p. 72), the prototype is not the main outcome of an RTD project (Fig. 4.2). Instead, the main outcome in Findeli's model is knowledge.

[7] See Gaver (2012, p. 937) for a discussion of more recent developments in this debate.

4.1.4 Earlier Developments

The discussion about how to combine design and science stands in the context of a larger debate about the relationship of the two. A prominent, earlier development in this debate is the design methods movement. Its origin can be dated to 1962, when the first conference on this topic was organised by Jones (cf. Jones (1992, p. xi)). Jones' original motivation was not design theory, but simply to emphasise human requirements in design (ibid., p. x). Therefore, and in contrast to its later-criticised over-theorisation, the design methods movement had originally been proposed as a *reconciliation* of theory and practice (Maldonado and Bonsiepe, 1964, p. 8). One of the developments from this time was Alexander's approach of a »pattern language«. It is based on splitting large problems into smaller ones, for which solutions may already exist or be easily achievable (Bayazit, 2004, p. 18) (cf. Alexander (1964)). Pattern-based approaches, like Alexander's, appear to be still valued in the HCI community (cf. Borchers (2001)).

Also the Hochschule für Gestaltung Ulm is considered to be a driving force of the »scientising« of the design process. Maldonado and Bonsiepe point out that the Hochschule für Gestaltung Ulm followed a comparably strict approach of scientific methods in and for design (Maldonado and Bonsiepe, 1964, p. 5). It is disputed whether this approach was a success or not. It is partially perceived as »cold, painstaking, humourless, sparse, inflexible« (transl.), but also as a »more or less successful model of a synthesis of science and design« (transl.) (ibid., pp. 5-6) (cf. Mareis (2010, p. 4)).

The design methods movement came into being in times of increased societal need, which is argued to have led to its strong interest in *optimisation*. Specifically, Bayazit (2004) argues that World War II influenced the development of the design methods movement. Bayazit (ibid., p. 17) argues that in times of material scarcity, highly efficient problem solving was necessary – and that the design methods movement seemed to be a worthwhile approach. For example, scientific methods were applied in order to design houses in ways that allowed for a maximum of living space at minimal cost. At the same time, controversial developments that diminished the humanistic aspects of architecture (e. g. »windowless buildings« (Bayazit, 2004, p. 25)) arose. This may illustrate the two-sided coin that »scientised« design could be – highly efficient on the one side, but less oriented to actual human needs on the other.

In parallel to the design methods movement, the notion of »design science« emerged (Buckminster-Fuller and McHale, 1963). It aims to maximise utility, while minimising cost (Bayazit, 2004, p. 17). In this approach, it was attempted to »formulate« design, and make its outcomes scientifically (or mathematically) predictable (Cross, 2001, p. 52). This idea of mathematically solvable design problems has later been criticised.[8] Today, the notion of »design science« appears to be rarely used.

A seemingly similar term to »design science« is the influential notion of the »sciences of the artificial« by Simon (1969). It has a different meaning, though. Simon is not as much concerned with how to change design activity (e. g. to make it scientific) – rather, his interest is the emancipation of the discipline. Firstly, he argues that everybody is a designer. He defines design activity as follows:

> »Everyone designs who devises courses of action aimed at changing existing situations into preferred ones.« (ibid., p. 130)

As mostly everybody devises courses of action to change existing situations into preferred situations in their everyday lives, everybody is a designer in these situations, according to Simon's definition. Then, Simon argues that there is a disciplinary speciality to design: its concern with the »artificial«. This, according to Simon, distinguishes it

[8] For a detailed discussion, see Maldonado and Bonsiepe (1964, pp. 20-21) and Mareis (2010).

from other disciplines. In that, Simon provides an important argument for the epistemic emancipation of design that emerged in the 1980s. He claims that design investigates a subject that is neither covered by the natural sciences, nor by the humanities. Schön (1984) criticises Simon's concept of a »science of design« for its focus on well-formed problems, arguing that design problems are usually not well-formed. Schön does not explicitly cite Rittel and Webber (1973) here, but his thought seems to be related to Rittel's notion of »ill-defined problems« (also called »wicked problems«). Schön (1984) argues for a more practice-oriented approach, which embraces uncertainty, vagueness and situation-specificity – an approach that he calls »reflective practice« (cf. Cross (2001, p. 53-54)). These positions are influential for the later development of RTD as they emphasise the designer's ability to »communicate« with the artificial world (i. e. to »read« and »write« the »material culture« (Cross, 1982)).

The debate about the relationship of design and science can, according to Mareis (2010), be traced back to earlier developments, e. g. to the Bauhaus and »De Stijl«. During this time, the 1920s, first attempts were made to »scientise« design (Cross, 2001, p. 49) (cf. Mareis (2010, p. 6)). It was attempted base design on scientific research and knowledge. Of the two disciplines, science is argued to have been the dominating one at this time (Cross, 2001, p. 52). But also, during the same period, proposals regarding art as a means of knowledge production were made. Kandinsky, for instance, is argued to have expressed such intentions (Mareis, 2010, p. 8). For this, according to Galison (1990, p. 738), he coined the term »practical science«. These proposals of artistic and designerly knowledge production were, however, largely superseded by the developments of the design methods movement. When the design method movement dispersed, they gained momentum again. The design methods movement's dispersal began during the late 1960s. Increasingly, its original protagonists began to distance themselves from it. Alexander (1971), for example, states: »I've disassociated myself from the field [...] I would say forget it, forget the whole thing.« A second generation of the design methods movement followed during the 1970s. It was rather concerned with user orientation and participation and might be seen as an early development towards participatory design (Bayazit, 2004, p. 21). It led to more flexibility and changed the role of the designer in society: the designer's role in society is described to have shifted from a craftsman to an expert in the domain of the artificial.[9] This shift is described as being followed by an epistemic emancipation of design research in the 1980s, which, also through the advancements of Archer, Cross, and Frayling, may have allowed for the establishment of RTD (Findeli et al., 2008, p. 72).

4.2 Epistemological Reference Points

Besides its roots in the history of design, RTD has roots in the history of research, as well: it is described as related to both *action research* and *grounded theory* (Jonas, 2004, p. 4).

4.2.1 Action Research

Action research is described as being concerned with the development of practice, in a way that is sensitive to theoretical implications (ibid., p. 4). Archer (1995, p. 6) defines action research as a »systematic enquiry conducted through the medium of practical action; calculated to devise or test new, or newly imported, information, ideas, forms or procedures and generate communicable knowledge«. One parallel of action research and RTD is that both work *through* practice (Avison et al., 1999, p. 95). Frayling (1993, p. 5) states that action research is a »type« of RTD. Findeli et al. (2008, p. 72), to the contrary, note that RTD is »action research in design« (i. e. a type of action research). Findeli (2010, p. 287) notes that action research has been »renamed ›project-grounded research‹ in design research«. This may underline, while it may be unclear which one of the two belongs into a sub-category of the other, that the two are closely related.

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[9] For a detailed review of this development, see Mareis (2011).

4.2.2 Grounded Theory

Grounded theory, on the other hand, is described as being concerned with theoretical advancement, in a way that is sensitive to implications for practice (Jonas, 2004, p. 4). It is described as standing in contrast to the traditional scientific paradigm of stating a hypothesis first, and then verifying it through experiment (Glaser and Strauss, 1967, p. 2). Glaser and Strauss (ibid., p. 3) argue that theories generated through grounded theory tend to fit practice better. Martin and Turner (1986, p. 142) argue that, in most cases, the researcher is not in possession of an adequate theory of the situation which would only need to be checked – more often, they argue, theories need to be developed in interplay with practice. Grounded theory is, according to Fernández (2005, p. 47), therefore suited for areas of research that is known only little about. One important methodological aspect of grounded theory is described as dealing with the researcher's own position *as elicited data* (ibid., p. 45). Forming theoretical concepts during the elicitation of data, not in advance (Urquhart, 2001, p. 107) (cf. Fernández (2005, p. 44)) is argued to be advantageous in several ways. For example, the generated theory is argued to be easier to test because it is more closely connected to the data (ibid., p. 47), and also to be more likely to be »empirically valid« (Eisenhardt, 1989, p. 547) (cf. Fernández (2005, p. 47)).

Both, action research and grounded theory, are individually proposed to solve the »crisis« (Susman and Evered, 1978, p. 582) or the »dilemma« (Fernández, 2005, p. 44) of *rigour and relevance* in IS research. This is notable because the same dilemma is posed by Findeli et al. (2008, p. 71), and he proposes RTD as the solution. This parallel also underlines the close relationship between RTD and the two. Both appear to interweave theory and practice (each putting more emphasis on either theory or practice). The two are increasingly accepted in the research community, and therefore may provide a helpful epistemological reference point for the establishment of RTD.

4.3 Researching »Embodiment« in HCI through Design

In this chapter, I have introduced RTD and Findeli's model of PGR. I have shown their historical and epistemological context, originating in Archer's early thoughts on Design Research, Cross' thought of »designerly ways of knowing«, and Frayling's differentiation between research »for, through, and about« design. I have summarised arguments for RTD being a valid means of research, contextualising it in its historical context, and methodologically associating it with action research and grounded theory.

HCI, as outlined in the beginning, is increasingly integrating itself into people's everyday lives. This makes it necessary for HCI research to adopt approaches that embrace this increasing »everydayness«. Design research, being deeply concerned with people's needs and abilities, may hold valuable potential in this regard. However, it appears to have found only scarce recognition in HCI research so far (cf. Forlizzi et al. (2008) and Gaver (2012)).

I therefore conclude that it should be assessed what RTD can contribute to the issue of »embodiment« in HCI. This issue, that I exposed in the previous two chapters, appears to be particularly suitable for a »designerly« inquiry, as one of its central questions is how different »representational embodiments« of digital information affect the »experientially embodied« user's experience of the interaction. We can hardly change the user's »experiential embodiment«, but we can design the »representational embodiments« of digital information. I therefore propose to pursue this question *through design*.

CHAPTER 5

Project: Physical Manifestations of Digital Information

> »A representation [...] only becomes meaningful for a person through the way it manifests itself to that person.« (Fernaeus et al., 2008, p. 255)

In this chapter, I report the Research Through Design (RTD) project I conducted for this dissertation. This project investigates how different kinds of physical manifestations of digital information influence users' experiences of the interaction. Through that, it explores the conceptual space that is opened by distinguishing between »representational embodiment« and »experiential embodiment« in Human-Computer Interaction (HCI).

In the first section of this chapter, I describe the prototypes I developed and report on previous studies, which were conducted with them.[1] In the second section of this chapter,

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[1] Even though I designed the prototypes, I did not build them on my own. Ulrike Gollner, Susann Hamann, Matthias Löwe, Anne Wohlauf, and Josefine Zeipelt worked, during my PhD project, as interns and student workers in our lab, helping me to build the actual devices. They are also co-authors of the respective publications that accompanied the project.

I report on a Repertory Grid Technique (RGT) user study that was conducted to compare the prototypes with vibration-based prototypes.

I hypothesised that designing the »representational embodiments« of digital information in orientation to the user's »experiential embodiment« in their socio-physical world would lead to interactions that are perceived as richer, less invasive, and more familiar.

The prototypes I developed in this project are mobile phone prototypes, based on socio-physical metaphors for digital information. That means that in the prototypes, digital information is represented (i. e. »embodied«) through simulations of object properties that normally occur in the user's socio-physical world (in which I understand the user to be »embodied« in). I hypothesised that users would be inherently familiar with these object properties. In a sense, it is attempted to »embody« digital information in the same world (i. e. the socio-physical world) that the user is »embodied« in. Besides, I hypothesised that the »representational embodiment«, when manifested like this, would »suit« the user's »experiential embodiment« better. As noted above (p. 52), this could be interpreted to be a general approach in Tangible User Interfaces (TUIs). However, such endeavours are rarely made in a way that allows for the comparison of different interfaces.

The basic principle I employed in the prototypes' design is that digital information should be embodied through something which users are inherently familiar with from their interactions in their everyday lives – persons and objects. Therefore, I looked for the basic properties of encountering the socio-physical world, and assessed if these encounters could also be used to embody digital information.

In our everyday world, we encounter objects. These objects have different physical properties: colour, material, temperature – all of these physical properties could be actuated, and thus be used to embody digital information. Different styles of physical actuation are actively explored by the TUI research community. Therefore, each of the prototypes is presented in its own respective academic context of related work.

One of the perhaps most fundamental physical properties of objects we encounter in our everyday lives is *shape*. Our hands feel the shape of hand-held objects without explicit thought. In this process, proprioceptive (i. e. felt through receptors for limb position and muscular activity) and tactile (i. e. felt through receptors in the skin) perception are mixed.[2] Not all shapes can be felt – some may be too small, and some may be too big. But many of the things we touch, we explore with our hands. Here, also other modalities (e. g. the sound, or the visual appearance of a texture) may cross-influence our haptic perception (Hoggan et al., 2008). Our hands' sensitivity to the shape of objects may offer a way to display digital information in a more »graspable« way. Thus, actuated shape may be one possibility to embody digital information in a way that builds upon the users' familiarity with the socio-physical world.

In the context of »embodied metaphors« (p. 46), information is, at times, metaphorically considered a »substance« (Lakoff and Johnson, 1980). For example, it is often said that one »grasps« or »gets a grip on« something when one has understood it. A description can be »thick«, evidence can be »thin« and data can be »rigid«. These are physical, shape-oriented metaphors for information.[3]

Therefore, I hypothesised that shape is particularly suitable for the display of the amount of digital information (e. g. amount of e-mails in the user's inbox). Furthermore, I hypothesised that also directional information could be displayed through thickening or tapering the device's geometry into a certain direction. To explore these hypotheses further, I investigated actuated thickness as a basic principle of haptic actuation in mobile devices. An overview of the developed prototypes is given in the next section.

[2] For a detailed discussion of the biomechanical aspects of cutaneous (i. e. skin-based) sensing of shapes, see Goldstein (2001, p. 535).

[3] Such metaphors based on the concepts of »substance« and »orientation«, are discussed by Lakoff and Johnson (1980, p. 25) as »ontological metaphors«, grounded in bodily experience.

Another physical property of things and beings in the socio-physical world is *mass*. Mass, through gravity and inertia, leads to the perception of an object's *weight*. Like shape, our hands sense the weight of a hand-held object often implicitly, without explicit thought or effort. Some objects may be too lightweight or too heavy to be perceived with bare hands. But with many hand-held objects, one easily gets a feeling for their weight. Therefore, changing the weight of an object to represent digital information inside of it may appear to be a viable approach. However, an object's mass is considered to be constant – to change it, it would be necessary to attach additional objects to it, or to remove parts of it. Thus, I sought an alternative. Besides to an object's weight, one may also be sensitive to its *distribution of weight* – i. e. to where an object has its centre of gravity. This seemed to be more suitable for hand-held interaction. If an object has its centre of gravity outside of its centre, this might lead to the sensation of it tilting into that direction. Thus, I hypothesised that the shift of an object's centre of gravity would be especially viable for the display of digital information regarding directions and positions.

In some cases, the »embodied metaphor« of »information is a substance« makes use of the concept of weight. For example, data can be »solid«, an argument can be »hollow«, and a text can be »heavy«. Therefore, I hypothesised that shifting the weight of a hand-held object would be a viable means to embody digital information, making it »graspable« for the user. I give an overview of the prototypes in the next section.

The term »*socio*-physical« metaphors implies a social dimension – other living beings. In our everyday experience, we encounter living beings, which generally utter *signs of life*. Their simulation is a principle of embodying digital information that I investigate in a third series of prototypes. Representing digital information through life-like cues appeared to be an interesting approach. It is based on the assumption that users are inherently familiar with life-like cues (indicating, for example, whether someone is excited or relaxed) from their experience in the socio-physical world. Given the many different ways in which a living being can utter itself, I had to decide which to include, and which to leave out. As I found them to be the most basic, and yet expressive enough to represent inner states of excitement and relaxation, I chose to focus on breathing and heartbeat. I hypothesised that users would, over time, get used to the permanent, rhythmic, repetitive movements of such a device. Thus, I hypothesised that the »living« mobile phone could remain unnoticed in the user's pocket, with a calm heartbeat and calmly breathing, until it, metaphorically, »needed the user's attention«. Then, the phone would express its »need for attention« through accelerated heartbeat and excited breathing. In that, this exploration exaggerates the user's relation to her or his device, providing another example of an »embodiment« of digital information, designed to be encountered in the socio-physical world that the user is »embodied« in.

In conclusion, I chose shape actuation, weight actuation, and simulated life-likeness to embody digital information in the prototypes. I hypothesised that these principles would be suitable to explore the encounter of »representational embodiment« and »experiential embodiment«.

5.1 Prototypes

In this section, I describe the developed prototypes. Different versions of the hardware are presented, as are different versions of the envisioned applications. Besides the *Shape-Changing Mobile* prototypes, the *Weight-Shifting Mobile* prototypes, and the *Ambient Life* prototypes, a series of vibration-based comparison prototypes is presented.

5.1.1 The Shape-Changing Mobile

The first series of prototypes concerns shape as a »representational embodiment« of digital information, manifesting it in the socio-physical world. This principle is based on the hypothesis that users would be inherently familiar with this type of actuation because of their »experiential embodiment« in the socio-physical world. It is based on the aforementioned assumption that shape is associated with substance, and that substance can serve as a metaphor for information. Hence, I propose the mapping of »more information« to »thicker«. Besides this mapping, the geometry of the hand-held device, if actuated, could be used to point users into directions, and display spatial information about contents inside the device. I assumed that users would, from their everyday experience, be familiar with the determination of a hand-held object's shape. I developed a series of shape-changing mobile phone prototypes. It consists of two prototypes. The first prototype is able to actuate its thickness along one axis, the second one is able to do so along two axes.[4]

The *Shape-Changing Mobile* stands in a context of other research on shape-actuated systems. In the »Dynamic Knobs« project (Hemmert et al., 2008), for example, shape change in mobile phones is explored, as well.[5] In this project, the shape change is achieved through a motorised button on the phone's side. This button can be changed in its haptic properties: hard to press when it causes the deletion of a contact, easy to press when it is used to take a photo. In another application, voice mail messages are displayed through the motorised button. This allows users to check for new messages through a quick grasp for the phone. The messages can be played back by holding the button. During the playback, the button slowly moves back into the device, creating the illusion that the message is being »squeezed out«. Further research in this area explores, for example, the motorised elevation of individual pixels on a »2.5-dimensional« display. Poupyrev et al. (2004), in the »Lumen« project, propose a matrix of motorised pixels, each of which can be controlled in colour and height. Similarly, the »Tactophone« by Horev (2006) employs a shape-actuated pixel matrix on its backside. Coelho et al. (2008, p. 3429), in the »Surflex« project, propose soft, malleable interaction surfaces that can change their shape. In that,

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[4] For a report on the one-dimensional version, see Hemmert et al. (2010a). For a report on the two-dimensional version, see Hemmert et al. (2010d). The following contains a condensed version of the papers.

[5] The overarching project to which the »Dynamic Knobs« prototype belongs, »Touch it«, was conducted together with André Knörig, Julia Werner, Hans-Peter Kadel, Reto Wettach, and Gesche Joost. It can be regarded as the predecessor of the *Shape-Changing Mobile*.

»Lumen«, »Tactophone« and »Surflex« allow for the simultaneous actuation of visuals and haptics.

Other projects rely less on visual cues, and rather provide reactive feedback upon *being* touched: »BubbleWrap« by Bau et al. (2009, p. 3607) proposes a combination of vibration-based (i. e. active) and stiffness-based (i. e. passive) haptic feedback. Furthermore, deforming shapes in computer peripherals are explored as a means of interaction. For example, »Inflatable Mouse« by Kim et al. (2008) is a device that can inflate and deflate. While it explores some applications concerned with volume-based output, it rather emphasises the potential of using deformation as an *input*. It makes use of the user's dexterity in deforming objects. »FlashBag« by Komissarov (2006) is, in turn, more focused on output. It is a concept of a storage medium that displays the amount of data in it through inflation. Using a slightly different mapping of digital information and shape, the »InSync« project by Horev (2006) proposes a shape-changing backup hard disk. Its status is displayed through the angle between its front and back plate: when the backup is complete, both are aligned to each other. When the backup is out-of-date, the device's front and back plate are twisted (ibid., pp. 39-40). Here, the metaphor is a different one than in the »FlashBag« concept: if the data on the backup disk is not »symmetric« to the original data, the device itself is also asymmetric.

Another mapping, based on actuating the geometry of a hand-held device, can be found in a project on vehicle teleoperation by Hughes et al. (2003, p. 501). They propose a remote control for a toy car. This remote control displays the tilting angle of the car (e. g. when driving a curve) through a corresponding tilt of its back plate. In this case, the tilt of the toy car is simulated in the remote control. This mapping is rather direct. Here, digital information is used as a carrier for physical aspects of the toy car, which are then reproduced in the remote control.

It can be concluded that different mappings of digital information and physical shape change can be found in the HCI literature. These range from the mere simulation of physical properties to »substance« metaphors (e. g. »more data is thicker«), haptic pixel

Figure 5.1: The *Shape-Changing Mobile* (one-dimensional version, illustration).

matrices and more abstract mappings, like »symmetric data corresponds to symmetric shape«.[6]

The mappings in the *Shape-Changing Mobile* prototype are rather indexical physical representations (»embodiments«) of digital information, but also other ones are explored. In the following, I give an overview.

The *Shape-Changing Mobile*, in its one-dimensional version, consists of a mobile phone-shaped box, measuring 100×60×45 mm. It is able to taper its back plate by +15° and -15°, measured against its front plate (Fig. 5.1, Fig. 5.2). The maximum distance of the back plate's edge from its resting position is 14 mm. Three applications, each employing a different degree of user involvement, are proposed: »interactive feedback«, »user notification«, and »ambient display« (Hemmert et al., 2010a, p. 250). In the »interactive feedback« application, digital photographs in a photo album application are physically represented through the device's thickness. For this application, the phone is held in landscape mode. The photos are laid out horizontally in the interface. The more photos are on the left side of the current viewing position, the thicker the phone becomes on the

[6] Different types of representation can be observed here. Some physical representations of digital information appear to be rather indexical (e. g. »more is thicker«), others are rather symbolic (e. g. »symmetry« as a shared property of two data sets and the device's physical shape). See Joost and Hemmert (2010) for a discussion of this topic.

FIGURE 5.2: The *Shape-Changing Mobile* (one-dimensional version).

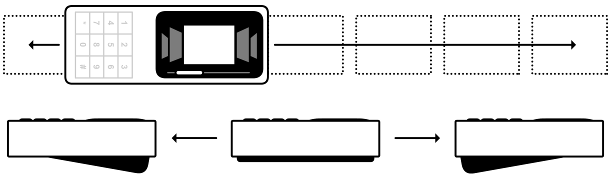


FIGURE 5.3: The *Shape-Changing Mobile* (one-dimensional version). Application: »interactive feedback«. Digital photos are physically represented through the device's thickness.

left side. Likewise, the right side of the device becomes thinner – and vice versa (Fig. 5.3). In this application, the »representational embodiment« of digital information (i. e. the photographs) is physical thickness. I hypothesised that, based on the »substance« metaphor for digital information, users would understand the principle of »more information is thicker«.

In the »user notification« application, a file download is displayed. It progresses from »top« to »bottom« (Fig. 5.4). This mapping follows the movement implied in the term »*down*load«. Furthermore, it is based on a »substance« metaphor for digital information:

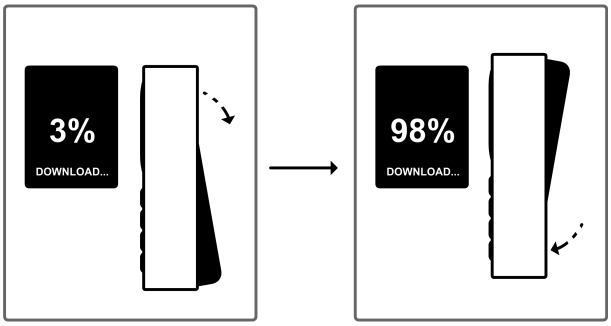


FIGURE 5.4: The *Shape-Changing Mobile* (one-dimensional version). Application: »user notification«. A file download is displayed through a physical thickness, progressing from the device's top to its bottom.

more digital information is thicker than less digital information. Hence, the progressing download is »representationally embodied« through physical thickness, moving from the device's top to its bottom. It manifests the metaphor (and the »download«) rather literally. I hypothesised that this would make sense to users, because of their »experiential embodiment« in the socio-physical world.

The »ambient display« application regards the phone's current battery status. It displays the battery charge level through the tapering of the device. The metaphor, in this case, is rather that of a »hungry« living being: when viewed as a body, the devices' stomach would be on its lower half. If this part of the device is thicker than its upper half, the phone is »stuffed« – which corresponds to a high battery charge level. If its lower half is thinner, though, the phone is »hungry«, which corresponds to a low battery charge level (Fig. 5.5). I hypothesised that this type of mapping would be understandable to users due to their »experiential embodiment« in the socio-physical world. Moreover, I hypothesised that the rather permanent character of this kind of actuation (i. e. the slow change of the device's geometry over the day, as the battery charge level lowers) would make it easier to ignore.

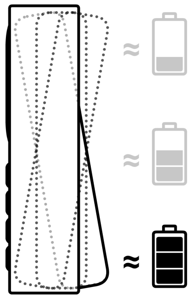


FIGURE 5.5: The *Shape-Changing Mobile* (one-dimensional version). Application: »ambient display«. The phone's current battery charge level is displayed through the device's shape.

The second prototype of the *Shape-Changing Mobile* allows for two-dimensional shape actuation. It consists of a mobile phone-shaped box (110×20×60 mm) and allows for a maximum tilt increase of 10° into each direction (Fig. 5.6, Fig. 5.7). The back plate's maximum levitation from its resting position amounts to 15 mm. Differently than the one-dimensional variant, this prototype can increase and decrease its thickness, keeping its front and back plates parallel to each other (Fig. 5.8a). Angular actuation, as in the one-dimensional prototype, is possible, as well (Fig. 5.8b). Three applications are proposed: dynamic ergonomics, the haptic display of off-screen contents, and a haptic compass (Hemmert et al., 2010d, p. 3077).

The ergonomic application (Fig. 5.9) is based on no underlying metaphor for digital information. I hypothesised that shape actuation would be appreciated by users for increasing the device's adaptivity to different usage situations, e. g. carrying it in the pocket and holding it in hands. When carried in the pocket, the device would be thin, whereas it would dynamically adjust its shape to the user's grip when held in hands.

The off-screen content application (Fig. 5.10) is based on a »substance« metaphor for digital information. It simulates a thickening of the device towards digital information

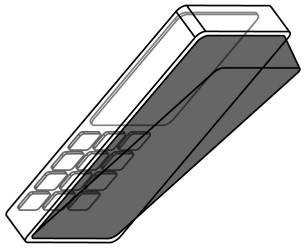
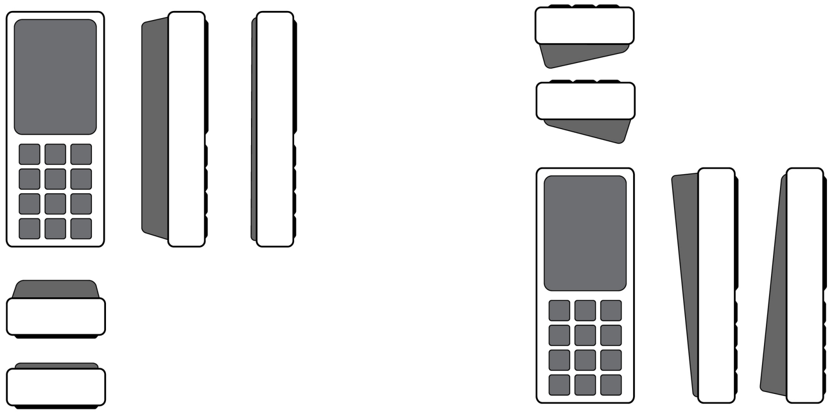


FIGURE 5.6: The *Shape-Changing Mobile* (two-dimensional version, illustration).

FIGURE 5.7: The *Shape-Changing Mobile* (two-dimensional version).



(a) Thickness actuation.

(b) Angular actuation.

FIGURE 5.8: The *Shape-Changing Mobile* (two-dimensional version, illustration).

FIGURE 5.9: The *Shape-Changing Mobile* (two-dimensional version). Application: »actuated ergonomics«. The device can be thin in the pocket, and dynamically adjust its shape when held in hands.

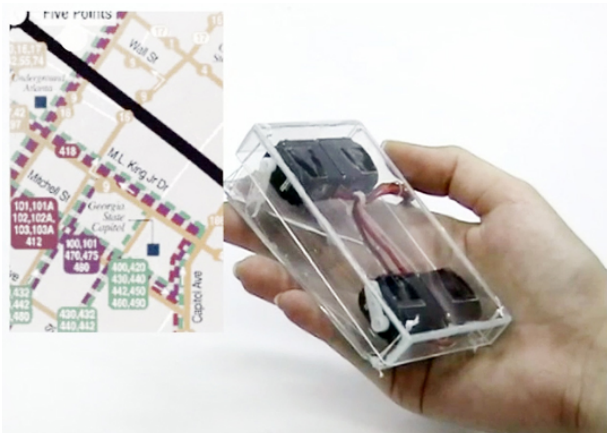


Figure 5.10: The *Shape-Changing Mobile* (two-dimensional version). Application: »augmenting GUI contents with thickness«. The device displays off-screen content through thickening towards the location of the content.

being virtually present off-screen, thus creating an angle in the device »towards« the off-screen information.

The haptic compass application (Fig. 5.11) is based on a »substance« metaphor for digital information, too. It is, however, not concerned with digital information inside the device, but with a place *outside* of it. Through shape change it manifests the direction of the destination, relative to one's own position.

Figure 5.11: The *Shape-Changing Mobile* (two-dimensional version). Application: »haptic compass«. The device provides directional information by thickening towards the destination's direction while navigating.

Previous Studies of the Shape-Changing Mobile

The one-dimensional prototype of the *Shape-Changing Mobile* was tested in a user study.[7] In it, the participants were asked to estimate the angle between the device's front and back plates, and to express their thoughts on the envisioned applications. In this study, 12 participants (6f, 6m, ⌀26.8 yrs.) were introduced to the system and shown its full movement range of +15° to -15°. The participants operated through a curtain (i. e. they were unable to see the prototype) and were presented the angular positions in a balanced, pseudo-randomised order. In 9 trials, each participant was asked to place the device on a table, where it would change its shape (i. e. the angle between its front and back plate). This procedure was chosen to avoid additional cues (e. g. through feeling the mo-

[7] I would like to thank Ina Wechsung and Robert Schleicher for their kind help with the statistical evaluation that was part of this study. For a detailed discussion, see Hemmert et al. (2010a).

tor's vibration). Then, the participants were asked to grasp the device and estimate its current angular position within the movement range. The target positions were evenly distributed along the device's full movement range. The recorded measures were time and error.

The results of the study indicate that such a style of actuation can support mobile interactions. The mean error for determining the angular position was 2.55° (SD = 3.26°), the mean time was 6.37 s (SD = 4.83 s). A repeated measures MANOVA was conducted, no significant main effect of trial on time and error (Pillai's Trace = .697, $F_{16,7}$ = 1.005, p = .531) was revealed (Hemmert et al., 2010a, p. 251). A univariate analysis showed a significant main effect of trial on time (Greenhouse-Geisser = 357.579, $F_{5,104}$ = 2.527, p = .036) (ibid., p. 251). The participants were also interviewed. They noted, regarding the photo browser application, that it would give them a feeling for their current position in the photo stack. For the download display application, they appreciated the »supportive, hand-friendly« character of the interaction. The battery status display, which was not introduced mentioning the »hungry/stuffed« metaphor, led to some confusion regarding the mapping of »up« and »down«, as some participants associated the thicker part of the phone with the current battery charge level, while others associated the thinner part with it. Further comments indicated that the phone would be more comfortable to grasp when the thicker part was at the bottom (i. e. in the palm) (ibid.). In conclusion, the participants appreciated the interaction's intuitiveness, but were, to some degree, confused about some of the mappings of »up« and »down«.

Also the two-dimensional prototype was tested in a user study, following a similar procedure.[8] Again, the participants were asked to estimate the angle between the device's front and back plate, in relation to the their full movement range. Differently,

[8] I would like to thank Ina Wechsung, Stefanie Lange, Sarah Diefenbach, and Marc Hassenzahl for helping with the statistical evaluation that is part of this study. For a detailed report, see Hemmert et al. (2010d).

in this study, they were asked to do so for both the X and Y axes. 12 participants (5f, 7m, ⌀28.8 yrs.) took part in the study. In the preparation phase, 15 combinations of angles on the X and Y axes, in pseudo-randomised order, were demonstrated to the participants. The experimental setup was similar to that of the previous study. The participants had no visual contact to the device, operating through a curtain. This time, the participants also wore headphones, as to avoid additional auditory cues through the motor's sounds. In each trial, they were asked to place the device on the table (i. e. as to avoid cues through feeling the motor movement's duration), where the phone changed its shape. After that, the participants were asked to pick up the device again and estimate the current X/Y position. They were asked to mark the position on a picture of the prototype, which was displayed on a computer that had been placed next to them. The recorded measures were time and error. Lastly, they were asked to fill out the »AttrakDiff« questionnaire (Hassenzahl et al., 2003), which assesses the interaction in terms of »pragmatic quality« and »hedonic quality«.[9]

The participants determined the back plate's angle with an average error of 5.46° (SD = 5.33°) on the X axis, and with an average error of 5.47° (SD = 4.96°) on the Y axis. The average time required for this was 7.01 s (SD = 4.71 s). A T-Test did not reveal any significant differences between the accuracy on the X and Y axes (T_{11} = .030, p = .485). A positive correlation between X and Y error was found, though (Pearson's r = .781, N = 12, p = .001). The results of this study were compared to that of a similar study, which had been conducted with the two-dimensional version of the *Weight-Shifting Mobile*. No significant differences between the participants' ability to determine the current positions (mapped to the respective prototype's full movement ranges) on the *Weight-Shifting Mobile* and the *Shape-Changing Mobile* were found (T_{11} = .685, p = .508). Significant differences appeared within the »attractiveness« ratings (T_{11} = 3.823, p = .003). The *Shape-Changing Mobile* prototype was rated as significantly more attractive (M = 5.09, SD = 0.58) than the

[9] The same questionnaire was filled out by the same participants after trying the two-dimensional version of the *Weight-Shifting Mobile* (Hemmert et al., 2010f).

Weight-Shifting Mobile prototype (M = 4.42, SD = 0.74). Also, the »hedonic quality: identification« scale showed differences (T_{11} = 3.422, p = .006). On this scale, the *Shape-Changing Mobile* (M = 4.69, SD = 0.56) was rated significantly higher than the *Weight-Shifting Mobile* (M = 4.39, SD = 0.69). For further details, see Hemmert et al. (2010d).

5.1.2 The Weight-Shifting Mobile

In this prototype, the »representational embodiment« of digital information is achieved through a shift of the device's centre of gravity. I hypothesised that feeling the distribution of weight within a hand-held object would be a feasible means to leverage on a »substance« metaphor for digital information, which I assumed users to be familiar with from their »experiential embodiment« in the socio-physical world. In colloquial language, weight-related expressions for information can be observed. We speak of »heavy stuff«, »loads of information« and an »information diet«. Thus, I hypothesised that such a metaphor would be easily understandable for users. I developed a series of prototypes. Several studies were conducted with them. In the following, I give an overview.[10]

Haptic actuation through weight shift stands in a broader context of research. Research in this area is often concerned with the actuation of how a device feels in the user's hand. Such research explores, for instance, thermal displays (Ottensmeyer and Salisbury, 1997). Wettach et al. (2007) propose a temperature-based navigation system for pedestrians, exploring how high and low temperature can be used as an ambient display for getting closer to a target. Furthermore, weight shift has been explored as a means of

[10] For a report on the one-dimensional version, see Hemmert et al. (2010b). For a report on the self-balancing version, see Hemmert et al. (2010e). For a report on the two-dimensional version, see Hemmert et al. (2010f). The following contains condensed versions of the papers.

simulating heaviness in the Virtual Reality (VR) context. Scheibe et al. (2005) propose weight shift as a means of haptic feedback in a VR fork lift simulator. When a box is placed on the virtual fork, an increase in heaviness is simulated in the hand-held controller. This simulation is achieved through shifting a weight in the controller, from the rear (i. e. inside the hand) to the front (i. e. outside of the hand). Relatedly, ungrounded force feedback is explored in mobile devices. »GyroCube« by Sakai et al. (2003), for instance, uses a combination of three spinning wheels to exert torque on the user's hand. This makes it possible to provide directional »pulling« cues, without having to mount the device, for instance, to a table. »Lead-Me« by Amemiya et al. (2008, p. 15:2) uses torque, too. Differently, though, it is based on moving a mass back and forth: quickly into one direction, slowly into the other. Like this, it aims to create the feeling of being »pulled«. Amemiya et al. (1999) propose an air jet-based haptic system, involving small air streams that provide haptic feedback to the user's fingertips.

These explorations show that haptic actuation in mobile devices is not limited to vibration or »shape output« – different styles of actuating the device's feeling, while being held in hands, are actively explored. However, it is unclear how these different styles of actuation are experienced in the interaction, in comparison to each other.

Motion-based input is actively researched in the HCI community, as well. In combination with weight shift-based output, interesting new applications may emerge. Research on motion-based input includes tilt input, for instance. Gilbertson et al. (2008) propose mobile phone games in which tilt is used as an input. Relatedly, Essl et al. (2008) propose tilt input for musical interfaces. Furthermore, Cho et al. (2007) explore how tilting a hand-held device can be used to browse content. This may relate to the metaphor of information as a »substance«, being attracted by gravity. Cho et al. (ibid.) note that making devices reactive to tilt can enhance the interaction because it supports the metaphor of physically responding information. Also gestural input in mobile devices is actively explored. Ballagas et al. (2007, p. 1929) propose a location-based game that integrates mobile phone gestures, i. e. »casting a spell« by performing a wand-like gesture with the device. This gesture does not appear to be directly related to a physical metaphor for digital information. Differently, Scheible et al. (2008, p. 957) propose a system which allows users to »throw« digital information by performing a throwing gesture with the mobile phone. This style of interaction seems to make direct use of a physical metaphor for digital information.

Furthermore, devices that are reactive to position, orientation, and grasp are explored. Hinckley et al. (2005, p. 31) discuss position-reactive interactions: for example, their device determines whether the user holds it next to her or his ear, and activates »sleep mode« when placed on a table. Besides that, Hinckley et al. (ibid., p. 31) propose switching between landscape and portrait mode in reaction to the phone's orientation. In part, this makes use of a physical metaphor, as the GUI is »pulled downwards« by gravity. Wimmer and Boring (2009, p. 359) propose »HandSense«, a grasp-reactive mobile phone that detects the way it is held, and by which of the user's hands. In a similar approach, Lee et al. (2009, p. 3521) propose a system that switches between different applications (e. g. phone call and camera) depending on the user's grasp. Such applications leverage on the user's manual dexterity and the implied intentions of grasping: to take a picture, one can just hold the phone *like* a camera. Here, the metaphor regards not the digital information, but the function.

In total, I developed four prototypes of the *Weight-Shifting Mobile*. First, a one-dimensional version of the *Weight-Shifting Mobile* was built, followed by a motion-reactive version. Then, a self-balancing version was built. Lastly, a two-dimensional version of the *Weight-Shifting Mobile* was developed. The one-dimensional prototype is an acrylic, mobile phone-shaped box, measuring 130×60×45 mm, weighing 70 g plus the moving weight (63 g, i. e. the motor and an additional lead weight). A mobile phone is attached to the prototype for visual content display (Fig. 5.12, Fig. 5.13, 5.14). The phone weighs 70 g. The two-dimensional prototype is a larger (150×60×115 mm) box, in which a 45 g weight can be positioned by two motor faders. As the X axis fader is moved together with the weight, the total weight that moves along the Y axis amounts to 117 g (Fig. 5.15, Fig. 5.16). A third prototype (also with one-dimensional weight actuation) explores the principle of self-balancing devices. It measures 155×33×48 mm and weighs 107 g, with an additional 20 g moving weight inside (Fig. 5.17, Fig. 5.18).

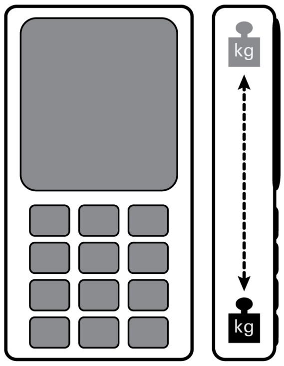


FIGURE 5.12: The *Weight-Shifting Mobile* (one-dimensional version, illustration).

FIGURE 5.13: The *Weight-Shifting Mobile* (one-dimensional version).

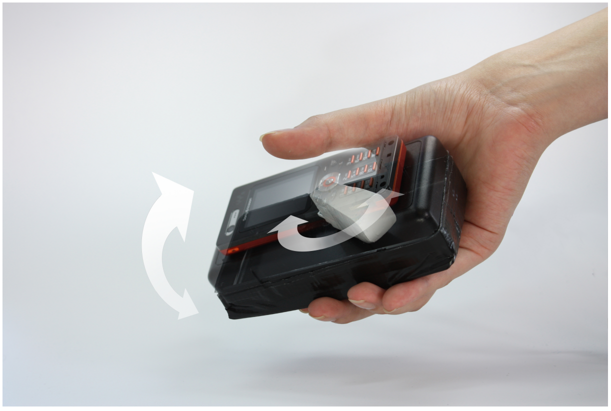


FIGURE 5.14: The *Weight-Shifting Mobile* (one-dimensional version, reactive to motion and tilt).

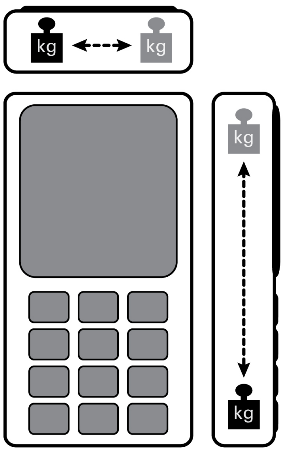


FIGURE 5.15: The *Weight-Shifting Mobile* (two-dimensional version, illustration).

Figure 5.16: The *Weight-Shifting Mobile* (two-dimensional version).

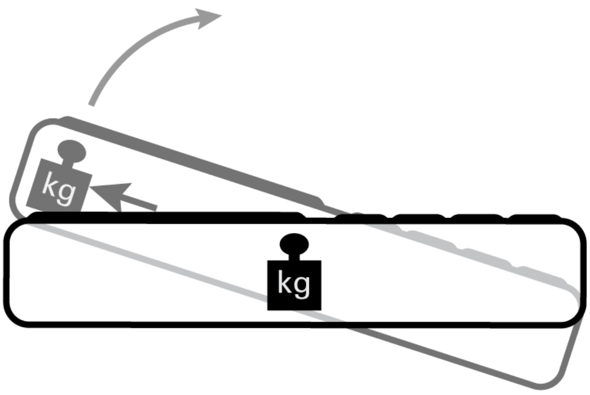


Figure 5.17: The *Weight-Shifting Mobile* (one-dimensional version, self-balancing, illustration).

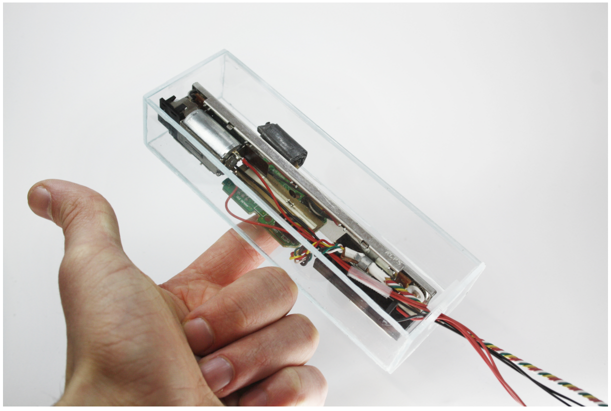


Figure 5.18: The *Weight-Shifting Mobile* (one-dimensional version, self-balancing).

I propose several applications for the prototypes. For the one-dimensional prototype, I propose »scroll feedback« (Fig. 5.19), »gestural feedback« (Fig. 5.20) and »counter-balancing« (Fig. 5.21). The last application, »counter-balancing« was explored in another prototype, the self-balancing version of the *Weight-Shifting Mobile*. This device was envisioned to shift its weight in reaction to tilt (Fig. 5.22), simulate virtual button clicks (Fig. 5.23), and shift its weight in reaction to the user's grasp (Fig. 5.24). However, these functionalities were not implemented. For the two-dimensional prototype, I propose »GUI augmentation« (i. e. through weight-based display of contents, Fig. 5.25), an »ambient display« for a music player scenario (Fig. 5.26) and »pedestrian navigation support« (i. e. a »haptic compass«, Fig. 5.27).

Several of these applications were developed to help users to »encounter« digital information in a bodily, familiar way. For example, the »GUI augmentation« application is based on a »substance« metaphor of digital information. A piece of digital information, visible on the screen, is »representationally embodied« through the device's centre of gravity, which is physically moved to the respective position under the screen. I hypothesised it to be easily understandable for users that digital information would be perceptible through simulated weight.

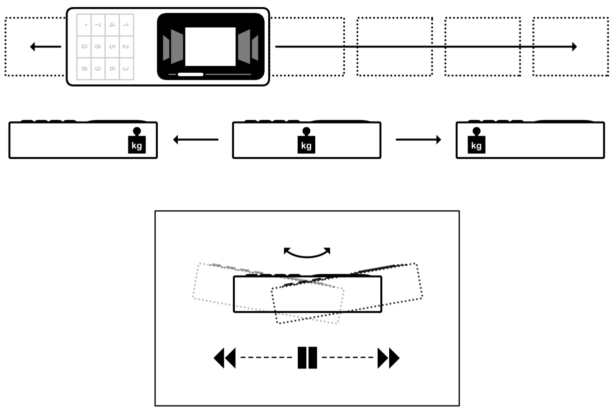


FIGURE 5.19: The *Weight-Shifting Mobile* (motion- and tilt-reactive version). Application: »scroll feedback«. The current scrolling position is displayed through the device's centre of gravity.

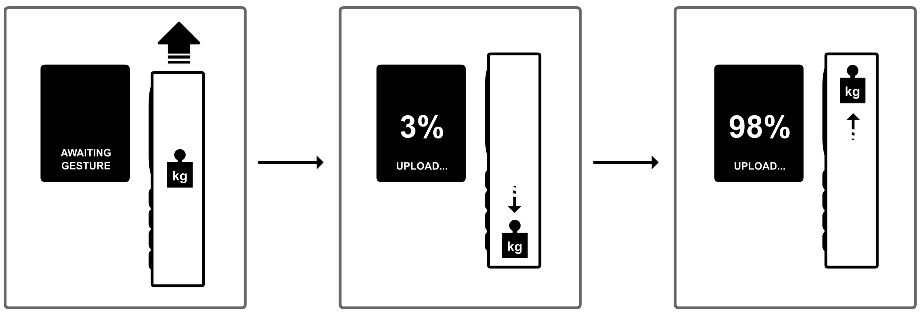


FIGURE 5.20: The *Weight-Shifting Mobile* (motion- and tilt-reactive version). Application: »gesture feedback«. After performing a »throwing« gesture, the user receives a haptic feedback.

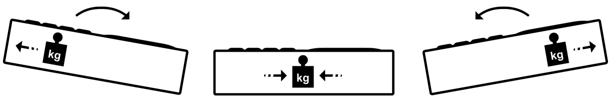


Figure 5.21: The *Weight-Shifting Mobile* (motion- and tilt-reactive version). Application: »counter-balancing«. The device counter-balances tilting by shifting its weight.

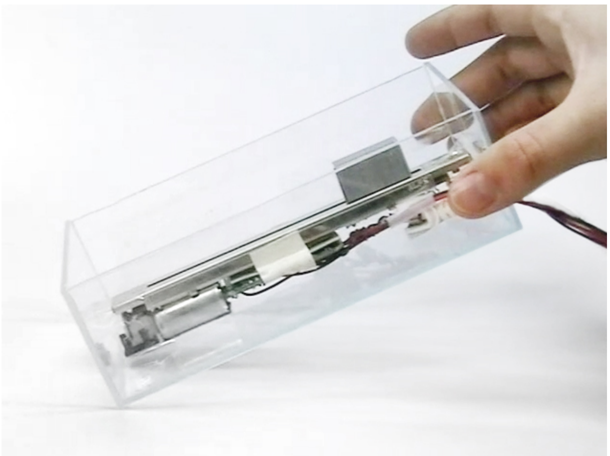


Figure 5.22: The *Weight-Shifting Mobile* (self-balancing version). Application: »counter-balancing«. The device shifts its weight, depending on how much it is tilted.

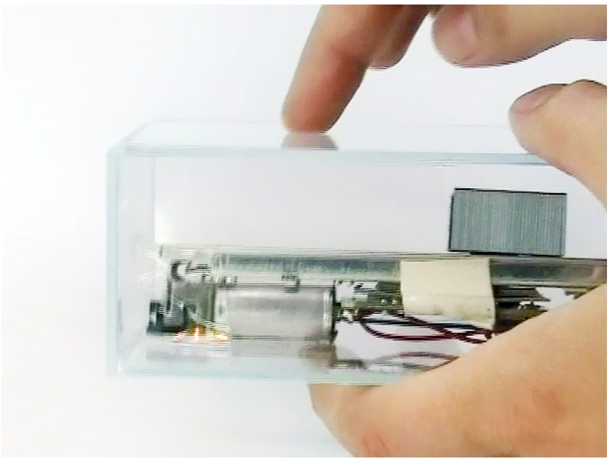


Figure 5.23: The *Weight-Shifting Mobile* (self-balancing version). Application: »virtual button clicks«. Button clicks are simulated through brief shifts of the device's centre of gravity.

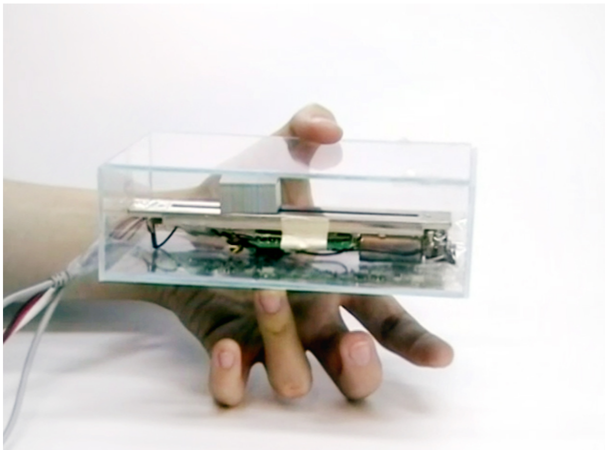


Figure 5.24: The *Weight-Shifting Mobile* (self-balancing version). Application: »grasp reactivity«. The device's centre of gravity is always moved to where the user's hand touches it.

Figure 5.25: The *Weight-Shifting Mobile* (two-dimensional version). Application: »GUI augmentation«. Digital contents are displayed visually and through the device's centre of gravity.

Figure 5.26: The *Weight-Shifting Mobile* (two-dimensional version). Application: »ambient display«. A music player's playhead position and playlist progress are displayed by the device's centre of gravity.

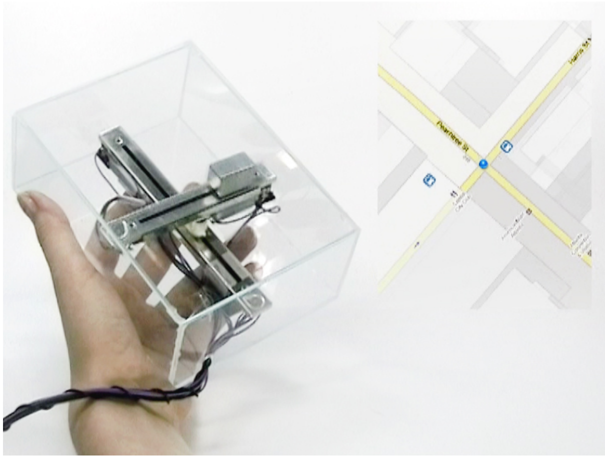


FIGURE 5.27: The *Weight-Shifting Mobile* (two-dimensional version). Application: »haptic compass«. The direction (»left«/»right«) and remaining distance to a destination are displayed through weight shift.

The »ambient display« application is based on a more symbolic mapping. In a music player scenario, the progress of playing the current song is mapped to the device's X axis. The progress of the current playlist, in turn, is mapped to the device's Y axis. The mapping of digital information and »representational embodiment« is rather abstract in this case. But, at the same time, both playhead position and playlist progress change only slowly. Thus, I hypothesised that such a »representational embodiment« would be easy to ignore, yet perceptible when focusing on it.

The »pedestrian navigation support« application is based on the metaphor of a compass needle. It moves from left to right, in response to the direction of the destination. At the same time, though, it displays the overall distance remaining by shifting the centre of gravity's position on the Y axis. At the beginning of the route, the weight moves to the top. During the navigation, as the user gets closer to the destination, it gradually progresses to the bottom. Thus, the X and Y dimensions are mapped to two different data points. This »representational embodiment« is a mixture of a compass needle and a display of the remaining distance to the destination. I hypothesised that this type of »representational embodiment« would be easy to follow and easy to ignore, at the same time.

Previous Studies of the Weight-Shifting Mobile

Several studies were conducted with the prototypes. In one study, the participants were asked to estimate the position of the one-dimensional prototype's centre of gravity.[11] 12 participants (5f, 7m, ⌀25.2 yrs.) took part. They were introduced to the device and its shifting weight's movement range. The mobile phone was not mounted to the prototype during the experiment. The participants engaged in 9 trials and wore headphones for the duration of the experiment. 9 target positions were presented to the participants in a balanced, pseudo-randomised order. The participants operated through a curtain, as to avoid visual cues. In each trial, they were asked to put down the device, as to avoid additional cues. Once put down, the device's moving weight was driven to the target position. Then, the participants were asked to pick up the device and estimate where its centre of gravity was, marking the position on a piece of paper, which showed a 1:1-scaled image of the prototype, in a top-down perspective. The recorded measures were time and error.

The mean error for the participants' estimation of the weight's position was 26.84 mm (SD = 23.35 mm). No effects of trial number or weight position on time or error were found. In 88.5 % of the trials, the participants were able to determine correctly whether the weight had moved, compared to the previous position, upwards or downwards ($\chi^2_{df=1, N=96} = 57.04$, $p_{1\text{-tailed}} = .000$). Different strategies to determine the centre of gravity could be observed, e. g. balancing the device on a finger, or moving it around. For further details, see Hemmert et al. (2009a).

[11] I would like to thank Ina Wechsung for her help with the statistical parts of this study. This study is reported in an earlier paper (Hemmert et al., 2009a), the following is an overview.

In another study, the motion sensitivity-enhanced version of the one-dimensional *Weight-Shifting Mobile* prototype, using tilt-based input, was compared to a button-based version.[12] In this study, the participants were asked to move the weight on the device's inside to a target position, using tilt in one series of trials, and using buttons in the other. 12 participants (6f, 6m, ⌀27.1 yrs.) took part in this study. In a training phase they were made familiar with the device's movement range and the 9 (evenly distributed) target positions. The participants engaged in 18 trials. In each trial, they were asked to move the weight to a particular target position. The group was split: 6 participants started with the button-based variant, 6 with the tilt-based version. After 9 trials, the input method was switched. The 9 target positions were presented in a balanced, pseudo-randomised order. The recorded measures were time and error. A short follow-up interview was conducted, in which the participants were asked about their impressions of the proposed interaction.

The results indicate no significant difference between the two input methods – however, participants pointed out in the follow-up interview that they enjoyed the tilt-based input, perceiving it to be a good match for the weight shift-based output. Using the button-based variant, the participants were able to move the weight to the target position in, on average, 10.6 s (SD = 9.7 s), with a mean error of 24.1 mm (SD = 31.8 mm). Using the motion-based variant (i. e. by tilting the device), this task was completed in 11.5 s (SD = 9.51 s), on average, with a mean error of 18.9 mm (SD = 20.7 mm). A MANOVA showed no significant main effect of the input method on time and error (Pillai's Trace = .026, $F_{2,9}$ = .120, p = .888). For further details, see Hemmert et al. (2010b).

[12] I would like to thank Ina Wechsung and Robert Schleicher for their help with the statistical parts of this study. This study is reported in an earlier paper (Hemmert et al., 2010b), the following is an overview.

The self-balancing prototype was tested in a user study, as well.[13] In this study, the participants were asked to balance the prototype on their finger, while following a path with it. This path was projected on a wall in front of them. Different conditions of the proposed counter-balancing (i. e. being activated, slowed down, and turned off) were compared. 12 participants (5f, 7m, ⌀28.8 yrs.) took part. In a pre-study, they were allowed to decide by themselves how fast they wanted to move the prototype. In the actual study, they were asked to follow a moving dot, which was projected on the wall. Two movement speeds of the dot were part of the experiment: »fast animation« and »slow animation« (corresponding to 2 s and 4 s durations). The prototype was tested in three conditions: »slow balancing«, »fast balancing«, and »balancing off«. In »balancing off« mode, the weight did not move out of the device's centre. In »slow balancing« mode, it moved at 20.1 cm/s, in »fast balancing«, at 25.7 cm/s. After a training phase, each participant engaged in 6 trials, consisting of all possible combinations of movement and animation conditions. Each trial consisted 20 rounds along the path, following the projected dot with the finger, on which the device was balanced. The recorded measure was error: letting the device fall down. For this reason, the device was loosely secured with a wrist strap. A questionnaire (Hassenzahl et al., 2003) was handed to the participants, and a short follow-up interview was conducted.

The results indicate that, under certain conditions, the counter-balancing helped the participants to balance the device longer on their finger than when it was turned off. One of the balancing-enabled conditions was also rated higher in terms of its »hedonic quality«. Interestingly, even though it *positively* affected the participants' performance in balancing the device, one of the balancing-enabled conditions was rated *worse* in terms of »pragmatic quality« than the control condition (i. e. with self-balancing disabled). For the »slow animation« condition, no significant differences were found between the three balancing modes ($\chi^2_{df=2, N=12} = 1.632$, $p_{1\text{-tailed}} = .232$). For the »fast animation« condition, a

[13] I would like to thank Ina Wechsung, Stefanie Lange, Sarah Diefenbach, and Marc Hassenzahl for their help with the statistic evaluation in this study. For the entire study, see Hemmert et al. (2010e).

MANOVA revealed a significant difference ($\chi^2_{\text{df=2, N=12}}$ = 12.67, $p_{\text{1-tailed}}$ = .001), with the »slow balancing« condition being the least prone to error ($M_{\text{»slow«}}$ = 1.00, SD = 1.34), ranking before the »fast balancing« condition ($M_{\text{»fast«}}$ = 2.33, SD = 1.92) and the »balancing off« condition ($M_{\text{»off«}}$ = 4.92, SD = 2.75). In the questionnaire, the »hedonic quality« was rated significantly different for »fast balancing« and »balancing off« (T_{11} = 3.644, p = .004). Here, »fast balancing« was rated higher (M = 4.57, SD = 0.76) than »balancing off« (M = 4.00, SD = 0.78). The »slow balancing« and »balancing off« conditions were rated significantly different in terms of »pragmatic quality« (T_{11} = -3.424, p = .006) and »hedonic quality« (T_{11} = 4.244, p = .001). Regarding the »pragmatic quality«, »balancing off« was rated higher (M = 4.69, SD = 0.80) than »slow balancing« (M = 3.94, SD = 0.98). For »hedonic quality«, »slow balancing« (M = 4.55, SD = 0.47) was rated higher than »balancing off« (M = 4.00, SD = 0.78). For further details, see Hemmert et al. (2010e).

The two-dimensional prototype was also studied in terms of the accuracy by which users were able to determine the X/Y position of its centre of gravity.[14]

12 participants (6f, 6m, ⌀28.0 yrs.) took part. In the familiarisation phase, they had visual contact to the device, while the actual position assessment was conducted only through haptic cues (i. e. the participants wore headphones and operated through a curtain). Again, the participants were asked to put down the device while the weight was moved, as to avoid cues through motor runtime and inertia. In each trial, after picking up the device, they were asked to estimate the weight's position and mark it on a picture of the prototype on a nearby computer. Afterwards, they were asked to fill out a questionnaire (Hassenzahl et al., 2003).

[14] I would like to thank Ina Wechsung, Stefanie Lange, Sarah Diefenbach, and Marc Hassenzahl for their help with the statistical part of this work. For the entire study, see Hemmert et al. (2010f).

In this study, the participants were able to determine the position of the weight on the device's inside with a mean error of 28.9 mm (SD = 22.1 mm) on the X axis, and with a mean error of 21.0 mm (SD = 19.2 mm) on the Y axis. On average, they required 6.31 s (SD = 5.17 s) for this. Some comparisons between the weight shift-based and shape change-based prototypes were made. For instance, the »AttrakDiff« questionnaire's results for the two-dimensional *Weight-Shifting Mobile* and the two-dimensional *Shape-Changing Mobile* were compared. The *Shape-Changing Mobile* was, in terms of »pragmatic quality«, preferred over the *Weight-Shifting Mobile*. No significant differences were found for the »hedonic quality: stimulation« scale (T_{11} = 0.491, p = .633). For the »pragmatic quality«, the shape-changing prototype (M = 4.10, SD = 0.71) was preferred (T_{11} = 2.548, p = .027) over the weight-shifting one (M = 3.52, SD = 0.57). For further details, see Hemmert et al. (2010d) and Hemmert et al. (2010f).

The one-dimensional version of the *Weight-Shifting Mobile* was also compared to the one-dimensional version of the *Shape-Changing Mobile*. On the *Shape-Changing Mobile*, participants were able to determine the currently displayed position with greater accuracy than on the *Weight-Shifting Mobile*. They performed significantly better in the shape-based assessment than in the weight-based one, in terms of error ($F_{1,22}$ = 32.865, p = .000), but not in terms of time ($F_{1,22}$ = .137, p = .715) (Hemmert et al., 2010a, p. 251).

In another study, the concept of a »haptic compass« was explored.[15] Here, the participants were asked to follow the direction that the prototypes indicated through body rotation. The direction was indicated in different ways, which were compared in the study: through shape change, weight shift, and also visually. In this study, other prototypes were used, in order to make the weight-shifting and shape-changing prototypes as similar as possible. Both measured 72×72×50 mm. The shape change-based variant was

[15] I would like to thank Ina Wechsung for her kind help with the statistical evaluation in this study. For more details, see Hemmert et al. (2010c).

able to thicken by 3 mm on the edges, resulting in a maximum tilt angle of 5.5° towards the respective edge. The weight-shifting version measured 90×90×45 mm and weighed 146 g, including a moving weight of 20 g. The visual condition was achieved through a mobile phone with an additionally attached gyroscope sensor. An arrow was displayed on the phone's screen. For a comparison of the prototypes, see Fig. 5.28. The participants were asked to sit on a rotatable office chair, holding the prototype in their hand. A traffic light was projected on a nearby wall. This was done in order to create a secondary task, which aimed to assess the participants' visual distractedness. They were asked to press a button on a wireless presenter, which they had been given before, as soon as the traffic light switched from green, after switching to yellow, to red. In a pre-test, the participants' field of vision was tested, measuring at least 135° for each participant. The recorded measures were directional error (accumulated over the duration of each trial, sampled every 0.5 s), and reaction time to the simulated traffic light's switching to red.

The results indicate that the participants were more accurate in following the target angle in the visual condition. However, they were also reacting significantly slower to the simulated traffic light in this condition. Using the shape-changing prototype, the mean error for following the angular cues was 57.56° (SD = 40.19°). With the weight shift-based prototype, the mean error was 52.36° (SD = 39.80°). In the visual condition, it was 33.53° (SD = 34.62°). Significant differences were found between all three conditions ($F_{2,20}$ = 17.62, part. η^2 = .638, p = .000), and, through a Scheffé test, also between them in the aforementioned order (p = .000). In the secondary task, the participants required a mean time of 1.29 s (SD = 0.98 s) in the visual condition, 1.23 s (SD = 1.18 s) in the shape change-based condition, and 1.05 s (SD = 0.72 s) in the weight shift-based condition. Significant differences were found between all three conditions ($F_{2,22.18}$ = 2.99, part. η^2 = .213, p = .035). A Scheffé test showed that the weight shift-based condition was significantly quicker than the visual (p = .006), and, yet only at a borderline significance niveau, quicker than the shape-based version (p = .051). For a detailed report, see Hemmert et al. (2010c).

FIGURE 5.28: Different prototypes in the »haptic compass« study.

In conclusion, weight shift has turned out to be a feasible means to embody digital information, and to let users interact with it. Users were able to feel where a hand-held device's centre of gravity was. However, it remains still rather unexplored how the different actuation principles are, in comparison with each other, experienced in the interaction.

5.1.3 Ambient Life: The Living Mobile

A third exploration of how digital information could be embodied is the *Ambient Life* project, the »living mobile phone«. In it, the »representational embodiment« of digital information is a simulated living being, which has a heartbeat, and moves in a breathing-like way. I hypothesised that this type of actuation would suit the users' »experiential embodiment« in the socio-physical world. The underlying assumption is that, besides »substance« metaphors, also »social« metaphors would be inherently familiar to users. The principle that I developed to explore this issue is based on the concept of simulating physical life-like signals as a means of displaying internal states of a mobile phone. It is based on a »life form« metaphor for a computer.[16]

Several prototypes were developed in the concourse of this project. Early versions followed the concept of »just-enough prototyping«, being constructed from a pack of tissues and an electric toothbrush's vibrating motor, as well as prototypes based on off-

[16] Originally, I proposed this idea in the »Touch it« project, which the Design Research Lab conducted together with the Potsdam University of Applied Sciences. The project team consisted of André Knörig, Julia Werner, Hans-Peter Kadel, Reto Wettach, and Gesche Joost.

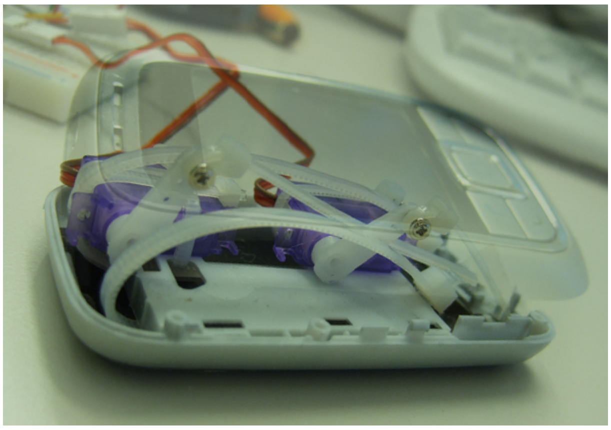


FIGURE 5.29: *Ambient Life* prototype, »phone case« version.

the-shelf mobile phones. Other versions consisted of actual mobile phone cases (Fig. 5.29). Later prototypes included explorations of hard and soft casings (Fig. 5.30, Fig. 5.31).[17]

This project stands in a larger context of research. Works in this area investigate, besides haptics in mobile devices, ambient displays and anthropomorphism in HCI.

In the HCI literature, ambient displays have been integrated in various contexts, including architecture, clothing, eyewear, and also into mobile phones. For example, Dahley et al. (1998, p. 269) propose »Water Lamp« and »Pinwheels«, two projects that integrate architecture with ambient displays. These make use of the user's familiarity with water, light, and wind – they are permanently present, reacting to the digital information that they represent. Williams et al. (2006, p. 1531) present »Damage«, a wearable ambient display, which leverages on the user's familiarity with traditional jewellery. Other

[17] Similar to the *Weight-Shifting Mobile* and the *Shape-Changing Mobile* prototypes, also the *Ambient Life* prototypes have been previously published (Hemmert, 2008a; Hemmert, 2008b; Hemmert and Joost, 2009; Hemmert, 2009).

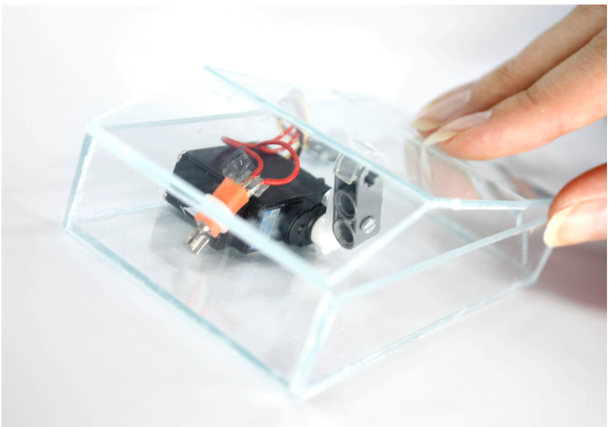


Figure 5.30: *Ambient Life* prototype, »hard case« version.

Figure 5.31: *Ambient Life* prototype, »soft case« version.

ambient displays integrate information in places where they can be easily ignored. For example, Costanza et al. (2006, p. 211) propose eyeglasses that have LEDs on their edges, as to provide visual cues to the user, on the edge of their vision field. Other approaches of making HCI »ignorable« leverage on aspects of existing interactions that are often ignored. For example, Schmidt et al. (2006, p. 1295) propose an ambient display in a mobile phone's screen saver. The screen saver is often ignored – in this case, it is used as an ambient display. In conclusion, different approaches to the design of »ambient« and »ignorable« interactions are explored.

Recently, discussions about the distracting aspects of interruptions have inspired works on activity-sensitive notifications in HCI. Zijlstra (1999, p. 163), for instance, explores how interruptions affect users' task performance. Also Cutrell et al. (2001, p. 99) report such a study, with regard to instant messaging. Relatedly, Adamczyk and Bailey (2004, p. 271) present a study on the timing of interruptions during work. Related discussions concern addiction-like qualities of mobile phone usage (James and Drennan, 2005, p. 87). The topics of interruption and distraction, but also addiction, are gaining interest in the HCI community, as the increasing research activities in this area show. Thus, they also emphasise that it might be of growing importance to make some aspects of HCI easier to ignore.

Anthropomorphous and zoomorphous systems (i. e. interfaces in human-like and animal-like form) are actively researched in HCI (see the above section on agents and avatars for an overview, p. 37). However, they seem to have barely been drawn upon in the context of ambient displays.[18]

[18] See DiSalvo and Gemperle (2003) for an overview. Often, as noted above, the term »embodiment« appears to be used in association with body-like visualisations in HCI.

The hard-case prototype consists of an acrylic box (95×55×30 mm), a vibration motor (simulating the heartbeat), and a servo motor (simulating the breathing, with a maximum levitation of the top plate of 10 mm, Fig. 5.30). The case's top plate is segmented, so that the different segments can move in reaction to the servo motor, simulating a breathing chest.[19] The prototype can be switched from »calm« to »excited« through a nearby computer. For the purpose of a user study, a vibration-only version of the prototype was implemented on a mobile phone, allowing for a permanent heartbeat-like actuation.

The soft-case prototype (95×45×23 mm) contains the same actuators as the hard-case variant and is driven by the same software. Differently, though, it is encased by a soft, gel-filled foil wrap (Fig. 5.31).

Previous Studies of the Ambient Life Prototype

In a first study, the user's reaction time to an excited pulse was assessed.[20] In this study, 7 participants (3f, 4m, ∅28.5 yrs.) took part. They were given a mobile phone, which ran the prototype software, resulting in a permanent heartbeat-like actuation of the vibration motor. The intensity of the vibration could be adjusted (however, the frequency of the heartbeat was fixed). The participants were asked to take the prototype with them and keep it within reach. To document their experiences with the prototype in different situations, they were given a diary. Due to the ongoing vibrotactile actuation, the prototype's battery life was decreased to a maximum of 6 hours, so the participants received a charger. The phone was in »calm« mode by default, but it would switch to »excited« at random points in time – never between 10 p.m. and 9 a.m., though. The participants

[19] The breathing motion is simulated, no air jet is invoked.

[20] This study has been published before, the following is only an overview. See Hemmert (2008b) and Hemmert (2009) for a more detailed discussion.

were asked to set the phone back into »calm« mode by pressing a button when they noticed that it had switched to »excited«. The time needed by the participants to switch the phone back to »calm«, after it had switched to »excited«, was measured by the software on the phone. The results indicate that the participants were able to accommodate to such a type of actuation, some even reported that they experienced a »gap« when they removed the prototype from their pockets.[21] See Hemmert (2008b) for further details.

Based on these results, a second study was conducted.[22] Here, the user's reaction time to *interruptions* of the pulse was assessed. 6 participants (3f, 3m, ⌀28.1 yrs.) took part. They were given a mobile phone, running a modified version of the prototype software. The phone was in »calm« mode by default, but, at random points in time (yet never between 10 p.m. and 9 a.m.), switched to »off« mode, in which no vibration occurred. In this case, the participants were asked to set it back to »calm« mode through pushing a button on the phone. All participants had taken part in the previous study, so they were familiar with the device. The participants were asked to carry the device for one day. The results indicate that the participants mostly noticed the pulsation's interruptions. After the study, some participants reported that they had perceived »phantom deaths« of the phone, i. e. they thought it had stopped pulsating, when it actually had not. 19 % of the responses were recorded to have happened within the first 10 s, 44 % within the first 30 s. 55 % occurred within the first minute. After 10 minutes, 90 % of the events had been confirmed. See Hemmert (2008a) for further details.

The *Ambient Life* prototypes explore a new way of embodying digital information, by simulating a living being. Many users enjoyed this type of »representational embodi-

[21] In total, 178 of these events were recorded. The reaction times varied greatly, between 20 s and 20 min. Some participants stated that they were able to get used to the pulse in noisy environments, while they found it annoying in calm environments.

[22] See Hemmert (2008a) for a more detailed report.

ment«. It seems to have served as a feasible approach to create an ambient display for missed phone calls and text messages. At the same time, new issues (e. g. »phantom deaths« of the phone) arose. It also remained unclear how such a device would be experienced in comparison to, for example, the *Weight-Shifting Mobile* and the *Shape-Changing Mobile* prototypes. When planning for a comparative study of the *Ambient Life*, *Shape-Changing Mobile*, and *Weight-Shifting Mobile* prototypes, I decided to design and include a series of vibration-based prototypes, as to allow for comparisons with the current style of haptic actuation in mobile phones.

5.1.4 Vibration-Based Comparison Prototypes

I also developed a series of vibration-based comparison prototypes: one prototype for »content display«, one prototype for »navigation«, and one prototype for »notification«. These offer similar applications like the previously described prototypes, but draw upon vibration to embody digital information.

Vibration was chosen for two reasons. Firstly, many current mobile devices employ vibration motors to integrate haptics into the interaction. Secondly, I assumed that vibration would rarely (besides in mobile phones) occur in the average user's experience of the socio-physical world.

The *Vibration: Content* prototype (Fig. 5.32) consists of an acrylic box and measures 120×65×21 mm. It contains a vibration motor and two pressure sensors, which are used to measure the pressure that the user exerts on the prototype's sides with their fingers. This allows for grasp-evoked information about content in the device by grasping and pressing it. If the device is »full« of digital content, already a gentle press would cause the vibration. If less digital content is in the device, it requires a stronger grasp to activate the vibration, accordingly. If no digital content is in the device, it does not vibrate. The simulated »amount« of digital content in the device can be controlled through a nearby computer.[23] In that, this prototype is also based on a haptic (i. e. vibrotactile) kind of »representational embodiment«, and in part, also on a »substance« metaphor of digital information. However, I assumed that this metaphor, in this form, does not manifest itself in a familiar way (e. g. through thickness or weight) – most substances in the user's socio-physical world do not vibrate.

The *Vibration: Navigation* prototype also consists of an acrylic, mobile phone-shaped box (120 × 65 × 21 mm) and contains four vibration motors. As the vibrations of one motor are not intended to affect the entire case, the four actuated sides of the device are mounted on rubber bands (Fig. 5.33). Through a nearby computer, the prototype can be controlled to vibrate »towards« each of the four directions. Like the previously described prototype, it is also based on haptic (i. e. vibrotactile) »representational embodiment«. Differently, it is *not* on a »substance« metaphor of digital information. In that, it is not designed in particular orientation to the user's »experiential embodiment«.

Similarly, the *Vibration: Notification* prototype (Fig. 5.34) also consists of an acrylic box, measuring 120 × 65 × 21 mm. It contains a vibration motor. Through a nearby computer, it is possible to activate the motor, as to simulate an incoming call. The vibration pattern resembles a typical »mobile phone vibration« and lasts for 3 s. Like the two others, also this prototype does rely on vibration for »representational embodiment«. It is, however, not based on a »substance« metaphor.

These prototypes stand in a context of different, vibration-based haptic augmentations of interactive devices. While a vibration motor is present in many current mobile devices, researchers have also proposed the usage of multiple vibration motors in one device. Regenbrecht et al. (2005, p. 381) discuss different vibrotactile actuation systems

[23] A frequently mentioned metaphor for this interaction scheme was that of a »tube of toothpaste«, which needs to be pushed strongly when it is almost empty, and only gently when it is full.

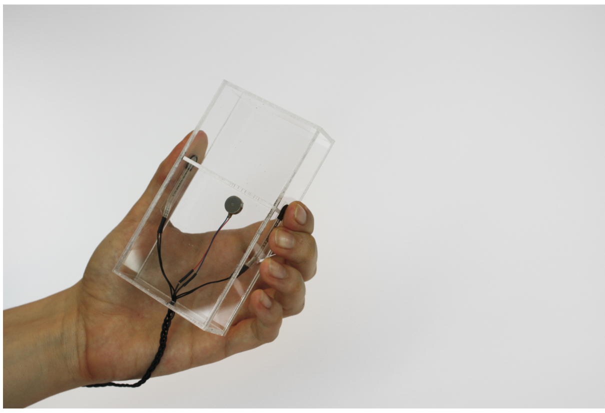


FIGURE 5.32: Vibration-based comparison prototype: *Vibration: Content*.

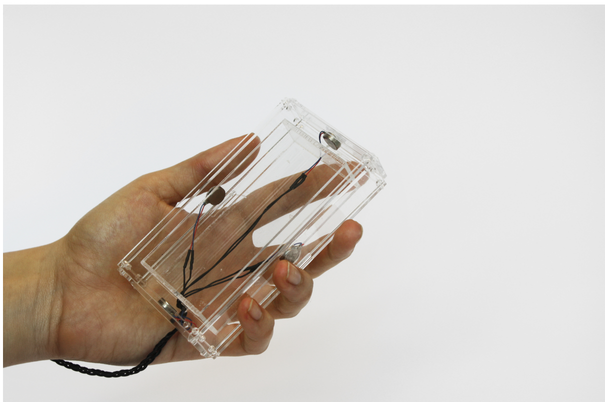


FIGURE 5.33: Vibration-based comparison prototype: *Vibration: Navigation*.

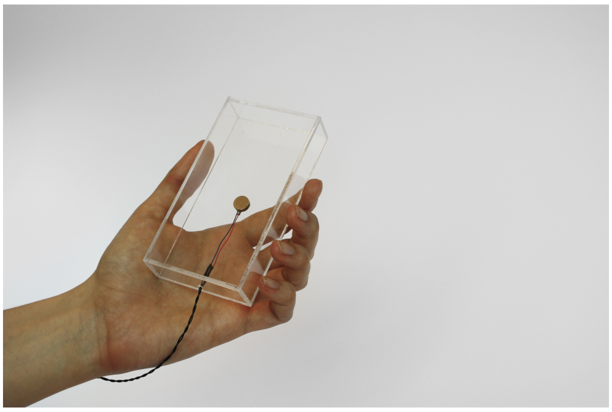


FIGURE 5.34: Vibration-based comparison prototype: *Vibration: Notification*.

and propose two prototypes, for which they make use of vibration motors and piezoelectric elements. Relatedly, Sahami et al. (2008) propose a mobile phone that is augmented with six vibration motors, supporting vibration in different locations within the device.

5.2 User Study

Even though most of the prototypes presented in this chapter (i. e. the *Weight-Shifting Mobile*, the *Shape-Changing Mobile*, and the *Ambient Life* prototype) were explored in several previous studies, these studies have contributed only marginally to the question of how the »representational embodiment« of digital information (and its orientation to the user's »experiential embodiment« in the socio-physical world) influences the experience of the interaction. A comparative user study, focusing on the effects of different kinds of »representational embodiment« on the experience of haptics-enhanced interaction, could help to shed light on this issue, though. I conducted a Repertory Grid Technique (RGT) study. RGT is a method that elicits users' personal descriptions of prototypes, which can be clustered afterwards.

RGT is a structured interview technique based on Kelly's concept of »personal constructs« (Kelly, 1955). Personal constructs consist of pairs of »poles«, which form a dimension of differentiation, e. g. »beautiful – ugly«. An advantage that is generally attributed to this method is that it is sensitive to the participants' opinions, but does not sacrifice its structure. Hassenzahl and Wessler (2000, p. 442) point out that more structured approaches, like questionnaires, are advantageous as they are more robust and efficient, but limited in terms of their sensitivity to unforeseen things. Hassenzahl and Wessler (ibid., p. 443) contrast these with less structured approaches (e. g. interviews), which are, as they note, also limited, requiring more work to be interpreted and being often less objective. RGT, as they argue, may overcome these issues, or at least provide a compromise. In that, RGT is seen to be a viable method to elicit user reactions to prototypes. For example, Hassenzahl and Wessler (ibid.) use RGT to compare different graphical user interfaces. Hassenzahl (2002) uses RGT to compare different website designs, proposing a variant of RGT, the »Character Grid«. Fällman (2003b) uses RGT to compare different TUIs. He draws on different methods to analyse the elicited constructs, though. Also Hogan and Hornecker (2012) employ RGT.

RGT has been argued to have some limitations. For instance, a comparably large number of prototypes is required, and it is not possible for the experimenter to help the participant in naming the constructs (Hassenzahl and Wessler, 2000, p. 456).

Its advantages, though, seem to be particularly promising in the pursuit of Findeli's model of Project-Grounded Research (PGR) and the questions that this dissertation seeks to address. Using RGT, prototypes could, directly, and with sensibility to the participants' opinions, be used to extract a contribution to the research answer from my prototypes.

Typically, a RGT study is structured into two phases, the »elicitation phase« and the »rating phase«, after an initial familiarisation. In this familiarisation, the participant is introduced to the prototypes. This phase may include a try-out session. At this point, a ranking, based on the prototypes' appealingness, may be elicited.[24]

In the first phase, the »elicitation phase«, the participant's personal constructs regarding the prototypes are elicited. Typically, sets of three prototypes (»triads«) are presented to the participant. The participant is then asked to split the triad in such a way that two of the prototypes share a property that is not shared by the third prototype. This dimension of distinction is called a »personal construct« (e. g. »natural – technical«). Personal constructs have two poles – the pole which is marked by the two »grouped« prototypes from the triad is called the »inclusive pole«, whereas the pole marked by the third prototype is called the »exclusive pole«. Hassenzahl and Wessler (2000, p. 452) also propose a threefold categorisation of constructs: descriptive, evaluative for selection (i. e. including preferences), and evaluative for redesign (i. e. including clear design requirements, e. g. »font size is too small – font size is appropriate«) . Hassenzahl and Wessler (ibid., p. 458) also note that through a short follow-up interview after the experiment, descriptive categories can be turned into evaluative ones, by asking the participant which pole of the personal construct they find more desirable or appropriate. The participant is asked to describe these poles as briefly and concise as possible. This procedure of eliciting personal constructs is repeated with randomly chosen triads of prototypes until the participant cannot find any new, meaningful constructs.

In the second phase, the »rating« phase, the participant is asked to rate each prototype on each of their previously stated personal constructs.

[24] Hassenzahl and Wessler (2000, p. 446) ask their participants to rank the prototypes by their appealingness after the familiarisation. Fällman (2003b, p. 306) does not report this step.

5.2.1 Participants and Procedure

12 participants (6f, 6m, ⌀32.4 yrs.) took part in the study.[25] The participants' age ranged from 18 to 53 years. They rated their degree of mobile phone expertise, on average, as 3.16 (SD = 0.98) on a scale from 1 (»novice«) to 5 (»expert«).

The participants were not informed about any expected or hypothesised outcomes of the study. They were informed that their responses in the study would be treated anonymously. They took part voluntarily and were not reimbursed for their participation. The experiment was conducted in German language, which all participants were fluent in.[26] In the room in which the experiment was conducted, the participant, the experimenter, and one to two assistants were present. The participants sat in a chair in front of a table, on which the six prototypes were placed (Fig. 5.35). The order in which the prototypes were introduced to the participants was randomised.

Each prototype was introduced to the participants in association with a particular application. The participants were introduced to the *Weight-Shifting Mobile* prototype as a means of navigation (i. e. becoming heavy »towards« the direction of a goal). They were introduced to the *Shape-Changing Mobile* as a means of feeling content in the device (i. e. through the device's thickness) by grasping it. They were introduced to the *Ambient Life* prototype as displaying events (i. e. missed calls were displayed through »excitement« in the device's breathing motion and heartbeat, as opposed to the normal state of calm breathing and heartbeat). The vibration-based comparison prototypes were introduced

[25] Regarding the number of participants, Hassenzahl (2002, p. 190) reports 10 participants to be in his study, Hassenzahl and Wessler (2000, p. 444) 11, Hogan and Hornecker (2012) 15. Fällman (2003b, p. 305) reports 18.

[26] The personal constructs were translated from German into English. All constructs, including the German original terms and my translations into English, are listed in the appendix (Table 14). The translations were made in correspondence to a dictionary (*Pocket Oxford-Duden German Dictionary* 2008).

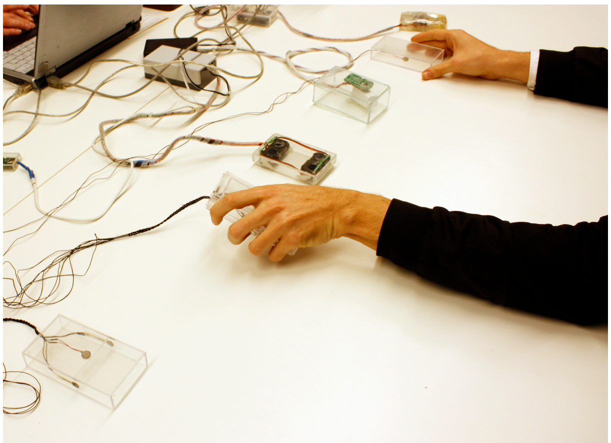


FIGURE 5.35: The RGT interview situation. All six prototypes are on the table.

FIGURE 5.36: The questionnaire that assessed the users' ratings of the prototypes was completed on a tablet computer.

to the participants as providing for similar applications: directional information (i. e. vibrating »towards« the direction), content display (i. e. being able to »squeeze« the device, in order to determine the amount of content in it), and event notification (i. e. vibrating as a call was received). The participants were allowed to familiarise themselves with each prototype as much as they wanted. Subsequently, they were asked to sort them by their appealingness. After that, the participants were offered a short break.

The elicitation phase was also conducted using the actual prototypes. In both Fällman's and Hassenzahl and Wessler's studies, not the actual prototypes, but pictures of them, were presented to the participants: Fällman (2003b, p. 306) uses »palm-sized cardboard cards«, Hassenzahl and Wessler (2000, p. 446) uses »[prototypes] on the screen«.

In each trial, three randomly selected prototypes (a »triad«) were placed in front of the participant.[27] The participants were able to try out and interact with the prototypes whenever they wished to do so. An assistant wrote down the personal constructs. The elicitation phase lasted as long as the participants were able and willed to create new personal constructs. On average, the participants named 12 constructs. After the elicitation phase, the participants were offered a short break.[28] The rating phase was conducted using a questionnaire on a tablet computer (Fig. 5.36), into which an assistant had entered the personal constructs during the elicitation phase. Each participant was asked to rate each prototype on each of their own personal construct scales, from 1 (i. e. the inclusive pole, e. g. »natural«) to 5 (i. e. the exclusive pole, e. g. »technical«). The ratings were not discussed with the participant. The rating process was not monitored, except for comple-

[27] Two exceptions to the randomisation were made: if they hadn't occurred by chance before, the 8th triad always included all vibration-based prototypes, while the 10th triad always consisted of the *Weight-Shifting Mobile*, *Shape-Changing Mobile*, and *Ambient Life* prototypes. These combinations appeared to be of particular interest.

[28] Fällman (2003b, p. 308) notes that »at around triad eight to ten, it was noticeable that most participants' ability to find meaningful construct pairs began to decrease significantly«. A similar phenomenon was observable in this study.

tion (i. e. the software on the tablet computer would point out missing items). The order of the prototypes was randomised for each item (i. e. for each personal construct scale) in the questionnaire. During this phase, small labels with the prototypes' names and applications (e. g. »Weight – Direction«) were placed in front of the prototypes. This was done because it was assumed that labelling the prototypes would make the rating task more comfortable for the participants.

After that, the participants were asked to name a preference for one of each construct's poles. This is a step that is not present in all RGT studies. In the »Character Grid« approach by Hassenzahl (2002, p. 192), the participants rate one of the poles as positive directly after stating them. In this study, the preferences were asked for at the end of the questionnaire. The participants were given no option for selecting both or none, i. e. one pole had to be chosen as the preferred one. At the end of the questionnaire, the participants were asked to state their degree of mobile phone expertise, their age, and their gender. On average, the »elicitation phase« took 32:35 min (SD = 11:29 min). The »rating phase« took, on average, 17:40 min (SD = 5:40 min).

5.2.2 Results

According to the initial ordering of the prototypes by their appealingness, the *Ambient Life* prototype appears to have been found to be the most appealing by the participants, followed by the *Shape-Changing Mobile* prototype, the *Weight-Shifting Mobile* prototype, the *Vibration: Navigation* prototype, *Vibration: Content*, and *Vibration: Notification* (Table 1).

In total, the participants named 145 constructs.[29] In an approach similar to the one followed by Fällman (2003b), the personal constructs were analysed in two rounds, using the Focus sorting and clustering algorithm. The Focus algorithm calculates the similarity of the constructs by comparing the prototypes' ratings and summing up the ratings' differences (ibid., pp. 311-313). The Focus analysis was conducted using the »WebGrid 5« software (Gaines and Shaw, 2005).[30] The »OpenRepGrid« package (Heckmann, 2012) for »R« (2013) was used for additional analysis. For the first round, a cut-off value of 90 % similarity was chosen. Clusters of three constructs or less were ignored. Out of the 145 constructs, seven clusters emerged in this first round of Focus sorting and clustering. Six of these clusters contained between four and 13 constructs, one contained 45 constructs. To split up this large cluster, a second round of Focus sorting and clustering was conducted. In this round, the cut-off value was increased to 95 % similarity, but the minimum number of constructs in a cluster was lowered to three. Nine clusters emerged using this rule set, containing between three and nine constructs. Six of these clusters were sub-clusters of the large cluster from the first round. It was split up using these six more fine-grained clusters. In other clusters from the first round, sub-clusters emerged, as well. These were dismissed, as they appeared semantically similar to the larger clusters they had emerged in. After the two rounds, twelve clusters (containing 77 constructs, i. e. 68 constructs were not included) were found. A name for each cluster was chosen from combinations of its constructs' poles.[31]

In the following, the twelve construct clusters are described. Each prototype's ratings, median values, and participant preferences are listed in the appendix (Table 2 to 13). I

[29] All personal constructs from the study are listed in the appendix (Table 14), including the German original terms used by the participants, my English translations, as well as the participants' preferences and ratings.

[30] It should be noted that the Focus algorithm in »WebGrid 5« can flip a construct if necessary: during the clustering, a construct's ratings can be inverted (while its poles are swapped), in order to consolidate the data.

[31] This naming procedure is adapted from the approach followed by Fällman (2003b, p. 318), as well.

chose median values instead of arithmetic mean values because they are less prone to be influenced by outlier values (e. g. caused through fatigue effects in the rating phase).[32]

Cluster 1, »initiative, active – work-intensive, passive« (Fig. 5.37), consists of four constructs (Table 2).[33] This cluster seems to be related primarily to the effort that the interaction demands. The *Vibration: Content* prototype seems to differ from all other prototypes here, being rated to be the most passive. The *Ambient Life* and *Shape-Changing Mobile* prototypes are rated to be the most active. The participants' preferences are mostly on the »initiative, active« side, with the exception of »control«, which is preferred over »loss of control«. »Easy to understand« is preferred over »knowledge required«.

Cluster 2, »known, defined – unknown, undefined« (Fig. 5.38), consists of four constructs (Table 3).[34] This cluster seems to be related to the familiarity of the interaction.[35] Two of the comparison prototypes, the *Vibration: Content* and *Vibration: Notification* prototypes, are rated as rather »known, defined«, together with the *Ambient Life* prototype. The *Shape-Changing Mobile* prototype is rated as the most »unknown, undefined«. All of

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[32] Fällman (2003b, p. 321) chooses median values, too.

[33] Their poles are »initiative«, »active«, »easy to understand«, and »loss of control« on the one side, and »work-intensive«, »passive«, »knowledge required«, and »control« on the other. It may be noteworthy that »active« and »passive« have been named by several participants in the study, but sometimes with rather opposed ratings. This may be reasoned in different attributions of who – or what – is active or passive: a »passive« prototype can demand the user to become »active« (as it may be the case for the *Vibration: Content* prototype), while an »active« prototype (e. g. the *Ambient Life* prototype) allows the user to remain »passive«.

[34] It is constituted by the poles »behaviour passive«, »known«, »simple«, and »defined« on the one side, and »behaviour alive«, »unknown«, »complicated«, and »undefined« on the other.

[35] It may be objected that the participants rated the *application* (i. e. being notified about missed calls). However, if that had been the case, the participants would have rated the *Shape-Changing Mobile* and *Vibration: Content* prototypes, which also offer similar applications (i. e. feeling the device's contents), more similarly, as well. Therefore, it seems more likely that the manifestation (and not the application) was rated.

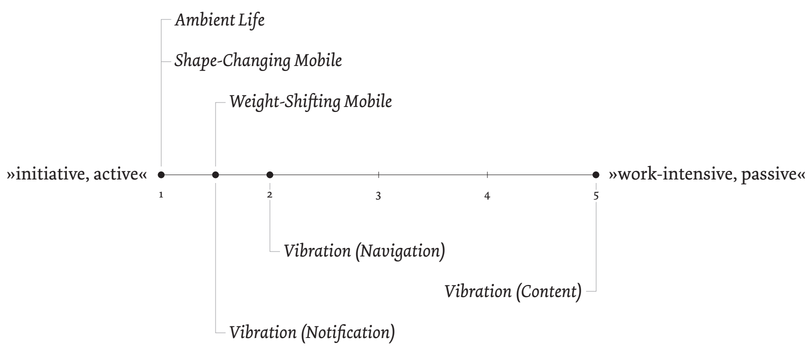

Figure 5.37: »Initiative, active – work-intensive, passive«. Median values for cluster 1.

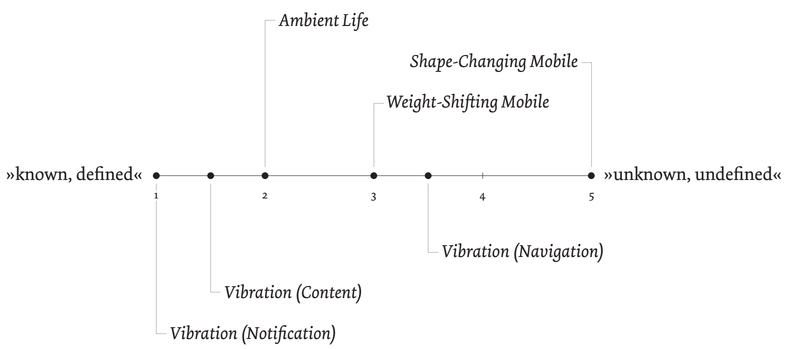

Figure 5.38: »Known, defined – unknown, undefined«. Median values for cluster 2.

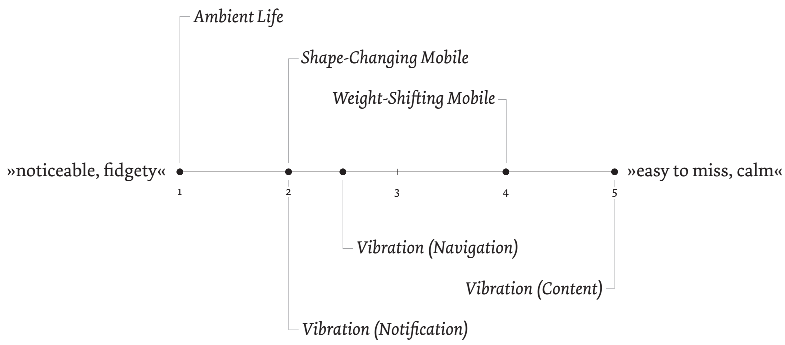

Figure 5.39: »Noticeable, fidgety – easy to miss, calm«. Median values for cluster 3.

the participants' preferences are on the »known, defined« side, except for the »behaviour passive – behaviour alive« construct, for which the »behaviour alive« pole is preferred.

Cluster 3, »noticeable, fidgety – easy to miss, calm« (Fig. 5.39), consists of four constructs (Table 4).[36] This cluster seems to be concerned with the attention that the device demands or arouses. The *Ambient Life* prototype is rated as the most »noticeable, fidgety«, followed by the *Shape-Changing Mobile* and *Vibration: Notification* prototypes. The *Weight-Shifting Mobile* prototype is rated as rather »easy to miss, calm«. Only the *Vibration: Content* prototype is rated as more »easy to miss, calm«. In this cluster, the participants' preferences appear to be rather mixed.

[36] Their poles are, on the one side, »noticeable«, »fidgety«, »passive« and »clear«, and »easy to miss«, »calm«, »active« and »unclear« on the other. The poles on each side seem somewhat inverse: prototypes rated as rather »noticeable« received similar ratings for being »passive«, while »easy to miss« was rather similar to »active«. The individual ratings, though, may suggest that the »active – passive« construct relates to the required *user* activity (i. e. one needs to get active in order to interact with the *Vibration: Content* prototype), while the others may rather relate to the *prototype's* activity.

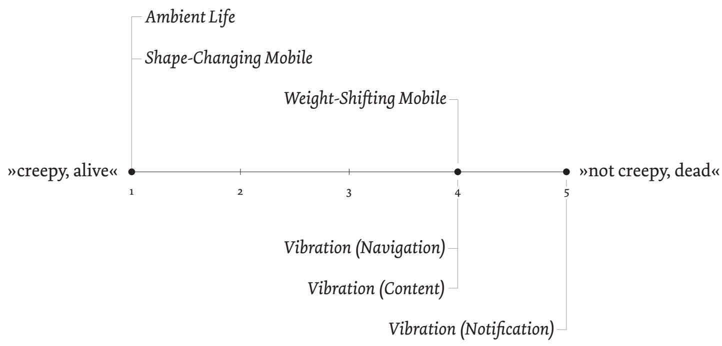

FIGURE 5.40: »Creepy, alive – not creepy, dead«.
Median values for cluster 4.

Cluster 4, »creepy, alive – not creepy, dead« (Fig. 5.40), consists of three constructs (Table 5).[37] This cluster seems to relate to an uncanniness of the interaction's perceived life-likeness. Both the *Ambient Life* and *Shape-Changing Mobile* prototypes are rated as »alive« and also as »creepy«. Their ratings differ quite strongly from the other prototypes. The preferences uttered by the participants in this cluster are mixed, appearing to be in favour of device that is »alive«, but »not creepy«.

[37] The cluster is constituted of »creepy«, »arouses emotion«, and »alive« on the one side, and »not creepy«, »emotionless«, and »dead« on the other.

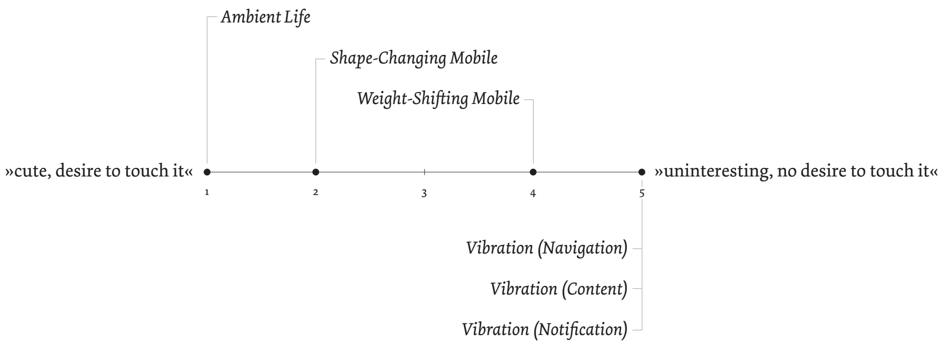

FIGURE 5.41: »Cute, desire to touch it – uninteresting, no desire to touch it«. Median values for cluster 5.

Cluster 5, »cute, desire to touch it – uninteresting, no desire to touch it« (Fig. 5.41), consists of five constructs (Table 6).[38] This cluster appears to relate to a perceived cuteness associated with life-like signals in the prototypes. The ratings are similar to those regarding the degree of creepiness in the previous cluster. The *Ambient Life* prototype received high ratings for the »cute, desire to touch it« side, and appears to be opposed, together with the *Shape-Changing Mobile* prototype, to the *Weight-Shifting Mobile* prototype and, more strongly, to the vibration-based comparison prototypes. In this cluster, the preferences are mostly on the »cute, desire to touch it« side, with one exception (i. e. one participant preferred »dead« over »alive«).

[38] It consists of the poles »alive«, »cute«, »desire to touch it«, »alive«, and »organic« on the one side, and »dead«, »uninteresting«, »no desire to touch it«, »machine-like«, and »technical« on the other side.

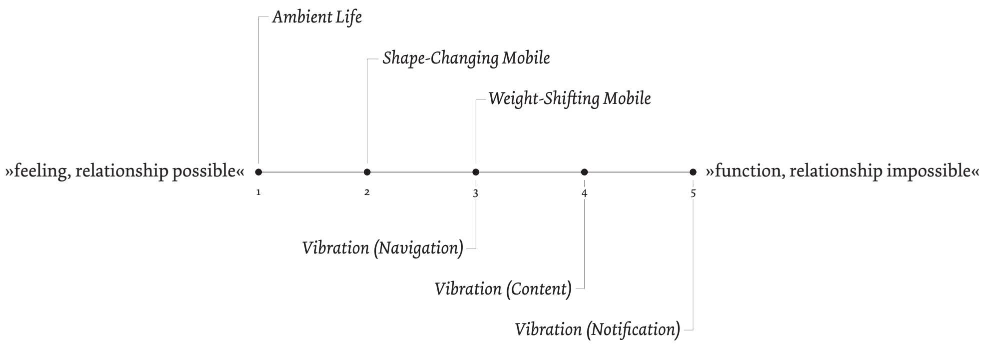

FIGURE 5.42: »Feeling, relationship possible – function, relationship impossible«. Median values for cluster 6.

Cluster 6, »feeling, relationship possible – function, relationship impossible« (Fig. 5.42), consists of eight constructs (Table 7).[39] This cluster seems to regard the degree of emotional attachment that the interaction allows for. The *Vibration: Content* and *Vibration: Notification* prototypes seem to be rated as rather functional, whereas the *Ambient Life* and *Shape-Changing Mobile* prototypes seem to be on the relational side. The *Vibration: Navigation* and *Weight-Shifting Mobile* prototypes received medium ratings. Preference-wise, the two sides seem to stand in conflict: functionalism appears to be desirable for the participants, as does a fun, emotional relationship to the device.

[39] It consists of the poles »feeling«, »relationship possible«, »organic«, »needs empathy«, »fun«, »behaviour cuddly«, »motion-intense«, »mechanical«, and »alive« on the one side, and »function«, »relationship impossible«, »static«, »purposeful«, »ordinary«, »behaviour hard«, »little motion intensity«, »organic«, and »machine-like« on the other side.

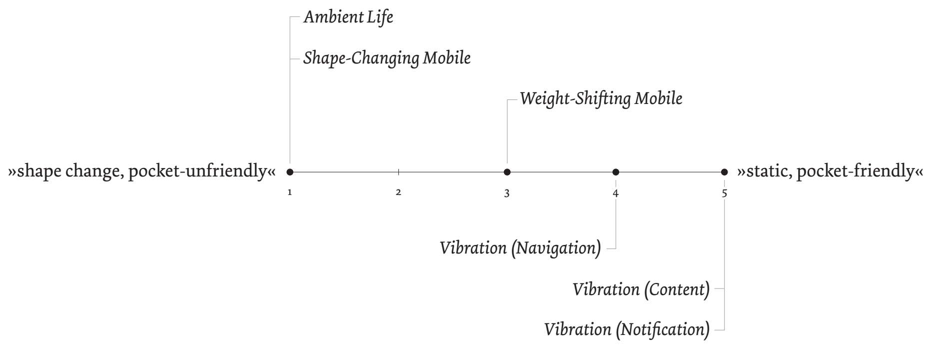

FIGURE 5.43: »Shape change, pocket-unfriendly – static, pocket-friendly«. Median values for cluster 7.

Cluster 7, »shape change, pocket-unfriendly – static, pocket-friendly« (Fig. 5.43), consists of five constructs (Table 8).[40] This cluster seems to describe rather pragmatic aspects of the interaction – physical actuation, in its different forms, may have implications for the device's everyday usability. This may, in the participants' constructs, be reflected in ratings of how »pocket-friendly« a device is. Here, the vibration-based comparison prototypes received higher ratings than the *Shape-Changing Mobile*, *Weight-Shifting Mobile*, and *Ambient Life* prototypes. The *Weight-Shifting Mobile* prototype seems to be the most »pocket-friendly« of these. The participants' preferences seem to be in conflict here: a shape-changing device may be desirable, but, at the same time, it should be pocket-friendly.

[40] On the one side, the poles are »shape change«, »many associations«, »pocket-unfriendly«, »changeable«, and »impulsive«. On the other side, they are »static«, »no associations«, »pocket-friendly«, »firm«, and »straightforward«.

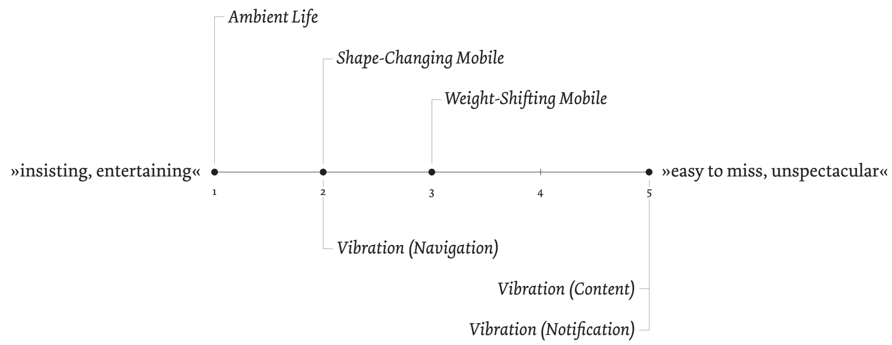

FIGURE 5.44: »Insisting, entertaining – easy to miss, unspectacular«. Median values for cluster 8.

Cluster 8, »insisting, entertaining – easy to miss, unspectacular« (Fig. 5.44), consists of seven constructs (Table 9).[41] This cluster appears to be, semantically, quite diverse. It is one of the less clear clusters. With some exceptions, the constructs in it seem to concern how much attention the device arouses (i. e. »entertaining«, »insisting«). The vibration-based comparison prototypes, except for the *Vibration: Navigation* prototype, are rated to be less insisting and more discreet – but also less entertaining. In this cluster, the participants' preferences are mixed.

[41] The poles in this cluster are »entertaining«, »unknown«, »individual«, »adult«, »insisting«, »alive«, and »insisting« on the one side, and »unspectacular«, »known«, »dependent«, »youthful«, »easy to miss«, »dead«, and »discreet« on the other.

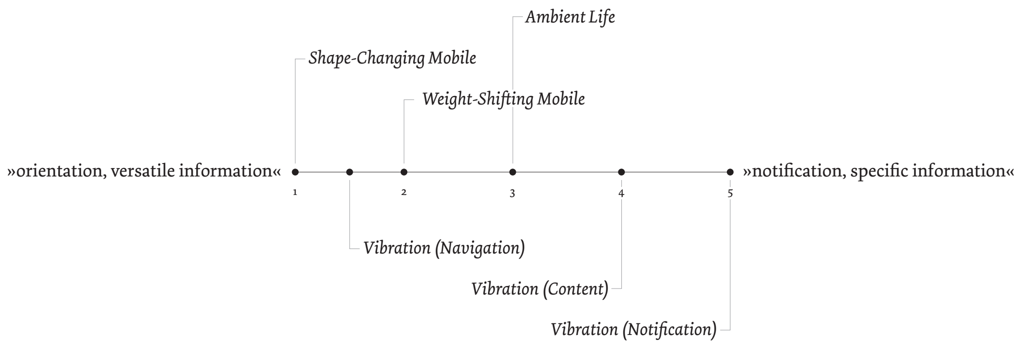

FIGURE 5.45: »Orientation, versatile information – notification, specific information«. Median values for cluster 9.

Cluster 9, »orientation, versatile information – notification, specific information« (Fig. 5.45), consists of four constructs (Table 10).[42] This cluster appears to regard the kind of information that the devices display. The three directionally actuated prototypes (i. e. the *Vibration: Navigation* prototype, the *Shape-Changing Mobile* prototype and the *Weight-Shifting Mobile* prototype) are rated similarly, towards the »orientation, versatile information« pole. These could be interpreted as being more outwards-directed, while the others may seem to be more inwards-directed, i. e. concerned with digital information inside of them. Here, the preferences are distributed rather on the »orientation, versatile information« side.

[42] It is marked by the poles »orientation«, »versatile information«, »flexible«, and »pointing« on the one side, and »notification«, »specific information«, »static«, and »not pointing« on the other.

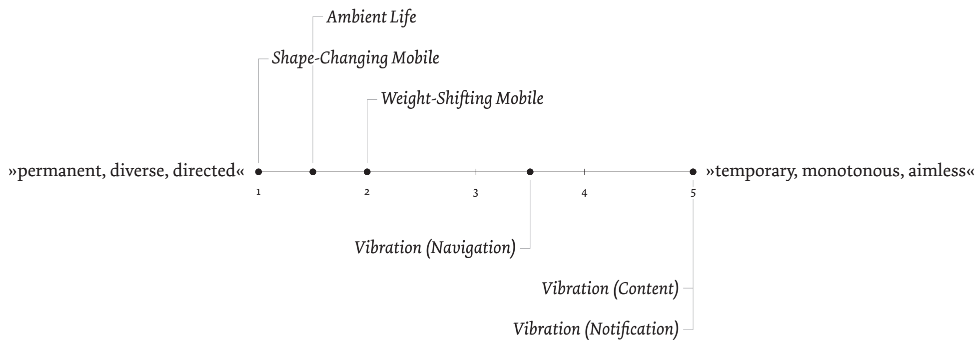

FIGURE 5.46: »Permanent, diverse, directed – temporary, monotonous, aimless«. Median values for cluster 10.

Cluster 10, »permanent, diverse, directed – temporary, monotonous, aimless« (Fig. 5.46), consists of 13 constructs (Table 11).[43] This cluster seems to be, semantically, rather diverse and unclear. It may be concerned with the degree of the actuation's ephemerality (i. e. how quickly the displayed information disappears after the actuation) and with its diversity. The vibration-based comparison prototypes are rated to be rather on the »temporary, monotonous, aimless« side.[44] The preferences in this cluster seem to be on the »permanent, diverse, directed« side.

[43] The poles on the one side are »diverse«, »multi-directional«, »shaky«, »motivating«, »shift«, »directed«, »experimental«, »permanent«, »strong«, »cool«, »process«, »multi-layered«, and »shifting«. On the other side, they are »monotonous«, »one-directional«, »static«, »neutral«, »frequency«, »aimless«, »conventional«, »temporary«, »weak«, »not cool«, »on/off«, »concrete«, and »central«.

[44] In this cluster, different aspects seem to overlap. There are some constructs in this cluster that seem to be related to the devices' innovativeness (e. g. »experimental – conventional«), but these are better covered by cluster 11. Thus, this aspect is not included in cluster 10's name.

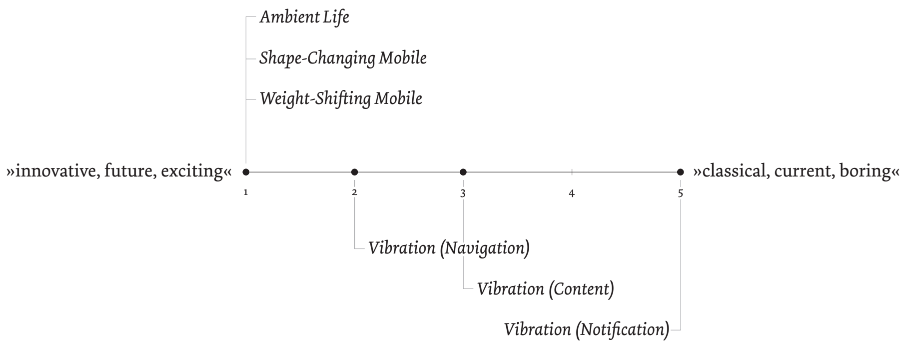

FIGURE 5.47: »Innovative, future, exciting – classical, current, boring«. Median values for cluster 11.

Cluster 11, »innovative, future, exciting – classical, current, boring« (Fig. 5.47), consists of 13 constructs (Table 12).[45] This cluster seems to address the device's innovativeness.[46] The *Ambient Life*, *Shape-Changing Mobile* and *Weight-Shifting Mobile* prototypes, but also the *Vibration: Navigation* (and to some degree, the *Vibration: Content*) prototypes are rated to be more innovative than the *Vibration: Notification* prototype. The preferred poles are mostly those on the »innovative, future, exciting« side, with the notable exception of »not demanding«, which is preferred, but on the »classical, current, boring« side.

[45] On the one side, their poles are »innovative«, »digital«, »application unusual«, »future«, »interesting«, »wandering«, »demanding«, »user activity possible«, »obedient«, »exciting«, »complex«, »fanciful«, and »clever«. On the other side, they are »classical«, »analogue«, »application usual«, »current«, »normal«, »static«, »not demanding«, »user activity impossible«, »disobedient«, »boring«, »simple«, »rational«, and »boring«.

[46] There seems to be one construct that regards another aspect in this cluster: »obedient – disobedient«. This construct appears to be related to some attribution of life-like properties to the device, and to the relational aspects of the interaction with such a »living« device.

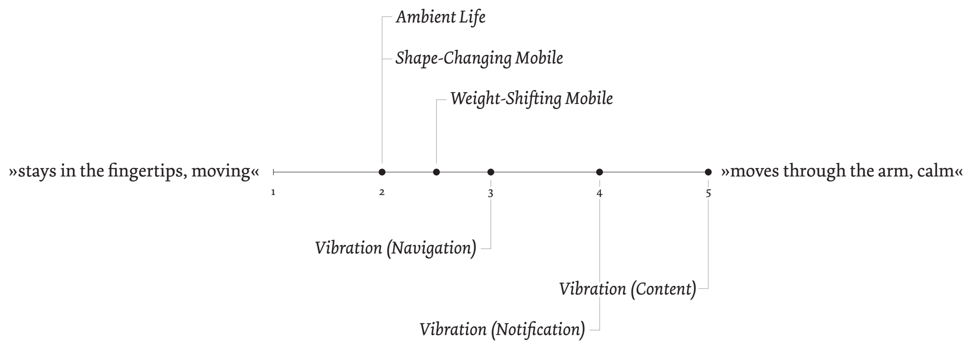

FIGURE 5.48: »Stays in the fingertips, moving – moves through the arm, calm«. Median values for cluster 12.

Cluster 12, »stays in the fingertips, moving – moves through the arm, calm« (Fig. 5.48), consists of six constructs (Table 13).[47] This cluster, while being somewhat unclear, could be interpreted to regard the perceived invasiveness of the actuation. The vibration-based comparison prototypes received higher scores on the scale towards »moves through the arm« than the *Shape-Changing Mobile*, *Weight-Shifting Mobile*, and *Ambient Life* prototypes. The preferences for these constructs are rather on the »stays in the fingertips, moving« side.

[47] The poles on the one side are »stays in the fingertips«, »indiscreet«, »moving«, »talkative«, »moved«, and »unnatural«. The poles on the other side are »moves through the arm«, »discreet«, »calm«, »silent«, »no motion«, and »natural«.

5.3 Discussion

Several findings can be concluded from the study. The *Shape-Changing Mobile*, *Weight-Shifting Mobile*, and *Ambient Life* prototypes seem to have been experienced as more novel than the vibration-based comparison prototypes. The innovativeness (as cluster 11 indicates, p. 137) of the proposed devices seems to distinguish them from the comparison prototypes. This innovativeness appears to be generally appreciated, as the participants' preferences indicate. The participants in the study had no prior experience with the prototypes, but owned mobile phones with vibration motors. Hence, they were likely to be used to vibration motors in hand-held devices, while the *Shape-Changing Mobile*, *Weight-Shifting Mobile*, and *Ambient Life* prototypes were new for them. A long-time study, in which people would be given the chance to get used to the actuation, may have yielded other results – see Hemmert (2009) for an example.

Interestingly, no aspect of the »bodily« (or »non-visual«) character of the interaction was mentioned by the participants. This may be the case because RGT elicits only *differences* between the prototypes: no prototype based on a GUI was included in the study.

I hypothesised that designing the »representational embodiments« (i. e. the physical manifestations) of digital information in orientation to the user's »experiential embodiment« in their socio-physical world (i. e. by drawing on »substance« and »life form« metaphors) would make the interaction richer, less invasive, and more familiar. Regarding this hypothesis, the participants' experiences with the prototypes seem to stand in partial conflict. In the remainder of this chapter, I discuss three themes that these conflicts may point to. Firstly, metaphorical charge can be helpful to make the interaction richer in associations, but it requires prior knowledge and may cause disappointment. Secondly, permanent actuation can improve a device's ignorability, but it may be annoying, as well. Lastly, life-likeness can be perceived as cute, but also as creepy.

5.3.1 Metaphorical: Rich in Associations, but Requiring Prior Knowledge

The RGT study's results point to an increased *richness in associations* of the *Shape-Changing Mobile*, *Weight-Shifting Mobile*, and *Ambient Life* prototypes. However, no increased *bodily richness* of the interaction was mentioned. This may be the case because RGT elicits only differences between the prototypes, and all of them were rather bodily.

On the other hand, though, it has been pointed out by the participants that *prior knowledge* is required to understand the metaphors drawn upon. One has to know about a metaphor in order to understand the interaction that it is based upon. This is in line with some earlier studies of the *Weight-Shifting Mobile* and *Shape-Changing Mobile* prototypes. In the *Shape-Changing Mobile* prototype, the mapping of »up« and »down« was unclear to some users, as it was not clear to them whether its thin side or its thick side was »pointing« into the target direction.[48] In these earlier studies, the metaphors were not inherently clear to the participants, as well.

Life-likeness was hypothesised to serve as a familiar metaphor for the users – however, the findings of the study do not confirm this. Cluster 2 (p. 128), for example, may indicate that the concept of life-likeness is not inherently connected to »known«, as I had hypothesised. Rather, it may be assumed that while people are generally familiar with the concept of »life-likeness«, they may be unfamiliar with it in the context (and form) of mobile phones.

[48] The participants in the earlier studies were able to explain both mappings: »thick« might resemble the *position* of an object, versus »thin« is »lower«, and things generally roll downhill, i. e. into the *direction* of »thin«.

Especially in previous studies, users often tried to socially interact with the *Ambient Life* prototypes, e. g. by talking to the prototype, or stroking it. The prototypes do not react to this kind of interaction, but the metaphor may be hypothesised to evoke such user behaviour. Waking »false expectations« seems to be a common problem of such highly metaphorical interaction styles.[49]

Basing the design of digital information's »representational embodiment« on metaphors from the user's socio-physical world (i. e. orienting it towards their »experiential embodiment«) might offer richness in associations. However, these metaphors may require prior knowledge and may evoke user expectations that will be disappointed.

5.3.2 Permanent: Sometimes Ignorable, but sometimes Annoying

The participants' comments during the construct elicitation indicate that different forms of »permanence« can be distinguished. In some cases (especially in the *Shape-Changing Mobile* and *Weight-Shifting Mobile* prototypes), a temporary actuation has a *lasting impact* on the device's physical properties. The *Ambient Life* prototype can be considered to make use of a different form of permanence – here, the actuation is permanent because it is *repetitive*. In the vibration-based comparison prototypes, the actuation is only perceivable at the time of the actuation. It is thus not considered a »permanent« actuation, it is only

[49] This can be regarded as in line with other discussions of metaphors in user interface design. For example, Hornecker (2012) reports a study on an Augmented Reality (AR) interface that raised user expectations about how to use it, but left these unfulfilled. The users expected the interface to allow for three-dimensional, gravity-compliant interactions, but it allowed only for two-dimensional interactions, without complying with gravity. This, according to Hornecker (ibid., pp. 176-177), confused the users. On a more general note, Bolter and Gromala (2003) point out that realistic things are also expected to behave like the real thing.

temporary. One aspect of permanent actuation that the participants seem to have appreciated is that it allows for *ignoring* the device.

This is supported by previous studies of the *Weight-Shifting Mobile* and *Shape-Changing Mobile* prototypes. Users were rather reliably able to determine the *absolute* positions of the shape and weight, which means that interpreting the actuation correctly does not depend on monitoring it for changes all the time. Regarding the *Ambient Life* prototype, users found the permanent actuation annoying in silent situations, but helpful in loud environments. Regarding this »ignorability«, cluster 3 (p. 130) shows two different aspects: in some situations, *ignorability* and »calm« interfaces are desirable, but in other cases – especially in the context of notification – *noticeability* may be desired.

The role of *repetition* in this context is rather unclear. A repeated actuation may be helpful in taking notice of an event (i. e. not missing it), but it could be annoying, as well. As the preferences in cluster 8 (p. 168) indicate, the degree to which a device's utterances are ignorable, and the degree to which it repeats them until the user takes notice, can be an ambiguous issue. Here, the type and the urgency of the digital information may be a determining factor. In some cases, one may not want to miss a notification, in others, one may not want to be disturbed.[50] Regarding this aspect of »ignorability«, it may be helpful to provide users with notifications that are ignorable at the time of notification, but permanently perceptible afterwards.

The concept of permanent actuation appears to be particularly interesting in consideration of the finding from a previous study, namely that users reported »phantom deaths« of an *Ambient Life* prototype when they carried the device for a weekend (Hemmert, 2008a). Similarly, a »gap« was reported upon taking the phone out of the pocket after a prolonged duration of wearing it. In these cases, the permanence of the heartbeat

[50] For a related study on urgency-augmented phone calls, see Hemmert et al. (2009b).

actuation may have caused the users to get used to it. When the actuation was interrupted, the users noticed this. Some users compared the interrupted actuation to a feeling of »incompleteness«. They described the feeling as similar to the feeling of leaving the house without their wallet or keys. Such descriptions of feeling »incomplete« without a device may be related to the perception of an object as an extension of one's body – an »embodiment« relation, as Fels (2000) names it.

Designing »representational embodiments« of digital information in orientation to users' »experiential embodiment« makes it necessary to provide interactions that are adequate – sometimes ignorable, sometimes noticeable – for different socio-physical situations.

5.3.3 Life-Like: Cute, but Sometimes Creepy

The perceived life-likeness of the *Ambient Life* and *Shape-Changing Mobile* prototypes split the participants into two groups: the prototypes were either perceived as »cute«, or as »creepy«. While creepiness appears to be not desirable in interaction design, it is striking that a mobile phone *can* appear creepy. For example, cluster 4 (p. 130) indicates that a life-like interface may be rich in terms of the interaction, and easily understandable in terms of its underlying metaphor. But it may, at the same time, be perceived as uncanny. In cluster 5 (p. 132), the ratings for »cute« are similar to those for »creepy« in cluster 4 (p. 130). Life-like interfaces may be perceived as interesting, but also may be scary, at times. This may be related the »uncanny valley« hypothesis, which describes a sudden drop in comfort when interacting with increasingly realistic robots.[51] A related aspect is the perceived potential of building a »relationship« to the device. The potential to build up a relationship to the device seems to be perceived as opposed to its functionality.

[51] See Mori (1970) for a more detailed discussion.

In the follow-up project to *Ambient Life*, the animation of a device in reaction to the user's nearing hand was studied. Also here, cuteness and creepiness seemed to be closely related.[52]

Thus, orienting the »representational embodiment« of digital information to the users' »experiential embodiment« by using a »life form« metaphor may be an approach to create intense interactions, but also entails the risk that these interactions are being perceived as creepy.

Summary

Designing the »representational embodiments« of digital information in orientation to the user's »experiential embodiment« in their socio-physical world has led to forms of interaction that users may experience differently than previous forms of interaction.

My hypothesis, that such forms of interaction would be experienced as richer, less invasive, and more familiar than previous forms of interaction, was not confirmed.

It may rather be concluded that these new forms of interaction come at a price. The *Weight-Shifting Mobile*, *Shape-Changing Mobile*, and *Ambient Life* prototypes show new ways of interaction – which are perceived as rich in associations, more permanent, and even life-like. But metaphors can be misunderstood, and also lead to disappointment. Ignorability can lead to missed notifications, while permanent actuation can be annoying. Lastly, cuteness can easily turn into creepiness.

[52] See Hemmert et al. (2013) for further details.

These aspects show the complexity of the conceptual space in which the digital information's and the user's »embodiment« encounter each other. Some of these aspects are already being actively researched in other fields, some could point to new research directions. For some future research activities, distinguishing between »representational embodiment« and »experiential embodiment« may be a helpful concept. It might, in the end, help us to design interactive technology that fits into our world.

CHAPTER 6

Reflection

In the first section of this chapter, I summarise the previous chapters and clarify the contributions that I claim to have made. In the second section, I detail some limitations that should be noted regarding this work. In the third section, I outline open questions and give an outlook on future research.

In the beginning of this work, I outlined the growing interest of Human-Computer Interaction (HCI) in the body and in »embodiment«. I demonstrated that the notion of »embodiment« is of increasing importance (p. 22), and that it is used in different meanings throughout the HCI literature (p. 34). In the third chapter (p. 39), I labelled two of these meanings as »representational embodiment« and »experiential embodiment«. This distinction was, in this explicit form, previously not existent in the HCI literature. I therefore claim it to be one contribution of this thesis.

In the fourth chapter (p. 57), I justified my research approach, Research Through Design (RTD), and, in particular, Findeli's model of Project-Grounded Research (PGR). I contextualised RTD (and PGR) in its methodological context, i. e. in the debate on how design and science might be combined. I provided an overview over the historical context and pointed to action research and grounded theory as epistemological reference points.

In the fifth chapter (p. 75), I then applied PGR to the proposed distinction of »representational embodiment« and »experiential embodiment« in HCI. Through a project on haptics-enhanced mobile phone prototypes, I explored the conceptual space that was opened by the two meanings. In particular, I investigated moments in which »experientially embodied« users encounter »representational embodiments« of digital information. The »representational embodiments« in my prototypes were based on socio-physical metaphors. I hypothesised that these metaphors would be inherently familiar to the users because of their »experiential embodiment« in the socio-physical world. Concretely, the metaphors that I employed were »digital information has physical thickness«, »digital information has physical weight« and »a computer is a living being«. I compared the different prototypes to each other and to vibration-based prototypes in a Repertory Grid Technique (RGT) study (p. 120). The results of the study indicated that the employed metaphors were experienced by the users as metaphorically rich, permanent and easy to ignore, and life-like. However, there were also downsides: at times, the users experienced the interaction as disappointing, i. e. when the prototypes did not fulfil the expectations that the metaphor had raised. In other cases, the permanent actuation was described as annoying. Sometimes, the prototypes' life-like movements were not only perceived as cute, but as creepy (p. 140).

For HCI, this means that the proposed distinction may offer potential for the exploration of new types of interaction – but these may also come at the price of new challenges, which need to be addressed, and which I began to outline.

For design research, this means that opening a space through a theoretical distinction, and then exploring it through design, may be a viable combination of design and research. In my case, design research contributed a unique, »project-grounded« perspective on the otherwise rather theoretical issue of »embodiment« in HCI. To clarify this point, I outline the contributions that I claim to have made in the next section.

6.1 Contributions

I claim that the proposed distinction between »experiential embodiment« and »representational embodiment« is a valuable contribution. It helps to refer explicitly to one of the two meanings, and thus may help to avoid confusion. The term »embodiment« is frequently used in the HCI literature, often without further explanation. Thus, it is sometimes unclear if just a representation is meant, or the foundation of experiencing a socio-physical world. Confusing the two could lead to computer-like conceptions of humans, or to human-like conceptions of computers. Here, a clear distinction between the two meanings appears to be helpful. Therefore, I hold it to be the first contribution of this thesis.

The space that is opened through the proposed distinction, I then explored *through design*. I do not claim this exploration to be exhaustive. Rather, it investigated different spots within the space – those spots in which the »representational embodiments« of digital information are manifested through socio-physical metaphors of shape change, weight shift, and life-like motion. These, I hypothesised to be particularly familiar to users, because of their »experiential embodiment« in their everyday world. I have also shown the research gap that each of these prototypes assesses (p. 80, p. 92, p. 112). Therefore, I hold that the prototypes and their underlying interaction principles are the second contribution of this thesis.

The prototypes that I developed in the course of this project were tested and compared to each other, as well as to vibration-based prototypes, in a RGT study. This comparison indicated that while the proposed prototypes were found novel by the users, that the interaction was not entirely rated as positive. Rather, the experience of the interaction with the proposed devices appeared to be much more often a »two-sided coin«. The metaphorical character of the interaction was perceived as rich and plausible, but criticised for the necessity of prior knowledge. Also, some expectations that the metaphors had evoked were not fulfilled by the prototypes. This disappointed the users. The permanent character of the interaction was enjoyed for its ignorability, but it was also perceived as annoying by some users. The life-like character of some of the prototypes was often perceived as cute, but some users found it creepy. These findings I hold to be the third contribution of this thesis.

In the second chapter, I outlined HCI's growing interest in the body, and in »embodiment«, by several examples of recent developments in HCI. In the following, I review these developments, through the lens of the proposed distinction.

Touch-reactive surfaces (p. 7), for example, especially when they are touch *screens*, can be regarded as based mainly on graphical »representational embodiments« – the encounter with these is mainly visual, and thereby relies less on the user's »experiential embodiment« than, for example, Tangible User Interfaces (TUIs). But being based on direct touch, they leverage on the principle of direct manipulation, which users are familiar with because of their »experiential embodiment« in the socio-physical world. In that, touch-reactive surfaces can be regarded as being based more on »experiential embodiment« than, for example, Command-Line Interfaces (CLIs): CLIs are based on abstract textual representations, and thereby only marginally leverage on the user's »embodiment« in the socio-physical world. It should be noted, though, that also CLIs employ bodily metaphors. For example, they commonly refer to »folders« (or »directories«) and »files«, which users are assumed to be familiar with from the office context, and a »path«, which users are assumed to be familiar with from wandering in the real world. These metaphors are manifested abstractly, in text, though.

The proposed distinction can also be applied to gestural interfaces (p. 10). Gestural interfaces are based on the user's familiarity with gestures from their »experiential embodiment« in the socio-physical world. Notably, most gestures (e. g. hand-waving from left to right to issue the command »play next song«) seem to follow a model of *communication*, while interaction based on physical metaphors (e. g. dragging a file to the trash bin) seems to be based on a model of *manipulation*. Gestural interaction might, thus, fall rather into the »communication« paradigm of HCI – which is interesting, because »bodily« (as in gestural) is usually accounted to the »embodied« interaction paradigm. *Bodily communication*, as in this case, might be a borderline example.

Using the proposed distinction, augmented reality (p. 13) can be described as the overlay of the socio-physical world (which users are »experientially embodied« in) through »representational embodiments« of digital information. The interaction with such interfaces is thereby based upon skills of interacting with the socio-physical world, which users are assumed to be familiar with.

In gaze interaction (p. 13), »representational embodiments« of digital information are not necessarily involved – it describes rather an input technique (as does »touch-reactive surfaces«). However, the role of »experiential embodiment« is interesting here. Gaze is a bodily action, but usually, it is a receptive, passive action: we usually do not trigger or manipulate things with our gaze. Rather, we tend to look first, and touch then. That means that such interfaces might not fully be based upon conceiving users as »experientially embodied« in a socio-physical world. Rather, they might conceive the user's body as a »vehicle« of acting in the world (i. e. through gaze), which is controlled by the mind, and thus follow a rather Cartesian approach.

Applied to projection-based interfaces (p. 15), the proposed distinction describes such interfaces as based on visual »representational embodiments«, which are projected on surfaces in the socio-physical world, in which users are »experientially embodied«. Compared to many current (e. g. glasses-based) augmented reality interfaces, which are usually limited to one user, projection-based interfaces hold the potential to be usable by multiple users at a time – thus, making further use of their »experiential embodiment«. They might also be socially more acceptable, as they offer bystanders an idea of what the user is doing.

For ambient displays (p. 17), the proposed distinction can be used to describe their goal: to make digital information easier to ignore by integrating its »representational embodiment« into the socio-physical world of the user. The ability of ignoring things appears to be a skill that users employ through their »experiential embodiment« in the everyday world. Ambient displays make use of this skill.

Most of these examples demonstrate how bodily action is employed in the interaction, to make it less obtrusive, or more productive. This goal, the unobtrusive, productive integration of an activity into one's habitus, can also be found in the aforementioned notion of »embodiment« of a tool in skilled use. Thus, to some degree of potential confusion, it appears that the goal of many body-oriented interaction techniques is to make the user »embody« the interaction. Therefore, the aforementioned third meaning of »embodiment« as »skilful embodiment« in HCI (p. 50) often appears to be the goal for letting »representational embodiment« and »experiential embodiment« encounter.

In general, HCI research often concerns how (»embodied«) users interact with representations (»embodiments«) of digital information. These representations need to be designed, and designing them in orientation to the user's »embodiment« might be a viable approach. In recent HCI theory, the role of the body is no longer understood as a »vehicle« (to use the Cartesian term) for a user, who is conceived as an information processor. Rather, the user's body and mind are understood as intertwined, thus the body plays a bigger role than before.[1] For basing an interaction design on this thought, the proposed distinction may be helpful.

In summary, I claim to have made three contributions:

- a distinction between a »representational« and an »experiential« meaning of »embodiment« in the HCI literature

[1] Some developments in HCI, like Brain-Computer Interfaces (BCIs) may indicate some developments into the opposite direction. Here, the body plays only a minor role. These developments of »un-bodies« and »cyborg or techno-bodies« (Cregan, 2006, p. 15) are a counter-movement to HCI's rising interest of the body.

- an exploration of the space in which these two »encounter«, through the design of experimental prototypes, which are based on the manifestation of digital information through socio-physical metaphors and
- three »two-sided« aspects of how the interaction with these prototypes was experienced by users in a RGT study, showing that the newly opened space may hold the potential for rich interaction, but also entails new challenges for interaction designers.

6.2 Limitations

Every research project is limited in its scope. In this section, I outline the limitations of this work, both in its methods, as well as in its findings. I start with the smaller limitations (which regard the study conducted) and then move to the larger, conceptual limitations of the path I followed in this work.

Regarding the RGT study, some methodological limitations should be noted. Firstly, the *Shape-Changing Mobile* prototype was controlled manually. The *Shape-Changing Mobile* prototype's ratings as rather »alive« may be an artefact of the prototype being controlled in this way (i. e. through the experimenter and/or one of the assistants) during the experiment, with a hand-held accelerometer. Would it have been controlled through a more discreetly-structured script (e. g. displaying »full« and »empty« states more distinctively, without smooth transitions), the participants' ratings may have been different. Secondly, the participants were able to see and hear the prototypes. In previous studies, participants wore headphones, and felt the prototypes only through a curtain. In these studies, this approach was chosen as the *accuracy* at which the haptic cues could be felt was of interest. In the RGT study, this seemed impractical, as users had to sort and group the prototypes. While the participants were asked to focus on the haptics, the results suggest that they were not always doing so: sometimes, visual and auditory aspects appear to have been included in the elicited constructs. Thirdly, fatigue effects may have occurred in the assessment phase of the RGT study. Some of the ratings appear to be flipped. In cluster 12, the *Ambient Life* prototype is rated as rather »unnatural«, while the *Vibration: Notification* prototype is rated as highly »natural«. It may simply be the case that the participants flipped the poles (or the prototypes) in the ratings. The randomisation of the prototypes in each of the questionnaires' items may have been complicating the assessment phase for the participants. The participants reported that they found the experiment cognitively exhausting. Also the fact that the participants had to choose one of the two poles as the »preferable one« may have led to false contrasts in the participants' responses. Furthermore, the chosen applications (which were part of the RGT study) may have influenced the participants' responses.

Methodologically, I set out to follow Findeli's model of PGR. It appeared to me as a step-by-step instruction at first: I thought I would, firstly, transform my research question into a design question, secondly, find a design answer, and, thirdly, extract a research answer. However, in practice, the development of theory and practice was much more a back-and-forth, a synthesis, or a dance of the two. I simply did not have a research question to start with. Being an interaction designer by training, I often made quick sketches, *while* working through the literature. I intertwined theory and practice, and design and research. Often, it was the practice that led to new questions – not the theory. But together, the two advanced the overall *project*.

The question, then, is: is this work really RTD? The definitions of »research« that I outlined above emphasise that research should lead to *communicable results*. In this work, I claim, that is the case. Several publications at research conferences accompanied the project, and also the prototypes were, in the end, compared to each other and to vibration-based prototypes. Also, many of the project's findings were exchanged with the different stakeholders involved in the project.[2] In that, I claim the project to qualify as research.

Furthermore, I conclude that design was a helpful means in the pursuit of the research. Building prototypes helped me to reflect on my thoughts, and to make them tangible for other people. Testing the prototypes often led to new questions, which led to new theory – which led to new prototypes, in turn. I believe that my process was similar to what Basballe and Halskov visualise as an oscillation between research interests and design interests (Basballe and Halskov, 2012). Because of that, I claim it to be research *through design*.

The influence of the researcher in project-grounded research is substantial. Therefore, I made my design decisions and the conclusions from the RGT study as explicit and transparent as possible.

6.3 Open Questions

In the course of this project, many questions remained unanswered, and new ones emerged. Thus, this section may be a valuable inspiration for future researchers.

First of all, the notion of »embodiment« in HCI remains complicated – the proposed distinction, and its exploration, can only contribute a small bit to its clarification. In the second chapter, I provided a brief overview of the different things that »embodiment«

[2] Different stakeholders were involved in the project. First of all, my academic peers, who reviewed the publications and served as sparring partners for ideas at the respective conferences, will hopefully benefit from the contributions of this thesis. A broader audience was reached through a five minute presentation on the TED website (Hemmert, 2010), in which I presented the prototypes that were created in this project. Several patents were filed and granted.

can mean in HCI. The proposed distinction between »representational embodiment« and »experiential embodiment« can help only a little to gain clarity in this issue – many meanings of »embodiment« in HCI fall into neither of the two categories.

Another question that remains unanswered for now regards the »creepiness« that some participants reported in the study. What are the factors that make an interactive object creepy, and how can they be overcome? When can this be of use in the interaction (e. g. as a warning)? Furthermore, the case of graphical »pseudo-physical« manifestations of digital information (p. 55) remains unclear. Many current interfaces use physical metaphors in graphical animations and interaction principles. To find out how these are experienced in the interaction, in comparison to real physical manifestations, more research is needed.

Furthermore, the proposed distinction between »representational embodiment« and »experiential embodiment« could be viewed from other perspectives than the »designerly« one. For example, »representational embodiment« can also be viewed from a sensory, semiotic or cultural perspective. It could be asked which other sensory capabilities of the human hand (or body) could be used to make digital information perceptible. It could be explored how different sign relationships (e. g. iconic, indexical, or symbolic) between digital content and physical manifestation are experienced in the interaction. »Experiential embodiment« can also be viewed from an anthropological, sociological, or phenomenological perspective. Each new perspective raises new questions, and offers potential to focus on in future work.

I explored, from a very limited angle, how different »embodiments« of digital information are experienced in the interaction – i. e. when they are represented through the haptic cues of shape change, weight shift, and life-like signals. But the field of haptics, of which I explored only a very small fraction, makes up only one, small aspect of *some* TUIs. TUIs, in turn, make up only a *niche* of HCI. Thus, this work can only be one small step on our journey of making the interaction with digital information more suitable for us.

Future developments, like BCIs and computation-enabled body implants, will pose new challenges for interaction designers and HCI researchers. The body and, with it, »embodiment«, are still of growing interest for the field of HCI. It may be questioned, though, how clear the *boundary* between user and computer will be in the future. While I assumed a clear boundary between the two in this thesis, this boundary is increasingly blurred by technological developments.

Giving physicality to digital information may be old-fashioned. Perhaps, one day, we will be able to encounter digital information directly, without any need for a body – a future vision that appears to be of at least questionable desirability. For now, making digital information tangible appears to be the more human option: we're not computers.

»Understanding is Grasping.« (Lakoff and Johnson, 1980, p. 20)

Appendix

Initial Prototype Ranking and Participant Data

This table shows the participants' initial ranking of the prototypes by »appealingness«. It furthermore shows the participants' demographic data, including age, gender, and mobile phone expertise.

Participant No.	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Mobile Phone Expertise (1 = »Novice«, 5 = »Expert«)	Age	Gender
1	6	4	1	2	5	3	3	24	male
2	4	3	5	1	2	6	2	51	female
3	2	6	3	1	4	5	3	47	female
4	1	6	4	3	2	5	4	20	male
5	2	4	3	5	1	6	2	26	female
6	1	6	3	4	2	5	4	53	female
7	1	4	6	3	2	5	4	28	male
8	3	1	6	4	2	5	2	39	male
9	4	1	2	3	5	6	5	29	male
10	5	2	3	6	1	4	4	26	male
11	4	5	2	6	3	1	2	18	female
12	4	5	2	3	1	6	3	27	female

TABLE 1: Each participants' ranking of the prototypes by appealingness (1 = »most appealing«, 5 = »least appealing«), mobile phone expertise, age, and gender.

Construct Clusters

The following tables shows all construct clusters that were found through the Focus sorting and clustering algorithm.

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»initiative«	*	1	1	1	1	5	1		»work-intensive«
»active«	*	1	1	2	2	5	2		»passive«
»easy to understand«	*	1	1	1	2	5	1		»knowledge required«
»loss of control«		1	1	2	4	5	2	*	»control«
Median		1	1	1,5	2	5	1,5		

TABLE 2: Cluster 1 »initiative, active – work-intensive, passive« (p. 128).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»behaviour passive«		2	5	3	4	2	1	*	»behaviour alive«
»known«	*	2	5	3	3	1	1		»unknown«
»simple«	*	2	4	2	4	2	1		»complicated«
»defined«	*	2	5	3	3	1	1		»undefined«
Median		2	5	3	3.5	1.5	1		

TABLE 3: Cluster 2: »known, defined – unknown, undefined« (p. 128).

1 – English (transl.)	*Preference*	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	*Preference*	5 – English (transl.)
»noticeable«	*	1	4	4	2	5	2		»easy to miss«
»fidgety«		1	2	4	2	5	2	*	»calm«
»passive«		1	2	4	3	5	2	*	»active«
»clear«	*	1	2	5	3	4	2		»unclear«
Median		1	2	4	2.5	5	2		

TABLE 4: Cluster 3: »noticeable, fidgety – easy to miss, calm« (p. 130).

1 – English (transl.)	*Preference*	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	*Preference*	5 – English (transl.)
»creepy«		1	1	4	4	4	5	*	»not creepy«
»arouses emotion«	*	1	2	4	4	4	5		»emotionless«
»alive«	*	1	1	4	4	5	5		»dead«
Median		1	1	4	4	4	5		

TABLE 5: Cluster 4: »creepy, alive – not creepy, dead« (p. 130).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»alive«		1	2	3	5	4	5	*	»dead«
»cute«	*	1	2	4	4	5	5		»uninteresting«
»desire to touch it«	*	1	2	5	4	5	5		»no desire to touch it«
»alive«	*	1	2	4	5	5	5		»machine-like«
»organic«	*	1	2	4	5	4	5		»technical«
Median		1	2	4	5	5	5		

TABLE 6: Cluster 5: »cute, desire to touch it – uninteresting, no desire to touch it« (p. 132).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»feeling«		1	2	3	3	4	5	*	»function«
»relationship possible«	*	1	2	2	4	4	5		»relationship impossible«
»organic«		1	2	3	3	4	5	*	»static«
»needs empathy«		1	2	2	3	5	5	*	»purposeful«
»fun«	*	1	2	3	3	4	5		»ordinary«
»behaviour cuddly«	*	1	2	3	3	5	5		»behaviour hard«
»motion-intense«	*	1	2	3	4	4	5		»little motion intensity«
»mechanical«	*	1	2	3	4	4	5		»organic«
»alive«		1	2	3	3	5	5	*	»machine-like«
Median		1	2	3	3	4	5		

TABLE 7: Cluster 6: »feeling, relationship possible – function, relationship impossible« (p. 133).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»shape change«	*	1	1	3	4	5	4		»static«
»many associations«	*	1	1	3	4	5	5		»no associations«
»pocket-unfriendly«		1	1	3	3	5	5	*	»pocket-friendly«
»changeable«		1	1	3	2	5	5	*	»firm«
»impulsive«	*	1	1	3	4	5	5		»straightforward«
Median		1	1	3	4	5	5		

TABLE 8: Cluster 7: »shape change, pocket-unfriendly – static, pocket-friendly« (p. 134).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»entertaining«	*	2	2	3	2	5	5		»unspectacular«
»unknown«		1	2	2	2	4	5	*	»known«
»individual«	*	2	1	3	2	5	4		»dependent«
»adult«	*	2	1	3	2	5	5		»youthful«
»insisting«	*	1	2	3	2	4	5		»easy to miss«
»alive«		1	2	3	2	4	5	*	»dead«
»insisting«		1	2	3	2	5	5	*	»discreet«
Median		1	2	3	2	5	5		

TABLE 9: Cluster 8: »insisting, entertaining – easy to miss, unspectacular« (p. 135).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»orientation«	*	3	1	2	1	4	5		»notification«
»versatile information«	*	3	2	2	2	4	5		»specific information«
»flexible«	*	3	1	2	2	4	5		»static«
»pointing«	*	3	1	1	1	4	5		»not pointing«
Median		3	1	2	1.5	4	5		

TABLE 10: Cluster 9: »orientation, versatile information – notification, specific information« (p. 136).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»diverse«	*	2	1	1	3	4	5		»monotonous«
»multi-directional«	*	3	1	1	2	5	5		»one-directional«
»shaky«	*	3	1	1	2	5	5		»static«
»motivating«	*	3	1	1	2	5	5		»neutral«
»shift«		5	2	1	3	5	5	*	»frequency«
»directed«	*	4	2	1	2	5	5		»aimless«
»experimental«	*	1	1	2	3	4	5		»conventional«
»permanent«	*	1	1	2	3	4	5		»temporary«
»strong«	*	2	1	2	4	4	5		»weak«
»cool«	*	1	1	1	4	5	5		»not cool«
»process«		1	1	2	4	5	5	*	»on/off«
»multi-layered«		3	1	2	3	5	5	*	»concrete«
»shifting«	*	2	1	2	3	5	5		»central«
Median		1.5	1	2	3.5	5	5		

TABLE 11: Cluster 10: »permanent, diverse, directed – temporary, monotonous, aimless« (p. 137).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»innovative«	*	1	1	1	2	2	5		»classical«
»digital«	*	2	2	2	3	2	5		»analogue«
»application unusual«		1	1	2	3	2	5	*	»application usual«
»future«	*	1	1	1	1	5	5		»current«
»interesting«	*	1	1	1	1	5	5		»normal«
»wandering«	*	1	1	1	2	4	5		»static«
»demanding«		2	2	3	3	2	5	*	»not demanding«
»user activity possible«	*	1	2	3	2	2	4		»user activity impossible«
»obedient«	*	1	2	3	3	2	4		»disobedient«
»exciting«	*	1	1	1	1	5	5		»boring«
»complex«	*	1	1	1	1	5	5		»simple«
»fanciful«		1	1	1	2	3	5	*	»rational«
»clever«	*	1	1	1	2	4	5		»boring«
Median		1	1	1	2	3	5		

TABLE 12: Cluster 11: »innovative, future, exciting – classical, current, boring« (p. 137).

1 – English (transl.)	Preference	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	Preference	5 – English (transl.)
»stays in the fingertips«	*	2	2	2	5	4	4		»moves through the arm«
»indiscreet«		2	4	4	3	5	3	*	»discreet«
»moving«	*	2	2	4	3	5	3		»calm«
»talkative«	*	2	2	3	3	5	4		»silent«
»moved«	*	2	2	2	3	4	4		»no motion«
»unnatural«		2	2	2	5	5	4	*	»natural«
Median		2	2	2.5	3	5	4		

TABLE 13: Cluster 12: »stays in the fingertips – moves through the arm« (p. 138).

Personal Constructs

This table shows all personal constructs named by the participants in the RGT study (p. 120), alongside the prototypes' ratings and the original German terms that were used by the participants. The participants' »preferred« poles were, for readability's sake, all flipped to the left side (i. e. »1«). When a construct was flipped, the ratings were mirrored, accordingly.

Table 14: Personal constructs from the RGT study.

Construct No.	Participant No.	1 – German (orig.)	1 – English (transl.)	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	5 – English (transl.)	5 – German (orig.)
1	1	»reaktiv«	»reactive«	1	3	4	1	5	4	»active«	»aktiv««
2	1	»genau«	»exact«	3	5	1	3	5	2	»inaccurate«	»ungenau««
3	1	innovativ«	»innovative«	1	1	1	2	2	5	»classical«	»klassisch«
4	1	»digital«	»digital«	2	2	2	3	2	5	»analogue«	»analog«
5	1	»tot«	»dead«	5	4	3	1	2	1	»alive«	»lebendig«
6	1	»Funktion«	»function«	5	4	3	3	2	1	»feeling«	»Gefühl«
7	1	»Anwendung gewohnt«	»application usual«	5	5	4	3	4	1	»application unusual«	»Anwendung ungewohnt«
8	1	»bindungstauglich«	»relationship possible«	1	2	2	4	4	5	»relationship impossible«	»nicht bindungstauglich«
9	1	»kein Fokus benötigt«	»no focus needed«	2	3	5	5	4	1	»focus needed«	»Fokus benötigt«
10	1	»nicht creepy«	»not creepy«	5	5	2	2	2	1	»creepy«	»creepy«
11	2	»Hausgebrauch«	»domestic usage«	5	5	5	1	5	1	»playful«	»spielerisch«
12	2	»lebendig«	»alive«	1	1	1	1	1	5	»silent«	»still«
13	2	»einfach«	»simple«	5	1	5	5	5	1	»unusual«	»ausgefallen«
14	2	»Zukunft«	»future«	1	1	1	1	5	5	»current«	»aktuell«
15	2	»ruhig«	»calm«	5	5	5	5	5	5	»moving«	»bewegungsvoll«
16	2	»vertraut«	»known«	5	5	5	5	5	1	»unknown«	»unbekannt«
17	2	»Arbeit«	»work«	1	5	5	5	1	1	»not work«	»nicht Arbeit«
18	2	»Verbindung«	»union«	1	5	5	1	1	1	»separation«	»Trennung«
19	2	»interessant«	»interesting«	1	1	1	1	5	5	»normal«	»normal«
20	2	»Kinderspielzeug«	»toy«	2	2	1	2	5	2	»senior citizen emergency button«	»Seniorennotruf«

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TABLE 14 – *Continued from previous page.*

Construct No.	Participant No.	1 – German (orig.)	1 – English (transl.)	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	5 – English (transl.)	5 – German (orig.)
21	3	»initiativ«	»initiative«	1	1	1	1	5	1	»work-intensive«	»aufwendig«
22	3	»gleichförmig«	»uniform«	5	2	2	2	3	3	»pulsating«	»pulsierend«
23	3	»Form veränderlich«	»shape changeable«	1	1	5	5	5	5	»shape stable«	»Form beständig«
24	3	»wandernd«	»wandering«	1	1	1	2	4	5	»static«	»statisch«
25	3	»bleibt in den Fingerspitzen«	»stays in the fingertips«	2	2	2	5	4	4	»moves through the arm«	»zieht sich durch den Arm«
26	3	»abwechslungsreich«	»diverse«	2	1	1	3	4	5	»monotonous«	»monoton«
27	3	»natürlich«	»natural«	2	2	2	4	3	5	»dashing in«	»hereinpreschend«
28	3	»unterhaltsam«	»entertaining«	2	2	3	2	5	5	»unspectacular«	»unspektakulär«
29	3	»reaktiv«	»reactive«	5	1	1	1	1	1	»permanent«	»dauerhaft«
30	3	»Orientierung«	»orientation«	3	1	2	1	4	5	»notification«	»Meldung«
31	3	»Multidirektional«	»multi-directional«	3	1	1	2	5	5	»one-directional«	»Unidirektional«
32	3	»prickelnd«	»tingling«	2	3	3	1	4	5	»insipid«	»fad«
33	3	»Musik«	»music«	2	3	3	1	4	5	»noise«	»Rauschen«
34	3	»beweglich«	»movable«	4	3	3	5	2	1	»fidgety«	»hibbelig«
35	3	»schwankend«	»shaky«	3	1	1	2	5	5	»static«	»statisch«
36	3	»motivierend«	»motivating«	3	1	1	2	5	5	»neutral«	»neutral«
37	4	»interaktiv«	»interactive«	4	3	4	4	1	3	»indicating«	»signalisierend«
38	4	»still«	»silent«	3	3	2	4	1	4	»active«	»aktiv«
39	4	»statisch«	»static«	5	4	3	3	2	1	»organic«	»organisch«
40	4	»Frequenz«	»frequency«	1	4	5	3	1	1	»shift«	»Verlagerung«
41	4	»bekannt«	»known«	5	4	4	4	2	1	»unknown«	»unbekannt«
42	4	»nicht fordernd«	»not demanding«	4	4	3	3	4	1	»demanding«	»fordernd«
43	4	»gezielt«	»purposeful«	5	4	4	3	1	1	»needs empathy«	»einfühlungsbedürftig«

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TABLE 14 – *Continued from previous page.*

Construct No.	Participant No.	1 – German (orig.)	1 – English (transl.)	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	5 – English (transl.)	5 – German (orig.)
44	4	»benutzbar«	»usable«	4	3	4	2	1	4	»perceptible«	»spürbar«
45	4	»spaßig«	»fun«	1	2	3	3	4	5	»ordinary«	»ordinär«
46	4	»mitbekommbar«	»noticeable«	1	4	4	2	5	2	»easy to miss«	»verpassbar«
47	4	»diskret«	»discreet«	4	2	2	3	1	3	»indiscreet«	»indiskret«
48	4	»in 1-2 Jahren«	»in 1-2 years«	5	3	3	2	1	1	»in 5 years«	»in 5 Jahren«
49	4	»bestimmt«	»certain«	5	3	4	3	1	2	»uncertain«	»unbestimmt«
50	5	»bewegend«	»moving«	2	2	4	3	5	3	»calm«	»ruhig«
51	5	»gerichtet«	»directed«	4	2	1	2	5	5	»aimless«	»ungerichtet«
52	5	»aktiv«	»active«	1	1	2	2	5	2	»passive«	»passiv«
53	5	»weich«	»soft«	1	3	3	4	5	5	»hard«	»hart«
54	5	»einfaches Verständnis«	»easy to understand«	1	1	1	2	5	1	»knowledge required«	»Wissen erforderlich«
55	5	»Formveränderung«	»shape change«	1	1	3	4	5	4	»static«	»statisch«
56	5	»assoziationsreich«	»many associations«	1	1	3	4	5	5	»no associations«	»assoziatonslos«
57	5	»subtil«	»subtle«	4	4	2	1	1	5	»captivating«	»auffällig«
58	5	»Verhalten kuschlig«	»behaviour cuddly«	1	2	3	3	5	5	»behaviour hard«	»Verhalten hart«
59	5	»Informationsgehalt vielseitig«	»versatile information«	3	2	2	2	4	5	»specific information«	»Informationsgehalt einseitig«
60	5	»geschwätzig«	»talkative«	2	2	3	3	5	4	»silent«	»still«
61	5	»zappelig«	»fidgety«	2	1	3	4	5	3	»lazy«	»faul«
62	5	»Beschleunigung langsam«	»gradual acceleration«	2	2	2	4	5	5	»sharp acceleration«	»Beschleunigung schnell«
63	5	»niedlich«	»cute«	1	2	4	4	5	5	»uninteresting«	»uninteressant«
64	5	»erwecken Lust zum Anfassen«	»desire to touch it«	1	2	5	4	5	5	»no desire to touch it«	»erwecken keine Lust zum Anfassen«
65	5	»lebendig«	»alive«	1	2	4	5	5	5	»machine-like«	»maschinell«

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TABLE 14 – *Continued from previous page.*

Construct No.	Participant No.	1 – German (orig.)	1 – English (transl.)	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	5 – English (transl.)	5 – German (orig.)
66	5	»emotionserweckend«	»arouses emotion«	1	2	4	4	4	5	»emotionless«	»emotionslos«
67	5	»unaufdringlich«	»not insistent«	4	4	3	2	1	5	»insistent«	»aufdringlich«
68	6	»keine Nutzeraktivität«	»no user activity«	4	5	3	2	3	1	»user activity«	»Nutzeraktivität«
69	6	»bewegungsintensiv«	»motion-intense«	1	2	3	4	4	5	»little motion intensity«	»wenig bewegungsintensiv«
70	6	»Nutzeraktivität möglich«	»user activity possible«	1	2	3	2	2	4	»user activity impossible«	»Nutzeraktivität unmöglich«
71	6	»lebensähnlich«	»life-like«	1	2	4	3	3	4	»dead«	»tot«
72	6	»bewegt«	»moved«	2	2	2	3	4	4	»no motion«	»keine Bewegung«
73	6	3D«	»three-dimensional«	2	1	4	5	5	5	»two-dimensional«	2D«
74	6	»vielfältig«	»diverse«	2	1	3	4	4	4	»limited«	»eingeschränkt«
75	6	»selbstständig«	»individual«	2	1	3	2	5	4	»dependent«	»unselbstständig«
76	6	»Bewegung flexibel«	»movement flexible«	2	1	3	4	4	5	»movement inflexible«	»Bewegung unflexibel«
77	6	»gehorsam«	»obedient«	1	2	3	3	2	4	»disobedient«	»störrisch«
78	6	»filigran«	»filigree«	2	2	5	2	2	3	»compact«	»kompakt«
79	6	»fleißig«	»diligent«	1	1	2	3	5	4	»lazy«	»faul«
80	6	»ruhig«	»calm«	5	4	2	4	1	4	»fidgety«	»kribbelig«
81	7	»flexibel«	»flexible«	3	1	2	2	4	5	»static«	»statisch«
82	7	»Verhalten lebendig«	»behaviour alive«	4	1	3	2	4	5	»behavior passive«	»Verhalten passiv«
83	7	»experimentell«	»experimental«	1	1	2	3	4	5	»conventional«	»konventionell«
84	7	»vieldimensional«	»multi-dimensional«	5	1	1	1	4	5	»one-dimensional«	»eindimensional«
85	7	»zeigend«	»pointing«	3	1	1	1	4	5	»not pointing«	»nicht zeigend«
86	7	»technisch«	»technical«	5	1	5	1	3	3	»biological«	»biologisch«
87	7	»spannend«	»exciting«	1	1	1	1	5	5	»boring«	»langweilig«

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TABLE 14 – *Continued from previous page.*

Construct No.	Participant No.	1 – German (orig.)	1 – English (transl.)	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	5 – English (transl.)	5 – German (orig.)
88	7	»komplex«	»complex«	1	1	1	1	5	5	»simple«	»einfach«
89	7	»interessant«	»interesting«	1	5	2	2	1	5	»uninteresting«	»uninteressant«
90	7	»spielerisch«	»playful«	3	1	1	1	5	3	»work«	»Arbeit«
91	7	»hosentaschen-freundlich«	»pocket-friendly«	5	5	3	3	1	1	»pocket-unfriendly«	»hosentaschen-unfreundlich«
92	7	»kommunikativ«	»communicative«	3	2	2	2	3	4	»uncommunicative«	»unkommunikativ«
93	7	»erwachsen«	»adult«	2	1	3	2	5	5	»youthful«	»jugendlich«
94	8	»mechanisch«	»mechanical«	1	2	3	4	4	5	»organic«	»organisch«
95	8	»permanent«	»permanent«	1	1	2	3	4	5	»temporary«	»kurzzeitig«
96	8	»aktiv«	»active«	5	4	2	3	1	4	»passive«	»passiv«
97	8	»muss ich nicht rausholen«	»no need to pull it out«	1	2	5	4	2	3	»need to pull it out«	»muss ich rausholen«
98	8	»Form«	»form«	2	1	4	5	3	3	»position«	»Lage«
99	8	»insistierend«	»insisting«	1	2	3	2	4	5	»easy to miss«	»verpassbar«
100	8	»tot«	»dead«	5	4	3	4	2	1	»alive«	»lebendig«
101	8	»diskret«	»discreet«	5	4	3	4	1	1	»insisting«	»aufdringlich«
102	8	»cool«	»cool«	1	2	3	4	2	5	»not cool«	»uncool«
103	8	»deutlich«	»clear«	1	2	5	3	4	2	»unclear«	»undeutlich«
104	9	»fest«	»firm«	5	5	3	4	1	1	»changeable«	»veränderbar«
105	9	»direktional«	»directional«	5	3	1	1	4	5	»undirected«	»indirektional«
106	9	»fein«	»fine«	4	5	5	2	1	3	»massive«	»massiv«
107	9	»natürlich«	»natural«	4	4	4	1	1	2	»unnatural«	»unnatürlich«
108	9	»abgekapselt«	»encapsulated«	4	5	1	2	1	1	»comes out«	»kommt nach draußen«
109	9	»stark«	»strong«	2	1	2	4	4	5	»weak«	»schwach«

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TABLE 14 – *Continued from previous page.*

Construct No.	Participant No.	1 – German (orig.)	1 – English (transl.)	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	5 – English (transl.)	5 – German (orig.)
110	9	»aufmerksam«	»attentive«	5	4	3	1	2	5	»blunt«	»stumpf«
111	9	»zurückhaltend«	»withdrawn«	5	5	4	3	1	2	»insistent«	»aufdringlich«
112	9	»elegant«	»elegant«	5	4	3	1	1	3	»esoteric«	»esoterisch«
113	9	»Kontrolle«	»control«	5	5	4	2	1	4	»loss of control«	»Kontrollverlust«
114	9	»funktionstüchtig«	»functional«	4	2	5	2	1	2	»ineffective«	»unwirksam«
115	10	»organisch«	»organic«	1	2	4	5	4	5	»technical«	»technisch«
116	10	»praktisch«	»practical«	2	3	2	5	1	1	»impractical«	»unpraktisch«
117	10	»bekannt«	»known«	2	5	3	3	1	1	»unknown«	»fremd«
118	10	»gesteuert«	»controlled«	1	5	1	3	1	2	»uncontrolled«	»unkontrolliert«
119	10	»lebendig«	»alive«	1	1	4	4	5	5	»dead«	»tot«
120	10	»modern«	»modern«	1	3	2	3	2	5	»classic«	»klassisch«
121	10	»vertrauenserweckend«	»trustworthy«	1	5	1	4	2	2	»not trustworthy«	»nicht vertrauenser-weckend«
122	10	»robust«	»robust«	5	4	1	3	2	1	»fragile«	»fragil«
123	10	»intelligent«	»intelligent«	1	4	2	4	3	5	»dull«	»dumm«
124	10	»ruhig«	»calm«	1	5	3	4	2	4	»excited«	»aufgeregt«
125	10	»bedacht«	»thoughtful«	1	3	2	4	2	3	»rash«	»unüberlegt«
126	11	»störend«	»disturbing«	1	2	4	2	3	5	»not disturbing«	»nicht störend«
127	11	»rational«	»rational«	5	5	5	4	3	1	»fanciful«	»verspielt«
128	11	»häufiger Gebrauch«	»frequent use«	2	4	2	5	5	1	»seldom use«	»seltener Gebrauch«
129	11	»emotional«	»emotional«	1	4	3	3	4	4	»factual«	»sachlich«
130	11	»einfach«	»simple«	2	4	2	4	2	1	»complicated«	»kompliziert«
131	11	»Verbundenheit«	»connectedness«	2	3	1	5	4	1	»disconnectedness«	»Unverbundenheit«
132	11	»situationsbedingt«	»situation-dependent«	5	4	3	1	1	4	»permanent«	»dauerhaft«

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Construct No.	Participant No.	1 – German (orig.)	1 – English (transl.)	*Ambient Life*	*Shape-Changing Mobile*	*Weight-Shifting Mobile*	*Vibration: Navigation*	*Vibration: Content*	*Vibration: Notification*	5 – English (transl.)	5 – German (orig.)
133	11	»cool«	»cool«	1	1	1	4	5	5	»not cool«	»uncool«
134	11	»entspannt«	»relaxed«	5	3	1	4	3	1	»frantic«	»hektisch«
135	11	»pfiffig«	»clever«	1	1	1	2	4	5	»boring«	»langweillig«
136	12	»mehrdimensional«	»multi-dimensional«	2	1	3	4	5	5	»one-dimensional«	»eindimensional«
137	12	»ein/aus«	»on/off«	5	5	4	2	1	1	»process«	»Prozess«
138	12	»beeinflussbar«	»influenceable«	3	2	4	4	1	5	»not influenceable«	»nicht beeinflussbar«
139	12	»definiert«	»defined«	2	5	3	3	1	1	»undefined«	»undefiniert«
140	12	»konkret«	»concrete«	3	5	4	3	1	1	»multi-layered«	»vielschichtig«
141	12	»maschinell«	»machine-like«	5	4	3	3	1	1	»alive«	»lebendig«
142	12	»linienförmige Bewegung«	»linear movement«	4	5	3	2	1	1	»free movement«	»freie Bewegung«
143	12	»reaktiv«	»reactive«	5	3	3	1	5	5	»active«	»aktiv«
144	12	»impulsiv«	»impulsive«	1	1	3	4	5	5	»straightforward«	»geradlinig«
145	12	»verlagernd«	»shifting«	2	1	2	3	5	5	»central«	»zentral«

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Table of Abbreviations

AR	Augmented Reality
BCI	Brain-Computer Interface
CLI	Command-Line Interface
CSCW	Computer-Supported Collaborative Work
DRS	Design Research Society
GUI	Graphical User Interface
HCI	Human-Computer Interaction
IS	Information Systems
NUI	Natural User Interface
PGR	Project-Grounded Research
RBI	Reality-Based Interaction
RGT	Repertory Grid Technique
RTD	Research Through Design
TEI	Tangible, Embedded, and Embodied Interaction
TUI	Tangible User Interface
VR	Virtual Reality

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