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Dear editors, dear reviewers,

Thank you very much for the valuable comments. We have revised the paper to the best of our knowledge. Please see the individual responses below.

@reviewer 1:
We understand the criticism about the technical contribution of the paper. However we believe that we make a significant contribution on a conceptual level.

On one hand the paper provides empiric findings that help to understand displays and display based pervasive applications. We hope that this inspires building new applications/appliances and guides developer in their work.

On the other hand we believe that the description of the methodology used is valuable for researchers and developers in pervasive computing that do human centred research. Even though many issues appear "obvious" or "clear" when reading the paper – our experience shows they are not. With this paper we aim to provide a reference in a - several step method - on how to do such research.

We believe this is an important contribution to move pervasive computing beyond the pure technical level.

@reviewer 2:
We revised the language and additionally got the paper proof-read by an external person. With these changes we hope that the introduction it clearer and easier to read.

@reviewer 3:
We agree that the method is not as strict as typically it is typical in natural science. However we see our contribution at the cross roads of computer science and design. Here we see a great chance to give pervasive computing impact in situation it more into the human space (and in particular into the home).

About the methodology and our background: one of the authors is a designer and the other a computer scientist. It is clear that even within our authoring team we have very different ideas about valid and useful methods. However without the friction between the disciplines we think we will not move user centred pervasive computing forward. We believe this paper shows an approach that bridges the gap – at least to some extent. If one of us would have written the paper alone the method would have been "purer" but in our eyes less helpful to achive useful, usable, and innovative applications and appliances.

Thank you very much for the detailed comments. They have been revised. We also had an external person proof-reading the paper.

Methods and Guidelines for the Design and Development of Domestic Ubiquitous Computing Applications

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Abstract

Bringing ubiquitous computing applications to home environments is a great challenge. In our research we investigate how applications can be conceived, designed, and implemented in a way that they fit into people's lives. We describe our experiments on how methods of user centered design and participatory design can be appropriated to elicit users' requirements and design ideas for ubiquitous computing applications for the home. In particular we report on a study on information presentation using display appliances. In a participatory design process enhanced with technology probes, we individually discussed potential solutions for specific homes with 14 people. Each of the resulting solutions is tailored to suit a single persona. For each of these individual solutions we specified prototypes that would accommodate the user's needs but are generic in its applicability at the same time. Based on this we derived a first set of guidelines for the design of display appliances in the home environment.

Keywords: domestic appliances, displays, user centered design, probes, HCI methods, pervasive computing user interfaces

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1. Introduction

With the emergence of Ubicomp scenarios for everyday life, research has been addressing other environments besides the working place and the desktop environment. This created many new challenges for finding and specifying user requirements [28]. In the last decade, the domestic environment has

become the playground for "smart technology", in which scenarios of context awareness and automation of appliances have been tested in living laboratories [14], [16], [19], [21], [23]. However, the research has had little impact on ordinary homes and the use of ubiquitous computing technologies in the home has been marginal so far.

Main issues that need to be addressed include whether users accept the system, how their privacy and trust concerns are treated as well as how simple it is to control and learn the interface. This has initiated academic research that adopted ethnographic approaches to investigate this domain and look at its social patterns [1], [5], [20]. This research focuses on understanding the users' needs but is often very conservative with regard to technology. In our approach we acknowledge the importance of ethnographic research to elicit users' needs but extend it by the in-situ introduction and discussion of new technology to gather design ideas.

To further explore this approach and to evaluate our methodology, we investigated a specific application domain for ubiquitous computing in the home. We set out with the question: what display technologies are useful and desirable in a home environment? Our participatory design method included the analysis of how people use (mostly non-electronic) displays in their everyday lives. Starting with simple display artifacts, we investigated possible novel display appliances in the domestic environment. Together with the home owners, we discussed potential ubiquitous computing display technologies in the concrete setting of their home environment.

The contribution of the paper is twofold:

- a method and approach for researching on the potential use of ubiquitous computing technologies in the home
- description of a number of design prototypes for domestic display appliances which have been created in a user centered design process

1.1. A taxonomy of domestic display artifacts

In everyday life, people use a great number and variety of display artifacts: calendars, post-its, posters and pictures. Display artifacts in home environments have many different forms, ranging from paper displays to objects that people make visible to themselves or others by putting them in a specific place. Displays serve various purposes such as externalization of memory (reminders of actions to take, awareness of important dates), expression of personality and social relationships (pictures of relatives, trips, souvenirs), or as media of communication to other inhabitants of the house. In our analysis we distinguish five types of display artifacts:

- reminder for future actions (e.g. a post-it, a shopping list)
- reminder of past events (e.g. tickets of a past concert, pictures of a trip)
- awareness media (e.g. a calendar, a clock, the transportation timetable)
- communication media (e.g. a message on a board, a post-it on a door)
- decorative (e.g. a poster, a sculpture, a puppet)

Employing such a categorization responds to the goal of understanding why and how people tend to favour some kind of displays over others. Understanding their choices can help to identify contexts where technology and additional information makes sense in the house. The idea is not to substitute existing displays or translating them into digital formats, but rather to augment and support display based activities and to generate ideas for novel display appliances. For this reason, the involvement of potential users in the design activity and their engagement with physical prototypes in a contextualized situation (in the familiarity of their own homes) becomes essential for the purpose of letting people figure out possible scenarios of domestic ubiquitous computing technology.

2. Related work

As our contribution touches methodology as well as displays in the home, we present work related to each of those areas. However, much work related to displays also reflects on methodologies used by the researchers.

2.1. Approaches to the design of Ubicomp applications

Ubicomp is inherently connected to applications. Hence research in this area is most often related to application domains or specific applications. Weiser's initial work in Ubicomp research [29] can be categorized as driven by technology. Systems were developed and built around a vision of available (or soon to be available) technologies. One particular focus was on solving hard engineering problems. The method of technology-driven research has been continuously employed till today and has produced many interesting prototypes and products (e.g., in handheld computing and mobile communication). Looking at intelligent home installations (e.g. [14], [16], [19], [21], [23]) this technology-driven approach can be observed, too. Tackling engineering problems, developing useful system architectures and making applications robust and usable is often a first step before pushing new technologies further into everyday life. However when concerned with complex multi-purpose environments such as the home, a pure technology-driven approach is not enough as it does not consider how people like to organize their real lives. In contrast to work environments where measurements can be made on productivity and efficiency these metrics do only partly apply in people's homes. Many other issues related to aesthetics, style, personal likes and dislikes play a major role. Additionally, as people often share the environment where they live (e.g., shared houses, families, couples) it is also a collaborative environment where certain rules and roles have been established.

The method of ethnographic studies for domestic environments is discussed in [10]. In the context of IT, ethnomethodology (or ethnography, as the approach is usually referred to) has been traditionally

applied in the CSCW research area to give background for the design of solutions for the social organization of work. It is a method of the social sciences dealing with the recognition and analysis of workflows, communication and layout of social spaces adopted to elicit requirements for the development of new computing systems. Early applications of such a methodology in the domestic environment [20] suggest that "small integrated computational appliances, supporting multiple collocated users throughout the home, is a more appropriate domestic technology than the monolithic PC". Moreover, ethnographic studies reveal that people do not live in random settings and that they have a personal understanding of how to organize their home environments. They use this for collaboration and communication in their daily lives [9].

A different approach to researching the home is given by cultural probes [13]. This methodology was developed and applied in the discipline of design research and is based on the use of open artifacts that explore the aesthetic and cultural implications of technology in everyday life. Such an approach is therefore not meant to collect and analyse precise data to gather user requirements; it rather relies on the subjective interpretation of users' expression of preferences and ideas and is meant to gain an inspiration about how to design for new experiences.

Bringing new technology into an established home setting is not trivial. In [3], researchers investigated how people would install sensors in their environments. One finding of their research was that people cared very much about their established aesthetics of their environments as this reflects their personalities (for themselves and even more for visitors). One lesson to be learned is that people need to participate in the creation and control of technology for the home to minimize the risk of building a system that nobody would ever use.

2.2. Displays at Home

The social construction of displays has been the focus of ethnographic studies [9] that mostly concentrate on what we call "communication media", i.e. displays that are used to communicate with one

another and to coordinate actions (named "coordinate displays" in [8]). In analogy to this work, Harper and Shatwell investigate the interactional properties of paper mail in households, sustaining its affordances and important impact on social patterns [17]. Our investigation also embraces other kinds of displays, such as decorative and awareness ones.

Perry and O'Hara have investigated the use of displays in the workplace [22]. In comparison to the working place, the domestic walls reflect much more closely the lifestyle of the inhabitants and become an expression of their personality and intimacy. The decision of what to put where, what to make easily visible for themselves and what to display for others, is highly dependent on the way people deal with information and affective media. This suggests that the location of embedded technology needs to rely on the social and spatial patterns of the house. Furthermore, the aesthetic appearance of such media and the relation to them (whether they are gifts, or memories) affects people's choices of where to put them. This implies that the design of home appliances needs to cope with the challenge to suit different people's aesthetic values and information management.

Our approach is more concrete in terms of novel technologies. Our aim is to find specific uses of technologies that are compatible with everyday life and welcome in a domestic environment. We extend the methods used by technology probes [18] that engage people with new display artifacts.

3. Researching domestic environments: tools and methodology

For this study we adopted a multi-techniques investigation which combines the methods of contextual inquiry [2], cultural probes [13], technology probes [18], scenarios-based participatory design and interviews in a qualitative research approach. This combination of techniques is extended by the use of functional technology probes to engage the user with potential solutions. The goal is to identify and interpret the attitude and the emotional aspects of users' behaviors in the house, to investigate how

people think about communication in the domestic environment as well as to see what motivates, drives and pleases them.

In summary, the following steps are pursued:

- *Step 1*: Technology research: to get an understanding of potential technologies, their advantages and limitations as well as typical application areas
- *Step 2*: Interview in the home environment: to get explanations why people organize their environment in the way they do it; to describe the environment systematically with respect to the technologies investigated
- *Step 3*: Cultural probes: to investigate how people deal with certain objects, spaces, places, in their domestic environment. The focus is on artifacts that relate to the technologies that are investigated
- *Step 4*: Technology probes: to inspire discussion by presenting working technology prototypes in the situation of the users home
- *Step 5*: Educate the user on technologies: to give the user a quick and easy understanding and overview of potential technologies that are available; this needs to be in a language the user understands and should also communicate pros and cons, as well as trade-offs of certain technologies
- *Step 6*: Participatory design session: to sketch and design a specific persona focused technology the users would like to have for their environment
- *Step 7*: Creating prototypes from person inspired designs: to identify generic technology artifacts or platforms for the home based on the specific user driven sketches from step 6

In the remainder of this section, the individual steps are discussed with respect to the experiment that was carried out. Here we use the domain of displays for the home as an example of how this process can be applied.

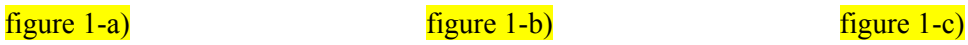

Fig. 1. Different types and technologies of displays are investigated. Figure a) shows a steerable projector for projection based interfaces; b) shows a tablet PC with touch screen technology embedded in the kitchen environment; c) shows a small wirelessly connected LCD display. Such displays provide different potential solutions and affordances for domestic displays.

3.1. Technology research

Before stating the research of potential uses of displays in a domestic context, we made an attempt to understand a wide variety of alternative display technologies. Knowing what types of technologies are available, what constraints are inherent in a technology, and how technologies can be embedded became central when discussing possible uses of displays in an environment. In particular, we looked into projection based displays (steerable projection), Thin Film Transistor (TFT) displays of various sizes, small Liquid Crystal Display (LCD) and monochrome and minimalist information displays (e.g., a Light Emitting Diode, LED, or a light as a reminder), see Fig. 1. Additionally, we researched the current state and development for interacting with displays, such as touch screens, camera-based interaction, gestures and various sensor-based input mechanisms. We also extended our technology research to auditory and ambient displays.

Altogether, we looked at what is commercially available and what has been suggested and demonstrated in the research community [11]. Building prototypes based on different technologies in our lab and experiencing these technologies ourselves were essential to understand them and get insight into possible limitations.

3.2. Contextual inquiries

We conducted in-depth interviews with individuals at their homes. More details concerning the sample of users and format of the interviews are provided in Section 4. The interviews took place according to a pre-defined format encompassing different phases which provided a coherent framework for comparison of results but still allowed freedom for brainstorming together with the interviewees. In a first step, an exploratory inquiry of the household and of its display environment in particular took place. In this phase, we were guided through the rooms and took pictures of display artifacts which we noticed on different surfaces and inquired about their purpose.

This inquiry is the basis to map which context could be augmented with what type of embedded technology for different people. For all artifacts we discussed with their users about the motivation of their location, the lifetime of such displays, whether they would be moved around in the house, taken outside the house, or would eventually be thrown away. Additionally, we asked questions concerning the wish to update, replicate or remotely access this kind of information. In figure 2, different kinds of domestic displays are shown.

3.3. Cultural Probes

In a second phase, the interviewees were confronted with physical objects, which we contextualized in a brief narrative: several postcards, a very small picture (3cm x 4cm) of a past social event, a reminder to pay a bill, a picture sent by someone met on vacation (with and without frame), a fluffy rabbit and a snowball. We investigated where people hold certain kind of information and in particular whether it belongs to private spheres (or, as Goffman describes, “back regions” [15]) or rather to public ones (“front regions”). Our questions also aimed at identifying what factors mostly affect this placement like, e.g., the relationship to the sender, the aesthetics of the artifact, its size, its quality. We also asked users whether they would like to replicate these artifacts, edit them, scale them, or reproduce them in digital format.

3.4. Technology Probes

The introduction of technology probes was motivated by obstacles we encountered in our previous research when discussing potential uses of technology. Such a methodology has already been used in [18] in a similar domain to stimulate people's creativity and inspire ideas for new technology in the domestic environment. In comparison to such work, our probes were less finalized in terms of casing and hardware design, as they were built to show the possible functionalities. This choice was motivated by the intention to avoid that people concentrate on the look of the probe, but rather to stimulate their imagination in terms of scenarios for the use of such technology. By presenting unfinished but working prototypes, we felt that users had no hesitation to suggest radical new form factors, usage scenarios, and applications. This is in line with the findings of prototyping in graphical user interfaces [6].

We realized that it can be very hard for people, especially when they do not have a technical background, to engage with abstract descriptions of technologies. The reactions we got can be classified in two main categories:

- *"I am happy with what I have."*

  People were reluctant to engage with the idea of novel technologies in their immediate environment. To them, it seemed too abstract and too distant to make an impact in their daily lives.

- *"I saw that in Star Trek."*

  During the interviews we often recorded ideas which people took from popular science-fiction movies or literature. As the technology did not seem real to them, in the moment of the interview they connected it to science-fiction and did not actually relate it to their everyday lives.

With technology probes, we engaged people with a specific but concrete and tangible piece of technology. People could try it out and see it is real – although it is a prototype: thus, they can relate it to potential uses in their environments. We saw that by using technology probes people really put the idea of a new technology in relation to their everyday life. In our research, we experienced that functional

prototypes, even if not perfect (in technology and appearance), engage people much more than paper prototypes or sole descriptions of technologies. We also noticed in this experiment and in previous projects (e.g., [24]) using this technique, that people accept the fact that prototypes are not fully working and that they have limitations.

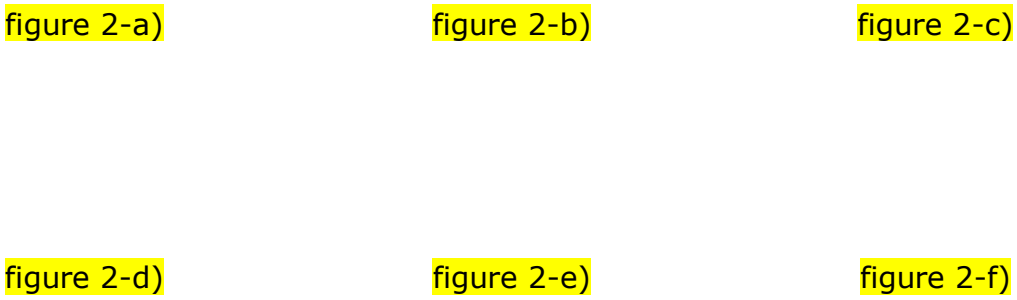

Fig. 2. Different display artifacts were discussed and documented in the visited homes. It is to be noted that people embed such artifacts in their physical environment: e.g., on the bookshelf as shown in picture c); on the door as shown in picture d); on the fridge as shown in picture e). Even though the location of such artifacts corresponds to individual spatial semantics, displays are mostly hybrid; i.e., in the same area decorative, reminder and communication displays can be found. For example, picture f) shows a communication display that also serves the purpose of reminding scheduled activities; picture a) shows decorative display artifacts, such as the picture of the cat, together with reminders such as a concert ticket.

In this study we introduced the interviewees to our vision of pervasive displays and showed them a pair of small wireless networked displays (black and white LCDs) as an example: a prototype of such displays is shown in figure 1, c). Users were invited to play with the connected displays and to think about possible scenarios of use.

3.5. Educating the user

Beyond the technology probes, we gave a quick overview of potential further technologies for the home. The persons were encouraged to imagine what kind of information could be displayed and dynamically updated. Additionally, we suggested that they should imagine applications if they had a large number of such displays, in the order of 20 or more.

With the use of technology probes and with the additional explanation we provided, we aimed to demonstrate the following issues:

- displays can be of any size and resolution
- displays artifacts can be wirelessly connected
- displays artifacts can detect and communicate interaction
- displays can be embedded into various objects and environments of everyday life

We used simple applications or application examples for demonstrating the functionality of the hardware in a very easy-to-understand way. All our participants understood the concept of the application. It is indeed essential for the technology probes that participants can understand them quickly and easily.

3.6. Participatory design sessions

The involvement of potential users in the design of domestic appliances was motivated by two main factors:

- Domestic environments are a very personal and private domain in which external assumptions of technology acceptance and use might result erroneous. Getting users' insights and ideas of domestic appliances would allow us to gather a picture of how people envision technology in their environments.

- The way people decorate their households and handle communication in the home is very diverse. This suggests that different people have different needs: in order to get a heterogeneous spectrum of design alternatives, the involvement of different individuals facilitates the design of different appliances.

In the participatory design sessions, people were stimulated to think about possible contexts of displays. They were asked what kind of information they would like to have where and when. In particular, we concentrated on four different scenarios belonging to four different regions of the house and are mapped to different routine activities:

- alarm clock display (e.g., when waking up or going to sleep)
- bathroom mirror display (e.g., while brushing their teeth)
- kitchen displays (e.g., while cooking)
- wardrobe display (e.g., when choosing clothes)

The open, informal discussions were meant to collect ideas as well as to get an overall picture of the individuals and their environments. By starting with very specific display settings, people could envision such displays very easily and express their excitement or concerns. This was done to identify some persona or user profile for which we would develop a design.

3.7. Creating prototypes from persona-inspired designs

Designs for an individual provide an interesting insight in what individuals would like to have. However it seems economically not yet realistic to build individual information appliances that suit exactly one person. When creating prototypes we searched in particular for similarities between design ideas, or for apparent connections between individual designs. The aim in creating the prototypes was to find abstractions that are valid across a set of individual designs and that match a set of requirements gathered. This is useful to understand a specific environment and hence helps to understand the desired

properties of potential appliance platforms. For each of the individual design ideas, we analyzed a potential technical realization and identified the following issues:

- potential hardware platforms (processing, communication and interaction)
- potential system software required
- content provided and information handled

These results provided us with a basis for creating prototypes of novel display artifacts that could accommodate the needs of various scenarios.

4. Experiment set-up

The interviews were conducted by two researchers in interviewees' homes and would normally take place around the kitchen table. A typical interview was scheduled to last about 60-80 minutes. The session would start with a brief introduction to the aim of the research and to the envisioned pervasive availability of displays into everyday life. In the initial explorative phase, existing display artifacts were observed in the environments, according to our display taxonomy (see Section 1.1.): we took pictures of such displays and formulated questions regarding motivation, lifetime and personal meaning related to them. The interviewers would take notes of the answers and ideas using a prepared questionnaire that served as track. The track consists of the following different phases, according to our methodological approach as outlined above:

- introduction of the study
- exploratory phase of display artifacts
- presentation of the cultural probes and related questions
- introduction of the vision of display technology in everyday life
- introduction of technology probes
- participatory design discussion about four different scenarios

Additionally, we collected socio-demographic data and interviewed people about their time management (e.g., how they manage their appointments and what calendars they use) and their electronic communication habits (e.g., their use and archiving of text and multimedia messages (SMS and MMS), e-mail, use of present systems and instant messaging).

The interview was carried out in a major European city. In total, 14 people took part, seven women and seven men in the age from 23 to 44. The participants had diverse academic and professional backgrounds (e.g., a computer science student, video editor, social worker, land surveyor, physics engineer). The technology equipment and computer literacy was heterogeneous (some had high speed internet, most had a PC, one person did not use a computer or a mobile phone). We visited six households, three flats that were shared by two people, two flats that were shared by three people and one flat that was shared by six people.

It is implicit in such an approach that small samples of users may not be representative of the whole complexity and diversity of attitudes: nor can an "average" be extracted. Our assumption, though, is that each individual may present attitudes that represent a segment of the population. To this respect, these results should be considered as suggestive and provocative for design, instead of definitive and valid for a general "average user" that is actually does not exist.

5. New ideas for display appliances

The experiment provided us with many insights about how people deal with displays in their home environment. During the discussion with people we got various design ideas that would fit an individual. Some of them are described in the next subsection. Generalizing these ideas, we show two prototype designs that are useful and can be customized to accommodate the persona-based design suggested above.

5.1. Persona-inspired design ideas

The use of personas in design is an established goal-directed technique [7]: the main account of such a design approach is that a "general user" does not exist. Rather, the detailed identification of a target audience and the distinction of different profiles can effectively support the design activity. In these terms, personas describe the goals and activities of archetypical users. Our interviews allowed us to sketch some primary personas that would drive our design and prototyping activity.

Given the number of people interviewed, we collected a large list of persona-based design ideas. The following list shows a selection of ideas for digital displays:

- A picture frame that periodically displays different postcards and a box that captures the postcards
- A weather display, in particular for rain probability, in the hallway
- An alarm clock that provides information about the schedule of the next day
- A fixed display in the bathroom that shows the screen of the mobile phone
- Dynamic news overview displayed onto the bathroom mirror
- A mirror that remembers what one has worn on a certain date or occasion
- A mirror that allows freezing an image to have a closer look
- A display in a wardrobe that gives suggestions about what to wear in combination, after the user has picked one item she wants to wear
- A display on the wardrobe that provides information on how to make a tie knot
- A remotely accessible shared display for notices on the kitchen door
- A display in the kitchen that can provide any type of information (television, web, video, chat, cooking instructions) at a spot that is always in the vicinity of the user

For each design idea we had an extended discussion with the users about what the appliance should do, what properties it should have and what properties it must not have. In particular, we were interested in how people would like to see it embedded in the environment or artifact, how people would like to

interact with it (implicitly or explicitly) and how much control over function and content they would like to have.

5.2. Towards prototypes

The persona-inspired design ideas provided us with a selection of display artifacts people could imagine in their environments. By seeing the place where people imagine such displays and by discussing with them the type of interaction, we understood constraints that matter for potential users. Based on these collected ideas and on the constraints observed, we specified prototypes of display artifacts for the home. Each prototype combines input from several of the generated ideas. The goal of these prototypes is to understand potential display platforms for domestic use. In the following sections, we present a selection of those prototypes.

5.2.1. Networked alarm clock with information display. Information access without effort was crucial in many design ideas. Just accessing information without the need of explicit interaction, or accessing information embedded into an interaction flow that is done anyway seemed to be central requirements. For most people in our study, the first information display they interact with in the morning is their alarm clock; similarly, for many people this is also the display they interact with when going to bed. Hence, as people already use its display function, several interviewees suggested to enhance the display capabilities of the alarm clock. Their suggestions for information content varied widely and included birthdays, personal or partners' schedule, weather forecast, news headlines and personal health information. A prototype resulting from such suggestions is described in [27].

In the user group we investigated, more than half did not share the flat with their partner. For them, sharing time-related (or ritual-related) information was a further central concern. People reported to send short text messages or to phone their partner when they go to bed or in the morning when they get up.

The data communicated was very much related to provide information on presence. Hence, using the alarm clock as a medium to communicate presence was suggested.

Others suggested extending this function beyond their partner to friends and family. Sharing information when going to bed and when getting up did not seem to be a concern. It was, however, central that this information was not automatically sensed but set by a gesture, such as switching on the alarm function in the alarm clock when going to bed. On top of such information, it was suggested to visualize who of your friends is already up and who is still sleeping directly on the alarm clock. Users suggested that this may enhance communication as well as it may foster a closer relationship between people. Collaborative functions such as "wake me up when most of my friends are up" were suggested, too.

Technically, such a platform would consist of the alarm clock extended with a small general information display and communication facilities (e.g., UMTS). The specific type of information that should be displayed and the form in which presence information should be shared and to whom would be customizable.

5.2.2. Enhanced mirror. Most of our participants found that the mirror in the bathroom is an interesting place for accessing information, as it has been suggested by Philips in their Ambient Intelligence project [23]. People spend time there during which further information may be provided. One of our participants reported that he usually goes to the living room to have a quick look at the morning news on TV while brushing his teeth. In his case, having headline news somewhere on the mirror was the obvious thing he suggested. Mirrors in other rooms were also suggested to be enhanced with display technology, in particular the bedroom or wardrobe mirror. Information that people would like to have on a display embedded into (or next to) the bathroom mirror includes upcoming birthdays and appointments, schedule information, different types of news, short entertainment (e.g., riddles to wake up and "get the brain

started") as well as tutorial information (e.g., how to make a specific tie knot). All our participants agreed that it was central that, if the mirror is enhanced, its basic functionality should still be available without any effort. Additionally, it was seen as a general agreement that the need for interaction should be minimal or the system should even work without any explicit interaction at all.

"Capture" and "display" were additional functionalities to allow visualizing spots that would otherwise be invisible from a frontal perspective. People suggested for example that the mirror could freeze an image (e.g., of a spot behind the ear) and provide this as a still image for closer inspection. Similarly, people suggested that seeing yourself from behind (especially your hair) is difficult and hence a capture and display function would make this easier. In the context of the wardrobe mirror, a similar functionality was proposed. A mirror that remembers what one was wearing at a specific day so that it would become possible to remember "what I wore last time I was out with the other person".

A technical solution that could accommodate these requirements is a mirror that includes a large display, a camera and a simple interface (people suggested gestures or audio commands; the idea of a touch screen was not welcome). Additionally, the system has to have network access and the ability to store images with contextual information (e.g., person and time).

Interestingly enough, the possible solutions envisioned by the interviewees were in line with the scenarios of Ambient Intelligence in the home presented by Philips Research in [23]. However, several features envisioned by the users go much beyond the research presented.

6. Lessons learned and discussion

A main challenge in understanding what kind of emerging services and technologies users need and what they are willing to accept is that users usually do not know the technological possibilities: what they believe is possible is limited by what works for them and their particular knowledge of today's technology.

6.1. On methodology

The presentation of physical prototypes, contextualized in the possible scenarios of everyday life activities that we suggested (e.g. “when you wake up”, “when you brush your teeth”), was particularly useful for generating design ideas and for understanding the user profile. Indeed, people find it easier to relate to the task-oriented nature of the scenarios, rather than to the abstract and often function-oriented nature of a system specification. The combination of the two, scenarios of everyday life and tangible previews of future technology, proved to be a powerful method to stimulate their creativity. When embedding analogue and physical display artifacts in their homes, people are usually not concerned about overload of information and intrusion, in contrast to when they deal with digital information. Using the technology probes, people were less worried about technologies invading their homes and seemed to be able to envision how to get hold of technology in a more personal way. It appeared that having a concrete example of technology reduced the fear of the unknown.

When looking at the results of qualitative research, it has to be kept in mind that these results are not numerical. Thus, they are not statistically reliable: they are more interpretatable and therefore strongly depend on the researchers’ empathy with the users. To this respect, it was our goal to create an informal atmosphere that stimulates people to share the stories behind the artifacts in their homes and to elaborate on the social relationships that might justify certain displays. This engages their creativity and facilitates their expression of personality.

In the later interviews, we added, at the end of the enquiry, a phase where we suggested ideas generated in previous interviews and asked people about their opinions on them. It was interesting to see how people reiterate on previous ideas and add their own requirements. For us, these discussions and especially seeing a certain convergence on specific technology requirements were helpful when working towards prototypes.

We also got feedback from people we met in the following weeks without having asked them. It seemed that some interviewees had not stopped thinking of potential display technologies and came up

with more ideas that they wanted to communicate to us. From this experience, it could be interesting to let people have the technology probes for a few days to get more feedback on potential uses.

6.2. On display artifacts in the home

In nearly all interviews, several ideas emerged revealing that people found that additional display technologies could enrich and ease their daily private life. However, across all interviews in our study, it seemed that people manage their daily life very well and that there is no immediate and obvious need to improve their "productivity". The augmentation with novel display artifacts was mostly meant to make the access to information and communication applications more engaging and playful. Our study showed that in many cases the lucid and playful elements, as suggested in [12], are central to the life of people.

In our study, efficiency was only a secondary concern: for most people their major issues were that an application must fit their lifestyles, their aesthetic values and it must be compatible with their social life. Examples concerned with increased productivity in the home as presented in many ubiquitous computing scenarios (automated shopping list, to-do list, time and calendar management) did not have a great appeal to our participants. This is in line with studies on the economics of the house [4] reporting that entertainment appliances such as radio and television have diffused much faster than household and kitchen machines.

In all our discussions, we could observe that people see a trade-off between having full control on the one side and automatic behavior with minimal interaction on the other. Overall, it appeared that people would like to have display artifacts that require minimal interaction in normal operation, but allow full control by the user (e.g., to switch it off completely).

Besides using display artifacts for information access, central application domains were social communication and sharing information. In many of these cases (e.g., sending a text message to the boyfriend "I am going to bed") it appears that not the information itself is central, but rather the fact of

being connected. Similarly, it seemed that there is a social function in some types of information access (e.g., calling one's mother and asking her for a recipe instead of looking it up).

With relation to aesthetics, people imagined interwoven solutions where technologies are part of their environment and not added to the environment. Overall, it appears that locations in the domestic environment are central for the information and communication requirements. Locations trigger functions, both for access of information and for initiation of communication.

7. Conclusion: Towards design guidelines for display artifacts

Based on the small group that we studied, we concluded a number of design guidelines that can help to create novel display artifacts for domestic environments.

7.1. Embedding information where and when it is useful

It is central to provide the information in a way that the user can benefit from it. Most conventional displays we saw serve that purpose. Often, the advantage is minimal (e.g., it is only useful once a month) but without providing an advantage it would not be there. We distinguish two basic functions of embedded information: to inform and to please (in some cases both functions are combined).

Usually, information to inform should be embedded at points where decisions are made, or where people have choices (e.g., at the key table when someone decides on the mode of transport). The information provided should increase people's ability to make informed choices.

Information and displays with the primary function of pleasing the user are more individual and often have the function of providing a reference for remembering some person or event. For these types of displays, we found that aesthetics are as important as content. This should be reflected in the design.

As the place and time where the provision of information is most useful may change, such designs should be aware of their users and of the dynamic environment. Simple context information such as "the person is not alone" or "the person is about to leave" can enhance the usefulness of a display artifact.

Making displays context-aware can offer great potential: however, from our study, we recommend to use this very carefully as it renders the conceptual model and the "predictability" of a display artifact more complicated.

7.2. It matters how information is embedded

The information provided should not be forced onto people or their immediate environment. Making displays unobtrusive is a central advice. If possible, it should be embedded in such a way that gives people the desired information without becoming an annoyance. In addition, concepts of ambient media [14] and calm technology are an important basis for the design of embedded information displays.

One further issue is that many spaces are shared and hence not completely private. This has to be taken into account when displaying personal information. In our study, we saw that this is a concern even when partners are sharing a flat. In different cases people suggested that they were happy with abstracted information to be displayed since, using their knowledge about the context, they could fill in the missing parts. Again, designing context-aware display artifacts is an additional possibility.

Another finding is that the "look and feel" matters: for home appliances to be accepted, they need to match with the aesthetic values, lifestyles and information management of the inhabitants of the household. To this end, appliance design for the home has to take into deep consideration tools that are typical of marketing disciplines such as segmentation and user profiles.

7.3. Full control but no interaction required

In the first place, this may seem odd. However, it appeared consistently throughout our investigation. People would like to be in control of the technology they have in their environment, but they do not want necessity to interact with it. Implicit interaction, as suggested in [23], where the system reacts to what the user does in the real world, can be a vision to achieve this. A counter example is a text message received on a mobile phone. Even if you are not interested in the message, you have to press some buttons to get the phone back to the normal state.

For the design of information appliances it is important that there is no action required from the user when information is provided. Such designs will therefore usually require dedicated information displays that are only used for providing a specific type of information.

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Figure 1a
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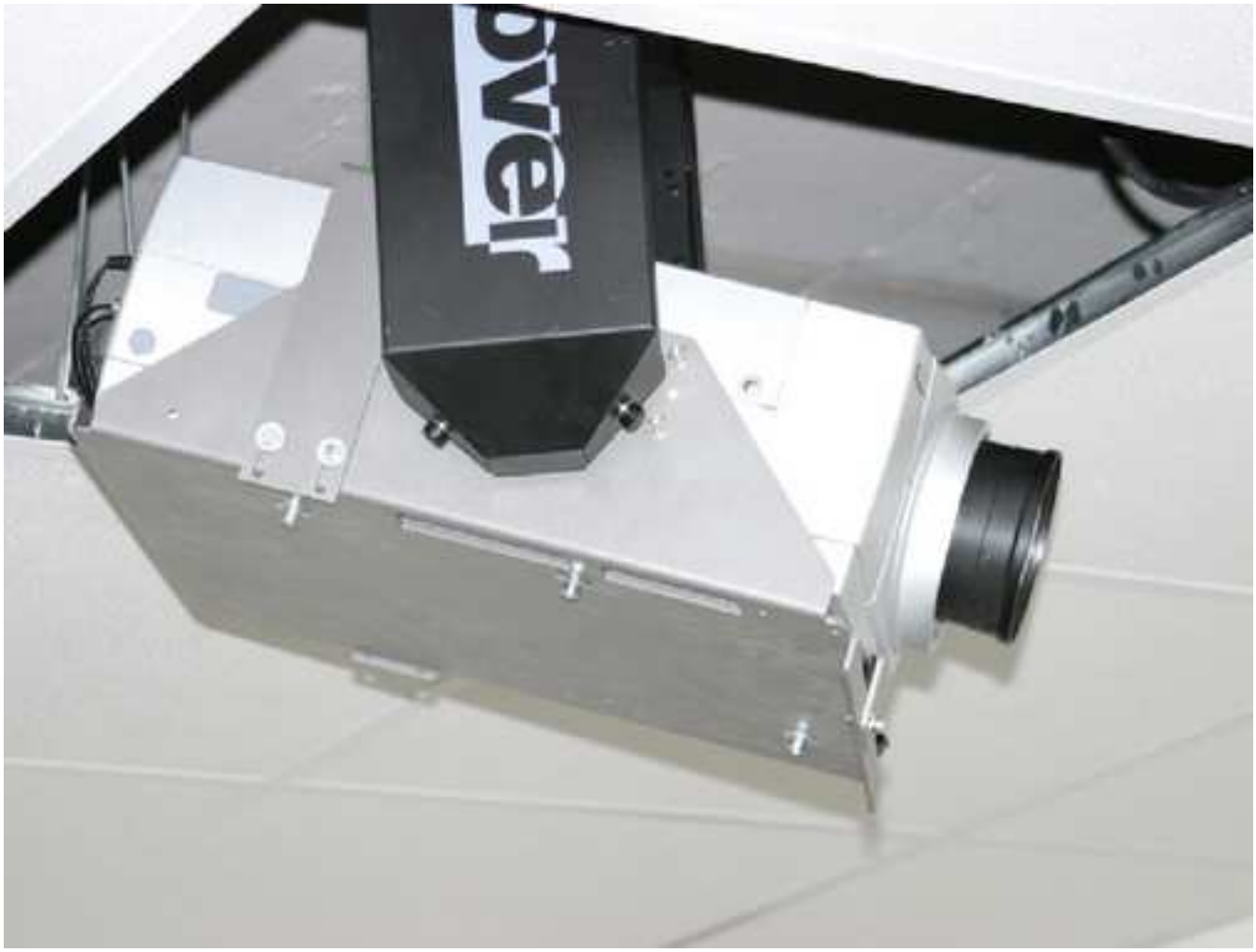

Figure 1b

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Figure 1c

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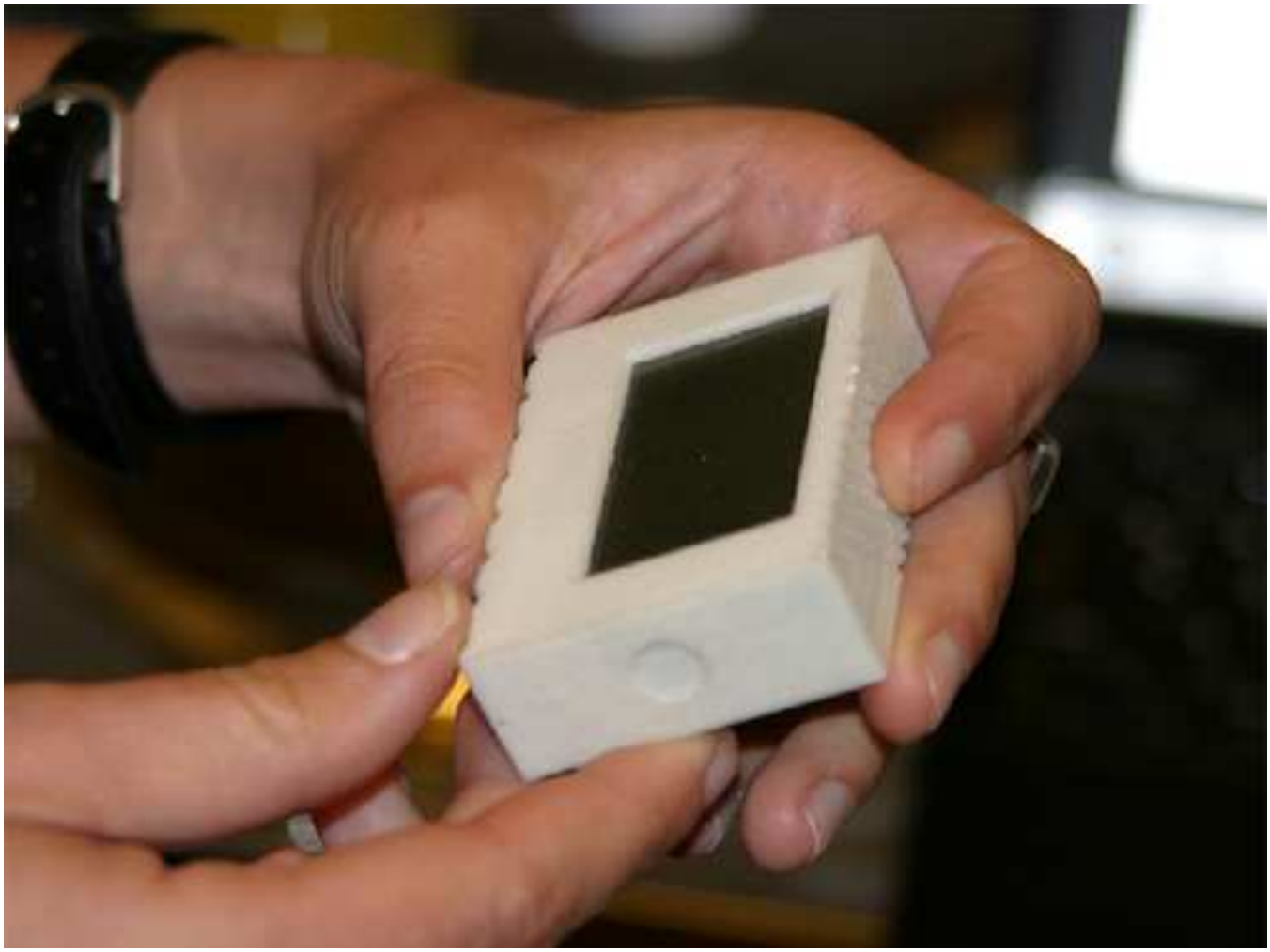

Figure 2a

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Figure 2b

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Short Bios

Albrecht Schmidt holds a joined position between the Fraunhofer Institute for Intelligent Analysis and Information Systems (IAIS) and the University of Bonn. He studied computer science in Ulm and Manchester and afterwards worked as a researcher at the University of Karlsruhe and at Lancaster University. There he completed his PhD thesis on the topic of "Ubiquitous Computing - Computing in Context" in 2003. Before becoming professor at the B-IT-Center, he headed the DFG-funded "Embedded Interaction Research Group" at the Ludwig-Maximilians University in Munich. His teaching and research interests are in media informatics and in particular in the areas of user interface engineering, pervasive computing and mobile interactive systems. Find more information about Prof. Schmidt at http://uie.bit.uni-bonn.de/.

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Paul Holleis is working towards his Ph.D. as full time research assistant at the University of Bonn at the User Interface Engineering group at the Bonn-Aachen International Center for Information Technology (b-it). Beginning of 2007, he transferred with his supervisor Prof. Albrecht Schmidt from the University of Munich (Ludwig-Maximilians-Universität) at the Chair for Media Informatics. Currently he is working as an intern in the User Experience Group at the Nokia Research lab in Helsinki, Finland focusing on wearable and tangible computing. He is a member of the research group "Embedded Interaction" (www.hcilab.org). His research currently focuses on programming paradigms for ubiquitous computing infrastructure, development support and integration of usability metrics and user models in the design process of novel user interfaces. In January 2004, he received his diploma in computer science from the University of Passau, Germany with which he still maintains strong links through several projects and interests in the graph drawing community like the graph toolkit Gravisto. In 2000/01, he spent a year as visiting student at the Department of Computer Science at the University of Edinburgh concentrating on formal methods for software engineering and algorithms in general. More information about him and his research can be found at http://www.hcilab.org/paul.

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