LivingLab: A white paper

P. Markopoulos and G.W.M. Rauterberg
e-mail: p.markopoulos@tue.nl

Abstract

The LivingLab is a planned research infrastructure that is pivotal for user-system interaction research in the next decade. This article presents the concept and outlines a research programme that will be served by this facility. These future plans are motivated by a vision of future developments concerning interaction with intelligent environments.

Introduction

This document is a white paper for the LivingLab, a major research initiative of the Eindhoven University of Technology (TU/e). This paper explains the conception of the LivingLab, related work, its industrial and scientific relevance, and a sketch of the research programme that will be 'housed' in this Lab. To spark the imagination of the reader we include a set of plausible scenarios for this LivingLab.

The purpose of this article is to disseminate our plans and our ideas but, more importantly, to attract interest in this venture from other departments of the TU/e and from related industries. We view the LivingLab as a platform for collaborative research projects that should serve as a development and testing ground for novel technologies.

The concept: 'Vacation on Campus'

A slogan that helps describe concisely the concept of the LivingLab is 'Vacation on Campus'. By this we mean that the LivingLab will be a building that provides temporary residence, for periods of one or more weeks, to experimental subjects, referred to as residents from now on. The LivingLab shall function as a normal home with all required facilities: bedrooms, living rooms, storage spaces, a bathroom, a kitchen equipped with appliances, etc. The residents could be paid, as is normal practice for participation in experiments but, still, the environment should be attractive and pleasant for them to live in.

During their stay in the LivingLab, the residents will experience a range of novel technologies. The purpose of their stay in the Lab is to let TU/e researchers investigate the use of these technologies in a situation that is as life-like as possible. In terms of realism, this is the next best thing to installing the technology at the resident's own home. Compared to this latter alternative, a LivingLab can provide significant cost savings and enables observations that would otherwise be impossible. The requirement for realism relates to the 'ecological validity' of the findings: it is questionable whether any laboratory experiment where the subjects participate for 1 or 2 hours under controlled conditions, can provide results transferable to the context of daily home-life. This is especially true with respect to the use of new ubiquitous computing technologies (Weiser, 1991) that are described later in this paper.

To support observation, the LivingLab will be equipped as an extended usability laboratory. This means installing infrastructure such as cameras for recording user activity and video equipment for editing and annotating video logs. The LivingLab should also have a 'machine room' for servicing the equipment unobtrusively. Furthermore, it should be equipped with infrastructure such as home networking and high bandwidth connections to telecommunication services.

Observation of every-day life raises serious privacy issues, which set living labs apart from traditional laboratories and need to be addressed during the detailed design of the premises and the experiments. Contrary to traditional laboratories, it should be possible for the resident to control or, at least, to be aware of the observation activities. This requires designing observation equipment with mixed control, by the experimental subject and the experimenter. In itself, this is an interesting methodological research problem.

A related and important issue is to ensure the realism of daily life. Care should be taken that the daily habits of the experimental residents are not unnecessarily disturbed. For example, the resident could be encouraged to bring his/her own music collection, personal artefacts, information, etc.

LivingLab vs. 'House of the Future'

The conception of a living lab is orthogonal to the types of technologies that we can test within its confines. Both established technologies can be tested, as well as state-of-the-art and futuristic concepts. The application domain can be anything from 'infotainment' to tele-medicine, nutritional advice, security systems, or even computer games for children (these are not restricted to desktop computers as we shall see in later sections).

Integrating futuristic home technologies in one house relates the LivingLab to concept-demonstration buildings, which can be called 'Houses of the Future'. Such houses integrate varied technologies, ranging from electronics and software, to novel insulation and painting materials. The main objective of such demonstration houses is to provide a glimpse into the future and to serve as a proof of concept for each of the technologies they integrate. These aims are quite valid in their own right, but are not the purpose of the Living Lab. One clear limitation of such a house is that current technologies become obsolete within 3-5 years. For example, the first such 'House of the Future' in Brussels has been subsumed by a second one only five years after its construction (see http://www.livtom.com/).

Contrary to a 'House of the Future' type of project, we do not aim to articulate an integral conception of how the future home-life will or can be. Rather, we restrict our aims to providing an 'ecologically valid' experimental platform for experimenting with emerging and future technologies. The technologies we choose to study reflect our vision of the future and our scope of investigation, but the research programme remains open for additions or modifications, which may result from research partnerships. For our part, we focus on the concept of ubiquitous computing and, in particular, how computing becomes part of every-day life and blends with the physical objects that surround us at home. We discuss this application domain under the header 'Every-day Computing'. This technology is a partially re-usable infrastructure, that can turn the LivingLab into a development resource for industries that can participate in future developments, but which do not have sufficient expertise or funds to develop this type of infrastructure for themselves.

Vision of the future: Every-day Computing

The term 'Every-day Computing' was introduced by Abowd and Mynatt (Abowd *et al.*, 2000) as a specialized area of ubiquitous computing (Weiser, 1991). Every-day Computing 'promotes informal and unstructured activities typical of much of our every-day lives'. These activities are constant, multi-threaded, interruptible, with no clear start or end, and are not best described in terms of tasks, goals, efficiency and performance (Abowd *et al.*, 2000). Central research topics for Every-day Computing include the following:

- The development of novel, 'natural', forms of interfaces, e.g., perceptual user interfaces (Turk & Robertson, 2000).
- Research in technological needs of people with respect to their daily home activities.
- Development of novel hardware and software infrastructures.
- Adaptation of techniques for designing and evaluating user-system interaction, to this emerging interaction paradigm (Bouwhuis, 2000a).

Related projects

There are several smart rooms, homes, and living labs under development around the world. Below, we review some of the earliest and most influential ones.

The Georgia Tech Living Labs

The Future Computing Environments Group at Georgia Tech is running a combined living lab programme that investigates smart home, office and classroom technologies for the future and wearable computing. Early 2000 this group had approximately 7 permanent staff and 20 graduate students, studying "the partnership between humans and technology that arises as computation and sensing become ubiquitous" (Abowd *et al.*, 2000). It is interesting to note that the expertise of the group is in computer science and human computer interaction, but they collaborate for this project with other departments of Georgia Tech: Electrical Engineering, Architecture, Psychology, Centre for Rehabilitation Technologies, and the School of Literature, Communication and Culture.

Construction of the Aware Home (Kidd *et al.*, 1999; Abowd *et al.*, 2000) was completed in May 2000, and its purpose is to serve as a living laboratory for ubiquitous computing in home life. The intent is to produce an environment that is "capable of knowing information about itself and the whereabouts and activities of its inhabitants" (Abowd *et al.*, 2000). It involves two parallel technology and human-centred research programmes for studying new technologies (e.g., smart floors (Orr & Abowd, 2000)) and supporting elderly occupants. As far as the Aware Home is concerned, we share the research aims of this group at Georgia Tech, particularly for the human-centred aspects. We shall, however, be focussing on different technologies. They also intend to pursue long-term observation studies although, at the moment of writing, these have not started yet.

The Dr Tong Louie Living Laboratory

The Dr Tong Louie Living Laboratory in Vancouver (http://www.harbour.sfu.ca/gero/livinlab.html), was opened in 1997, and is a research facility with a full-scale simulated home that is used to study different environmental designs and products for older adults and persons with disabilities. Its infrastructure supports remote observation and observation through an amphitheatre with an audience. It features flexible walls that allow different environmental configurations to be tested, and supports testing kitchen or bathroom designs, the height of cupboards, and the location of appliances. The configuration of the bathroom, for example, may be changed to determine the arrangement that is most sensitive to an older person's needs. There are some similarities in the set-up with the proposed LivingLab, but the major difference is that this lab is not intended for a prolonged stay.

The Adaptive House, at Boulder, Colorado
The University of Colorado set up an experimental residence (Mozer, 1999) which provides certain services:

- Predicting when the occupants will return home and determining when to start heating the house so that a comfortable temperature is reached by the time the occupants arrive.
- Detecting statistical patterns of water use, such that hot water is seldom if ever used in the middle of the day on weekdays, allowing the water heater to shut off at those times.
- Inferring where the occupant is and in what activities the occupant is engaged and controlling lighting patterns and intensities accordingly, e.g., anticipating which rooms are about to be entered and turning on the lights before the room is occupied.

The project provides one of the most advanced concept demonstrators in this field, but so far there are no reports of experiments assessing how the residents perceive and whether they accept such adaptive behaviour. Most experimentation has been concerned with testing the machine learning and not the USI aspects of this technology.

Living Tomorrow
Two noteworthy demonstration houses have been built outside Brussels, and are called 'Living Tomorrow' and 'Living Tomorrow 2' (see http://www.livtom.com/). These houses are exhibition centres of which the purpose is to raise awareness of novel technologies, demonstrate concepts and act as a showpiece for the funding industries. While several innovations have been installed, little attention has been paid to serving actual user needs, introducing several gimmicks, i.e., technologies demonstrating the feasibility of the concept as opposed to addressing a real user need such as, for example, turning off the shower with a touch-screen. The dominant interaction forms envisioned are voice-control and the use of touch-screens. Touch-screens support a Microsoft Windows style interaction, to perform every-day activities; this contrasts the vision for technological artefacts disappearing into the background (Weiser, 1991; Norman, 1998) and becoming a part of life (Bouwhuis, 2000b).

HAL
HAL is an interactive environment that uses embedded computation to observe and participate in the normal, every-day events occurring in an office-room at MIT. This system supports the concept of perceptual interfaces (Turk & Robertson, 2000): "it has cameras for eyes, microphones for ears, and uses a variety of computer vision, speech and gesture recognition systems to allow people to interact naturally with it" (Hirsh, Coen, Mozer, Hasha & Flanagan, 1999). The project combines complex sensing and computer

vision techniques. HAL has demonstrated an impressive array of functions, which are integrated in a room for the first time, and has shed light on how to address the complex software engineering problems that arise.

Microsoft's home
Microsoft has built yet another notable demonstration house on their campus in Redmond, Washington. Here, too, as in the Belgian Home of the Future, the suggested form of interaction is by voice-recognition and by touch-screens. A Microsoft initiative, oriented more towards perceptual interfaces, is the 'Easy Living' project. This project focusses on the software technologies needed to create a smart home environment, such as software agents, computer vision, machine learning, etc. Some of the concepts described in their home page (http://research.microsoft.com/easyliving) are similar in purpose to the activity interpreter and the adaptation component of the LivingLab, which are discussed in later sections. One of the open issues that Microsoft researchers identify is how to let the residents determine how the system should interpret and react to their actions. This is one of the central research questions that we wish to pursue for the LivingLab.

Some scenarios for the LivingLab

This section aspires only to provide some idea about the type of experiments that will be conducted in the LivingLab. The location of this apartment shall be inside the IPO building or elsewhere on the university campus as a separate house. We hope that the scenarios below will help build an image of possible activities in the LivingLab. Each scenario is written in italic print, and comments about its purpose follow in normal print. The scenarios are listed in order of technical complexity, starting from currently available technology and moving towards more futuristic concepts. They gradually build-in more elements of an aware home environment, addressing a range of methodological, design, and technical research issues.

Ellie visits Dad
It is Sunday afternoon. Ellie (35) who works for the European Commission in Brussels wants to keep company to her father in Athens. Sunday afternoons he normally spends with the TV switched on, reading his second Sunday paper. They each make coffee. Ellie connects to her virtual visit system first. She sits in the couch and sees a projection of Dad on the white-wall next to her. She sees a large, clear picture of him, similar in quality to the TV image. She can see the whole of her Dad, his coffee table, and half of his Living Room. He sees a similar image of her, and sometimes her children wandering in and out of the visible area. They chat a bit about their day, but they've said most things on the phone anyway. They start reading their papers. Every now and then Dad sniggers and reads a piece out of the paper. Ellie gets annoyed because she was absorbed in her own paper. Ellie answers the phone, talks to her friend and asks a question to Dad while her friend is on the other end of the line. When she finishes, they chat a bit more and decide to end the visit; she has to do ironing for the kids and he wants to watch a boring news analysis.
- "Tomorrow then?" asks Ellie.
- "Well, I'm going to the cinema but it would be nice to see you on Wednesday".

The emphasis in this scenario is to find ways to characterize, assess and engineer the affective benefits of a real visit through advanced video conferencing techniques. We are specifically interested in distinguishing information communication (e.g., giving a news update) from the sensorial and emotional benefits of a visit.

What's on tonight?

Joanne has a cough. She goes to the medicine cupboard. She finds some old cough syrup, but can't find the paper explaining the dosage. She points to the cupboard with a palmtop and gets the list of all the medicine she has bought that hasn't expired yet. She finds the information that the doctor had prescribed; it should be two spoons before each meal. She takes the medicine and sits on the sofa. The palmtop is now a browser for TV programmes. In fact she wants some music, so she modifies the display to browse through her record collection.

This scenario focusses on location sensitive access to information, which utilizes some of the input technologies that should be integrated into a ubiquitous computing environment. It can be seen as a stepping stone towards a more 'intelligent' activity interpreter, both from a computational perspective, but also from an interaction design perspective.

Pauline relives the fairy tale

Pauline (2) has just started to talk, although only her mum can understand most of the things she says. She likes stories that her mother reads to her, or that her mother invents for her when they play. Last time, they had dressed the doll together for a party and mum had sung a song. Mum is cooking now, letting Pauline drag the doll around the house by its hair. Pauline, starts redoing the same things they did yesterday. She takes it to the table to dress, and she hears the description of the fashion accessories that her mother said yesterday, she puts it on the sofa and covers it with a kitchen towel and hears the lullaby her mother sang. When the doll is close to the teddy, one of her favourite songs plays on the CD. Mum is happy because she thinks the way she 'programmed' the living room yesterday was quite to Pauline's taste.

This scenario shows how affective benefits can be accrued by computation, in a manner that is not disruptive to every-day activities and that targets children users. The design issue in this case is to see whether and how 'Mum' can control the system and let it know which 'intimate experience' it should recreate for her daughter. To identify what such an intimate experience is and to recreate it are very involved research questions, interesting for the field of user-system interaction (USI). The basic technology involved can be very simple, essentially recording and playing back audio, but to achieve a seamless integration and a simple control of the system are interesting technical and design challenges.

Pauline and Annouck burst the bubbles

Mum has subscribed to a new computer game targeting ages 18-30 months for her daughter Pauline. Mum starts it up, and a Disney-like scenery is projected onto two of the walls away from the window. Pauline and her friend Annouck see a mirror image of themselves surrounded by bubbles. They look at the mirror image and sway their toy-wands bursting the bubbles around them. Little pigs drop out and sing some nursery rhymes. In a while, the bubbles have dried up. Pauline and Annouck protest, so Mum starts the game again, this time with small ducklings. In a while they forget about the *ducklings and the pigs, and they play with their real dolls and rocking horse. The image fades away letting them concentrate on their own game.*

The scenario requires interpreting and predicting user activity. The adaptive behaviour of the system is very simple, it simply knows when to switch off. The interaction is quite complex, the gestures of the children have to be interpreted and some complex image processing is involved. The scenario also demonstrates some of the advantages delivered by ubiquitous computing. Interaction can seamlessly integrate with the activities of the children, letting them play in teams, moving around instead of sitting in front of a machine.

Bart buys his grocery

Bart (72) lives alone, and is busy writing a travel guide for elderly travellers. He doesn't enjoy household stuff and eats too much convenience food. His fridge monitors his buying habits by reading the bar codes of the items within it. Occasionally, the fridge provides nutritional advice and when it notices that he has regular habits, it asks him permission to place orders for items he buys regularly at his local grocery. When he goes shopping himself, he asks for a list of things to buy, and the fridge comes up with a list of suggestions, based on his shopping history. When Bart goes on a holiday, the activity interpreter of the house is aware of this and lets the fridge know that it should stop current orders, and that it should not assume that Bart's appetite is diminishing.

The challenge in this scenario is to make the right recommendations but also not to interfere too much with the life of the subject. The point that this scenario could demonstrate is how the adaptive behaviour of the fridge receives feedback and feeds into the activity interpreter for the household. In general, an aware home could involve numerous adaptive systems that should adapt and learn from the behaviour of each other.

John learns to read

John (6) has just learned to read at school. He is good at reading sentences word by word, but has trouble getting to the meaning of the sentence. His parents play a treasure hunt with him. They put clues, parts of a story and little gifts in various places in the house: drawers, shelves, under the bed, etc. John reads directions on his palmtop, such as "go to the bedroom, open the third drawer of the chest, look for something blue". The parents hope that John will be more motivated to look for the meaning of what he reads.

This scenario focusses on educational activities. As with the other scenarios, the purpose is not the demonstration per se but rather, in this case, to see how educational activities can be supported through an augmented reality system. Such a system can be tested in the LivingLab, provided a small family can be hosted, and can be a first test-bed of an activity interpreter for activities throughout the home. The advantage of such an application is that it is not invasive in the lives of the inhabitants, it can be switched off, and we can quickly obtain some idea as to the success and acceptability of the system.

Joanne rearranges the furniture

Joanne (34) has just gotten rid of the computer table and her old PC tower. She decides to make the most of the space; she puts her favourite armchair closer to the window. There are four cameras around; they are all automatically pointing at the new 'place' *she has created. She picks up the tablet-computer from the desk, circles the image of the armchair and checks some options: reading, looking out of the window, and drowsing with a paper. Next time she sits there with a book, a directed light is aimed at her book. A little while later, her gaze drifts out of the window. She stays in that position some time, and gradually the light softens.*

This scenario focusses on the personalization of a ubiquitous computing environment. The point is that it should be as easy as rearranging furniture. We focus on computer vision, but the interpretation of user activity needs to rely on more forms of input. Reconfiguration by the resident is a major research issue that no other research group is addressing at the moment. The configuration of intelligent environments is a challenging research problem that needs to be addressed before aware homes become a reality.

Furnishing the LivingLab with a research programme

As mentioned already, the LivingLab is not simply a project, but an experimental platform and a framework for carrying out different research projects. This section sketches some research topics that will be investigated using the LivingLab.

Location-aware home information system

This research project concerns the location-sensitive access of information on a hand-held device. The general concept is that any information/entertainment appliance in the home, which is portable enough to be carried, should not be bound to a single room. For example, Internet access can be more convenient and enjoyable as a ‘lean-back’ activity on the couch, when performed on a special purpose light-weight tablet (McClard & Somers, 2000). Indeed several companies, e.g., Compaq, are launching such products this year. The services provided by such portable devices can be enhanced with the benefits of location awareness. Most of human activities are related to a particular place: we study on a desk, we watch television on the sofa opposite the television set, etc.

We plan to investigate and develop a location sensitive in-home service, running on a hand-held device. This will communicate with a home-server wirelessly. Initially, the service will provide information related to the nearest physical object it is aware of in the system, e.g., the manual for the washing machine or the television programme when close to the sofa opposite the television. Home-related information, e.g., the local plumber or the shopping list, will be accessible and manipulable through the mobile device, a sharable persistent display, e.g., something like the FRIDGE prototype (Vroubel, Markopoulos & Bekker, 2001), or a device such as the television or the computer.

This type of service poses some software architecture challenges for the seamless integration of these technologies, and requires significant innovation in the USI domain. We need to establish methodological knowledge for the suitable design of such services and factual knowledge concerning the technological needs that such services could support.

In-home activity interpreter

Information and entertainment services, as well as the automatic control of home appliances, can be enhanced through a rich model of the context of use: Who is holding the device? What are his/her habits? Who else is in the room? Etc. Such information can be obtained and synthesized by a home-activity interpreter. Such an interpreter should integrate information from a heterogeneous and extensible array of context sensing systems, e.g., computer vision based, position tracking, microphones, pressure sensors, detectors, etc. The activity interpreter builds a model of the resident activity and uses it to present relevant information or to take appropriate action, e.g., control lighting, heating, air quality, or even call emergency services.

To explain the importance of constructing appropriate models of user activity, consider a thermostat, for example, that controls the temperature of a room to a desired setting. Putting a user inside the system makes this apparently closed system open. What the controlled variable should be is how hot/cold the user feels; furthermore, next to changing the thermostat setting, the user may resort to opening/closing a window, which may well not bring the desired effect. In conclusion, the problem of such systems is to provide rich enough activity models and powerful enough controls, so that the combined system does not become unstable. Moreover, the unpredictability of humans compromises the veracity of the controlled variable values. Consider, for example, a nutritionist that monitors the contents of a fridge, or even analyses the eating habits of the resident through a ‘smart toilet’. Such an apparently ‘intelligent’ system can provide nonsensical advice as soon as guests come to the house. Thus, for any home adaptation system to work, the context model constructed by the system must be made sufficiently rich and the actuating behaviours of the system can only be tested in a real-life experiment.

A sophisticated example of an adaptive home environment is the ACHE system, which controls lighting, ventilation and heating, based on observation and modelling of the pattern of living of its inhabitants (Mozer, 1999).

The main technical challenge is to develop an extensible software architecture, which allows us to integrate these different sensing technologies. Each service that uses this activity interpreter poses its own special requirements. For example, air quality can be manipulated by directly controlling temperature, humidity, by filtering, or simply by opening/closing the window. An intelligent control system can take into account the whereabouts and the activity of the resident (whether or not the resident is in the house), as well as direct measurements of the air quality inside and outside of the house.

From an interaction design point of view, it is necessary for the user to feel in control of the system that observes him/her, so that he/she manages to create an appropriate mental model of the observation, the interpretation, and the reactive behaviour of the system to control the system effectively. This topic is largely unexplored, as the related research has mainly focussed on the technical problems surrounding the adaptive and reactive behaviour of such systems.

Novel interaction styles

The ubiquity and the plethora of devices that ubiquitous computing brings about should not result in a corresponding increase in the workload and complexity of interaction for the user. This requirement necessitates the development of interaction styles that are pleasurable and very simple to use, and will let the residents pursue their normal activities while providing timely and useful services to them. The ‘naturalness’ of the interaction, e.g., as the term is understood by Turk and Robertson (2000), becomes very important. For example, the FRIDGE prototype (Vroubel, Markopoulos & Bekker, 2001) used a simple graspable interface and pen input to support simple messaging functionality between household members. The scenarios of the previous section illustrates how users can implicitly interact with a home system, i.e., the system monitors their activity, without requiring extra and explicit interactions to perform its functions.

Children's toys and games can provide excellent test cases for the development of natural interfaces. These will serve as example applications for location awareness, the activity interpreter, and the interaction styles developed. They can serve as case studies for related IPO research into design techniques for children users.

A tele-visit service and affective co-presence

An important benefit expected from (mid-term) future technological developments is affordable, high bandwidth, video-based communication. The LivingLab can provide a testing ground for the long-term field-testing of high bandwidth 'tele-visit' services, such as that outlined in the scenario 'Ellie visits Dad' of the previous section. We shall try to elicit ergonomic and technical recommendations for the design of such a service.

We are concerned with the emotional benefits attained through long-term usage of a tele-visit service, as part of actual every-day life of the residents. These emotional benefits are encapsulated in the concept of tele-relating; an affective slant on the concept of co-presence (Short, Williams & Christie, 1976). In this view, rather than assessing the subjective illusion of being together while communicating, we wish to explore the satisfaction experienced by a virtual visit, and to what extent it compares to the satisfaction experienced from a physical visit. The research will be concerned with defining, operationalizing and engineering affective co-presence. The experimental set-up could support the notion of a 'virtual window', through which the Living-Lab resident will be able to communicate with close family and friends. We envisage natural size, high-definition images of interacting parties, but we shall be investigating alternative set-ups, and how they contribute to satisfying the emotional needs of the residents.

To conclude this enumeration of research issues, we note that this list is a snapshot of our intentions at the moment of writing this report. It organizes the ideas listed in the room-by-room description on a project-by-project basis. It may be extended, or reduced, as research collaborations materialize.

Scientific relevance

The focus of this research on Every-day Computing is consistent with developments in computational and human-computer interaction research, but also with the emergence of technologies that enable the concepts of ubiquitous computing (Weiser, 1991) or the Disappearing Computer (Norman, 1998). For computation and, more generally, technological artefacts to become parts of our every-day lives, we require developments in the following areas of USI research:

- *Natural interaction styles*. Naturalness here means that the interaction should support common and familiar forms of human expression and leverage more of our implicit actions in the world (Abowd, 2000; Turk & Robertson, 2000). It is our goal to use the LivingLab to host and to experiment with novel interaction techniques, developed in house or taken off-the-shelf.
- *Modelling and adapting to the context of interaction*. The function of technological artefacts must adapt to the context of interaction: the users' identity, the time and place, etc., eventually constructing and manipulating a veracious and adequate

model of user activity. At a very abstract level, the intelligent environment can be metaphorically characterized in various ways, such as an intelligent butler that tries to guess and serve the resident, totally obedient to him or her, or an ‘intelligent advisor’ that recommends improvements to the lifestyle, and urges him/ her to take a positive course of action. The full range of interaction styles with an intelligent environment should be identified and their appropriateness and acceptability for different persons and contexts must be assessed.

- *Identifying technological needs of targeted population segments*. Technological developments must address real, every-day needs of people, and must be evaluated as an integral part of people’s life. Field research for identifying technological needs and field testing of design concepts are an essential aspect of this research. Basing the design of a tele-visit service on the concept of co-presence is an example of engineering to address real, rather than invented, needs of people.
- *Adaptation of user-centred design techniques*. Current design techniques originally developed for desktop interaction, e.g., for collecting user requirements and techniques for usability testing, need to be revised for the context of Every- day Computing. Furthermore, we need to consider how the special needs of the targeted segments of the population (elderly people and children) can be addressed.

Industrial relevance

To a large extent, a ‘Smart’ or ‘Aware Home’ no longer is science fiction, but is technologically feasible. This fact creates new markets mainly for electronic appliances and networking infrastructure. It also creates opportunities for domestic and mobile telecommunication services. An upbeat quote by M. Coen (Hirsh *et al.*, 1999) concerning the size of the market for this technology is that “Intelligent rooms promise to have the ubiquity of, well, rooms and the ‘upgradability’ of PCs”. New services can be provided to users, linking these developments in computation and interaction to services such as e-commerce, or tele-medicine. This type of service can represent larger volumes of business than the devices that will support them.

Large corporations like Philips and IBM are building their own future houses. Jini (SUN) and Home API, by several companies including Microsoft and Mitsubishi, provide software solutions for home networking. Companies specializing in security systems are building their own version of a ‘smart home’. Indoor positioning systems also are an emerging market, see for example the 3D-iD positioning system (Werb & Lanzi, 1998).

The technology we described earlier as ‘Every-day Computing’ still is a novelty and has not even reached the early adopters. Before this type of technologies can reach the level of maturity required for the market, we need to obtain much more experience regarding their use, integration, and their acceptance by users. For the average person, this technology represents a quantum leap in the number of devices used and the activities supported. Long-term user testing in a realistic setting is a necessary and valuable ingredient in making this technology usable and useful to address pressing needs of our society.

Conclusions

The LivingLab is a planned infrastructure that will provide an experimental platform for future home-related technologies. We plan partnerships for developing the required technologies, and for testing research concepts or novel products in an 'ecologically valid' manner.

The LivingLab concept is orthogonal to the technologies that will be tested within it. However, such an infrastructure becomes necessary for assessing the usability of intelligent environments. In the next few years, USI research must redefine the notion of usability for the emerging paradigms of interaction described above as 'Every-day Computing'. Furthermore, USI research will need to provide methodological guidance for designing and testing intelligent environments, and will need to produce novel, multimodal interaction styles, which will capitalize on implicit interaction with the user. Such methodological knowledge can only be validated by its application in practice. The implementation and testing of some of the scenarios described in the body of this paper, is the only way to understand, learn to design, and test for this new emerging conception of usability.

The research programme described focusses on core infrastructures for the LivingLab:

- Materialising the concept of 'Every-day Computing'.
- Accruing methodological knowledge for conducting round the clock observations of people at their home.
- Developing interaction design knowledge for intelligent environments.

Acknowledgements

We wish to thank Prof. Don Bouwhuis for his contribution in shaping the ideas discussed, and Mathilde Bekker for comments on an earlier draft of this paper. Finally, special thanks go to Peter Barten for correcting our reference section, and to Unni van Amelsfort for her editorial efforts.

References

Abowd, G.D., Atkeson, C.G., Bobick, A.F., Essa, I.A., MacIntyre, B., Mynatt, E.D. & Starner, T.E. (2000). Living laboratories: The future computing environments group at the Georgia Institute of Technology. In: G. Szwillus and T. Turner (Eds.): *CHI 2000 Extended Abstracts, Conference on Human Factors in Computing Systems, The Hague, The Netherlands, April 1-6, 2000,* 215-216. New York: ACM Press.

Bouwhuis, D.G. (2000a). Ambient intelligence: The need for a new concept of usability. Unpublished presentation at the 1st International Symposium on User-System Interaction, Eindhoven University of Technology, September 11-12, 2000.

Bouwhuis, D.G. (2000b). Parts of life: Configuring equipment to individual life style. *IPO Manuscript No. 309.*

Hirsh, H., Coen, M.H., Mozer, M.C., Hasha, R. & Flanagan, J.L. (1999). Room service, AI-style. *IEEE Intelligent Systems Magazine, 14(2), 1999,* 8-10.

Kidd, C.D., Orr, R., Abowd, G.D., Atkeson, C.G., Essa, I.A., MacIntyre, B., Mynatt, E, Starner, T.E. & Newstetter, W. (1999). The aware home: A living laboratory for ubiquitous computing research. In: N.A. Streitz, J. Siegel, V. Hartkopf and S. Konomi (Eds.): *Cooperative Buildings: Integrating Information, Organizations and Architecture,* 191-198. Berlin: Springer.

McClard, A. & Somers, P. (2000). Unleashed: Web tablet integration into the home. In: T. Turner, G. Szwillus, M. Czerwinski and F. Paternò (Eds.): *CHI 2000 Conference Proceedings, Conference on Human Factors in Computing Systems, The Hague, The Netherlands, April 1-6, 2000,* 1-24. New York: ACM Press.

Mozer, M.C. (1999). An intelligent environment must be adaptive. *IEEE Intelligent Systems Magazine, 14(2),* 11-13.

Norman, D.A. (1998). *The Invisible Computer.* Cambridge, MA: MIT Press.

Orr, R.J. & Abowd, G.D. (2000). The smart floor: A mechanism for natural user identification and tracking. In: G. Szwillus and T. Turner (Eds.): *CHI 2000 Extended Abstracts, Conference on Human Factors in Computing Systems, The Hague, The Netherlands, April 1-6, 2000,* 275-276. New York: ACM Press.

Short, J., Williams, E. & Christie, B. (1976). *The Social Psychology of Telecommunications*. London: John Wiley.

Turk, M. & Robertson, R. (2000). Perceptual user interfaces. *Communications of the ACM, 43(3),* 33-44.

Vroubel, M., Markopoulos, P. & Bekker, M.M. (2001). FRIDGE: Exploring intuitive interaction styles for home information appliances. In: J. Jacko and A. Sears (Eds.): *CHI 2001 Extended Abstracts of the Conference on Human Factors in Computing Systems, Seattle, WA, USA, March 31 - April 5, 2001,* 207-208. New York: ACM Press.

Weiser, M. (1991). The computer for the 21st century. *Scientific American, 265(3),* 94-104.

Werb, J. & Lanzi, C. (1998). Designing a positioning system for finding things and people indoors. *IEEE Spectrum, 35,* 71-78.