

The evolution of buildings and implications for the design of ubiquitous domestic environments

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ABSTRACT

This paper considers how we may realize future ubiquitous domestic environments. Building upon previous work on how buildings evolve by Stewart Brand, we suggest the need to broaden existing considerations of interactive design for domestic environments. We identify a number of classes of research activity and the issues associated with these. We then consider the ways in which current buildings undergo continual change. In doing so we outline the stakeholders involved, the representations used and the way change is managed. We contrast our understanding of how buildings change with research activities before identifying new challenges that will need to be addressed by those involved in designing ubiquitous technologies for domestic environments.

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General Terms: Design, Human factors, Theory;

Keywords: Ubiquitous computing, domestic environments.

INTRODUCTION

"We call our work "ubiquitous computing". This is different from PDA's, dynabooks, or information at your fingertips. It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere." [37]

Those interested in realizing the vision of ubiquitous computing outlined by Mark Weiser have sought to understand how interactive technology can be built into the very fabric of our everyday environment [1]. A growing focus has been the transformation of the homes we live in into ubiquitous computing environments. This work has focused on uncovering new forms of interaction [15], new areas of application [23] and novel forms of computer [12].

The appeal of the home as a specific domain is that it offers

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new sets of challenges that move our understanding of interaction beyond the current focus on information and knowledge work [15]. These include the demands of new user groups (e.g., the elderly [23]), the impact of broader cultural values [12] and the need to support activities other than work [29]. This research is often articulated in terms of visions of the future that postulate how our homes will look [29, 6] and a number of purpose built spaces have been constructed to provide "living laboratories" that allow researchers to explore how inhabitants might experience the home of the future [4, 22, 18].

However, future ubiquitous domestic environments are unlikely to be purpose built; rather they will evolve from our existing homes. As Grinter *et al* argue [10]

"new technologies will be brought piecemeal into the home; unlike the 'lab houses' that serve as experiments in domestic technology today these homes will not be custom designed from the start"

It is important that current research activities are seen in the broader evolutionary context of how our buildings change over time. This is particularly true given the diversity of research activities that need to be brought together to realize ubiquitous environments and the paucity of concepts to allow these activities to be related to each other [2].

This paper contributes to our understanding of the design of future domestic environments by building upon work by Stewart Brand on how buildings change [3]. We exploit the framework presented by Brand in three distinct ways:

- We relate the diverse set of activities involved in ubiquitous domestic environments to each other.
- We place ubiquitous computing for domestic environments in the broader context of how buildings change.
- We outline some new challenges for research into ubiquitous domestic environments.

By outlining a broader framework and mapping research activities to the framework outlined in this paper we wish to lay the foundations for the future design guidelines and the development of supporting principles called for by Bellotti *et al* [2] among others.

DEVELOPMENT FOR THE HOME

One of the most striking aspects of the work in developing ubiquitous computing environments for the home is the

diversity of the approaches involved. These include:

- Those interested in understanding domestic settings, often from a range of different methodological backgrounds.
- Those concerned with the aesthetic and functional form of household artefacts and interactive devices.
- Those interested in the nature of the broad interactive environment and supporting infrastructures and communications protocols.

With the convergence inherent in each of these perspectives we are left to wonder how the various endeavors relate to each other or indeed how we may seek to understand the broad development of these interactive environments themselves. We begin by examining each of these approaches in greater detail.

Different Understandings of the Domestic

One the most challenging aspects of designing for domestic environments has simply been gaining an understanding of domestic settings. A variety of research approaches are currently in use. These include ethnographic studies [26] of the routine activities in the home [32], long term studies of the introduction of technologies to the home [20] and novel methods that aim to inspire new designs such as cultural probes [13]. These embody different forms of empirical investigation and have grown from a wide variety of methodological backgrounds. Each provides different sets of sensitivities to the potential developers.

- *Ethnographic studies* have highlighted the everyday nature of domestic activities and the need for future technology to be sympathetic to everyday routines [32]. For example, studies of set top boxes have contrasted the concentrated model of interaction with the broad set of activities distributed throughout the home [26].
- *Longitudinal studies* have highlighted the ways in which technologies are used. For example, studies have highlighted the shift toward increasing leisure use of the Internet within domestic settings [19] and the impact on particular groups including children [31].
- *Design based methods* such as cultural probes [13] have highlighted the need to be sensitive to a broader set of cultural values within the home. For example, Gaver *et al* highlight a set of concerns that are quite different from those traditionally associated with work oriented settings [12].

These methodologies can be seen as providing different pieces of the overall puzzle of understanding the context of the home. Researchers have also sought to develop techniques for presenting material to designers. For example, Vankatesh [34] has developed a series of models of technological development and placement within the home [35]. Others have developed techniques to convey activities within the home to designers [16, 7].

Different Devices for Domestic Settings

The diversity evident in understanding the home is

similarly reflected in the different approaches to the development of interactive technologies for domestic settings. Researchers have broadly sought to develop devices that can be used; to understand their use, and then alter these devices to reflect the lessons learned. They have made these technologies manifest within the home in different ways. Three key approaches are evident.

- *Information Appliances* are stand-alone interactive devices that are self-contained with specific functionality [25]. Many of these have been realized in the home by layering interactive functions onto existing household appliances using standardized communication facilities. Examples of these include the Internet fridge [11] and handheld and mobile devices [21] supporting specific forms of interaction.
- *Interactive Household Objects* merge interactive capabilities with existing household objects to offer new forms of interaction. These often build upon the cultural values associated with existing artifacts. Examples of these include augmenting picture frames with new display and interaction facilities [23], adding new communication capabilities to household notice boards [15] and augmenting cups [14].
- *Augmented Furniture* adds interactive capabilities to the different furniture in the home. These include the DiamondTouch interactive table [28] and proposals to augment cupboards [6] and garden furniture [12].

Each of these adopts a different interaction style. The techniques used by each are summarized in table 1.

Approach	Interaction Technique.
Information Appliance	Often using touch screens, the form of interaction is very similar to those of PCs and handhelds
Interactive Household Object	Interaction is incorporated into the form of the object. Thus picture frames become displays, cups are augmented with temperature/motion sensors.
Augmented furniture	Interaction is mediated through sensors detecting actions with the furniture.

Table 1: Interaction styles used by different devices

These three different approaches vary in terms of the prominence of the digital technology and the ways in which the technology is made available to inhabitants. The technology is most intrusive in information appliances and then reduces in household objects and augmented furniture.

Developing Environments and Infrastructures

In order to address the need to consider how a range of devices may fit into a domestic setting and to allow “in-situ” development, a range of purpose built environments has being constructed. These vary from demonstration domestic spaces [4] to purpose built homes [22, 18]. They tend to be illustrative in nature and either showcase devices or provide “living laboratories” for research.

These environments also allow interaction to be broadened beyond devices and augmented artifacts to consider how the environment itself can be embodied with interactive properties. This has involved two broad explorations

- *New forms of Context Sensing* focuses on exploiting a broad range of sensors in order to infer the particular context of interactions. Settings such as the aware home [18] and the EasyLiving space [4] exploit positional information, video tracking systems and tagged entities to make inferences from a range of contextual cues.
- *Embedded interactive technologies* focus on technologies that make the fabric of the environment more interactive. The broad presumption is that these technologies form part of the fabric of the space and are seldom modified by inhabitants. These include developments such as the Georgia Tech smart floor [27] and embedded displays [23].

Often, the aim has been to make the supporting technology as invisible as possible [25]. Research has focused on the development of appropriate sensing models and techniques for programming devices that react to different contextual cues [30]. Until recently there has been less emphasis on the interactive models needed by these environments [2].

Researchers have sought to develop a flexible *digital infrastructure* to underpin these environments. These include Jini [36], UPnP[33] and the Coolbase platform [5]. The focus of these infrastructures has by necessity been on the development of appropriate protocols and techniques to allow devices to discover each other. Limited consideration has been given to how users may compose these to meet particular demands. Other systems such as Speakeasy [24] and the Context Toolkit [8] have started to explore how best to expose the infrastructure to users.

The work on a flexible infrastructure has also extended to consider the way in which technology can be used to alter the *built environment* making up the fabric of buildings. Endeavors such as the Changing Places/House_n consortium at MIT [17] have started to explore the impact of technology on how we may build future homes.

In summary, there is already a rich body of research into ubiquitous domestic environments, spanning understanding domestic settings, creating new devices and establishing an underlying infrastructure. The following section offers a new perspective. It considers the evolution of buildings, especially the importance of change within the buildings we inhabit and also the various parties involved in realising this change. This perspective offers new insights into the relationships between current approaches and also leads us to identify new research challenges.

THE EVOLUTIONARY NATURE OF THE HOME

The research associated with the developments in the previous section seeks to transform our everyday homes into interactive environments. Although many technologies appear to be revolutionary in nature it is important that we realize that technology will need to find a place within our homes and that our homes will need to change to accommodate this technology.

Domestic environments evolve. They are open to continual change and the need to understand and support this change

will be important to ensure the successful uptake and management of digital devices in domestic spaces. For example, previous studies have highlighted how inhabitants continually reconfigure domestic spaces and the technologies within them to meet particular demands [26].

In this section we wish to reflect on the ever-changing nature of buildings by turning to existing work exploring the process involved in the evolution of buildings. In order to do this we will exploit the framework presented by Brand [3] to explain the various interlinked process involved in shaping the buildings we inhabit. Brand outlines what he terms the generic “six S’s” as the core to understanding the nature of how buildings change (table 2).

SITE (Fixed)	This is the geographical setting, location, and the legally defined lot, whose boundaries and context outlast generations of ephemeral buildings.
STRUCTURE (30-300 yrs)	The foundation and load-bearing elements are perilous and expensive to change, so people don't. These <i>are</i> the building. Structural life ranges from 30 to 300 years
SKIN (20-30 yrs)	Exterior surfaces now change every 20 years or so, to keep up with fashion, technology, or for repair.
SERVICES (20-30yrs)	These are the working guts of a building: communications wiring, electrical wiring, and plumbing. Buildings are demolished early if their outdated systems are too embedded to replace easily.
SPACE PLAN (3-30yrs)	The interior layout – where walls, ceilings, floors, and doors go. Turbulent spaces can change every 3 years or so; exceptionally quiet homes might wait 20-30 years.
STUFF (Continual)	Chairs, desks, phones, pictures, kitchen appliances, lamps, hairbrushes; all the things that twitch around daily to monthly. Furniture is called <i>mobilia</i> in Italian for good reason.

Table 2: Brand’s layers of changing buildings (from [3])

The different layers of change highlighted by Brand are significant in that the issue arises as to whether the development of interactive digital devices for domestic spaces support the process documented by Brand. The core of the issue here is understanding who is involved in the evolution of buildings, how the process is managed and what sorts of representations are central to these processes.

What skills are involved in making the changes?

Although it is routine for us to think of the buildings we live and work in as purely our own the process involved in managing change involves a substantial collection of people. Some of the different people involved in executing the changes to building and the role of inhabitants are summarized in Table 3 (over)

SKIN, STRUCTURE or SITE changes often require the involvement of external legislative bodies (e.g. town authorities and city planners). However, it is worth stressing that the inhabitants are seldom the people who execute these changes. Rather the inhabitants employ and coordinate a host of specialized professions. These include builders, architects, landscapers etc. For very significant changes, they may even employ professionals such construction site managers to coordinate the other professionals.

The role of the inhabitant is much more central when we

Brands Level	Dominant Skills	Inhabitants role	Representations	Time to make change
SITE	Civil Engineers Architects Regulatory Bodies Builders	Coordination with external expert Involvement in planning	Maps, Site Engineers Plans and Planning Bodies Notations	Months to Years
STRUCTURE	Regulatory Bodies Builders Painters	Coordination with experts Some advanced DIY expertise	Engineering plans Architectural Draws	Weeks to Months
SKIN	Regulatory Bodies Builders Painters	Coordination with expert Some advanced DIY expertise	Architectural views and diagrams	Weeks to Months
SERVICES	Service Providers Plumbers Electricians Inhabitants	Coordination with service providers DIY enthusiast	Specialized diagrams, notations and models associate with each service.	Days
SPACE PLAN	Designers Painters Inhabitants	Coordination with experts Inhabitant based decoration DIY enthusiast	Simple Layouts Feng Shu	Hours to Days
STUFF	Inhabitants	Introduction and movements of Stuff	Design magazines	Minutes to Hours

Table 3: The stakeholders and representations involved in building changes.

consider the internal nature of the building and the different forms of change that take place. The inhabitant is far from the only person involved in this process and is often not the person executing a change but rather coordinates others who undertake the change. This is most significant in terms of SERVICES (water, gas, telephone etc.) where a number of professions are routinely called upon to make changes. In fact, service providers often require explicit certification and training for those who wish to amend services.

Amendments to the SPACE PLAN are generally considered less daunting to users and they will undertake changes to décor and arrangement of the space. However, many often draw upon trained professions to undertake these in the form of interior designers, decorators and local tradesmen. The role of the inhabitant is again one of coordinating the various people involved and managing the logistics of the activity.

Changes to the STUFF are almost entirely undertaken by the inhabitants. These changes focus on the introduction of new artifacts and the movement and removal of existing artifacts. The frequency of change requires that inhabitants do not feel that the cost of these changes is too high or the overall fluidity of the home will be significantly impacted. The need for this flexibility and the need to support inhabitants have been a driving force in many of the technologies developed to date.

As a final reflection it is worth highlighting the active and growing “Do It Yourself” (DIY) industry which provides a wide range of supporting tools and materials to allow inhabitants to undertake work to alter the SPACE PLAN and SERVICES within the home. One of the key aspects of the DIY market is the provision of explanatory material that makes the nature of the SERVICES and SPACE plan more accessible to the inhabitant. The various representations used to manage each of these different features of buildings are key to this.

What representations support change?

As well as the different people involved in the changes that

occur in our buildings it is also worth reflecting on the resources and representations used to support change. Each of Brand’s levels exploits its own set of representations to support those who manage and execute the change.

Each representation is aimed at particular group and exploits notations that make sense to that group. External changes to the SITE draw upon a series of maps demarking boundaries and upon a series of external city level plans. The STRUCTURE and SKIN rely on architectural diagrams that exploit notations and conventions central to architectural practices.

Within buildings we see more of a schism in the use of specialist notations and conventions. Different SERVICES exploit their own representations to indicate the ways in which the service is made available. These include diagrams to show the layout of services and notations to convey the properties of the service. The point to stress is that these different notations and conventions speak to specific professions and convey the nature of the service to these professions and the standards that need to be followed. Understanding how services are provided and the limits to extending these services is a learned practice and the target audience is seldom the inhabitant of the building. The onus is the person seeking to amend the service to learn the conventions surrounding the service. In fact, a large number of “Do It Yourself” manuals are based on explaining the models underlying the provision of electric, water and heating services in the home.

We find less use of specialized notions and conventions in terms of the SPACE PLAN and STUFF within the building. The SPACE PLAN occasionally uses simple layout diagrams as part of the process of interior design. There is a growing popularity in alternative SPACE PLAN representations such as those of Feng Shui. There are also a host of lifestyle magazines and displays in shops that convey idealized possible SPACE PLANS and arrangements of STUFF. However, the absence of specialist conventions and notations is notable in the case

of STUFF. Essential STUFF seeks to be readily understood by the inhabitants with only limited use of design and lifestyle magazines and so forth to act as a guide.

So far we have considered who is involved in the various levels of change in buildings and the ways in which these levels are represented to those undertaking the change. Our final consideration is how the different parties involved coordinate and manage their activities.

How is change managed and controlled?

Managing the various layers of change is key to ensuring that change takes place in an orderly manner. Each of these different levels of change becomes the responsibility of different people. As Brand highlights

“The layering also defines how a building relates to people. Organizational levels of responsibility match the pace levels. The building interacts within *individuals* at level of **Stuff**; with the *tenant organization* or family at the **Space Plan** level; with the *Landlord* via the **Services** (and slower levels) which must be maintained; with the public via the **Skin** and entry; and with the whole community through city or county decisions about the footprint and volume of the **Structure** and restrictions on the **Site**” [3] page 17 (our emphasis)

We would also argue that much of the management of control is linked to ownership. The level of involvement of inhabitants in this change and the associated responsibility varies in terms of this ownership. This varies across different forms of building. The demarcation of responsibility is most explicit in offices and places of employment with the separations becoming less clear as we move towards homes that are owned by the inhabitants.

Figure 1 illustrates the different people who may initiate change in some illustrative classes of building. It is worth stressing the growing influence of the inhabitants as we move from offices to owned homes. However, it also worth noticing the remaining influence of service providers.

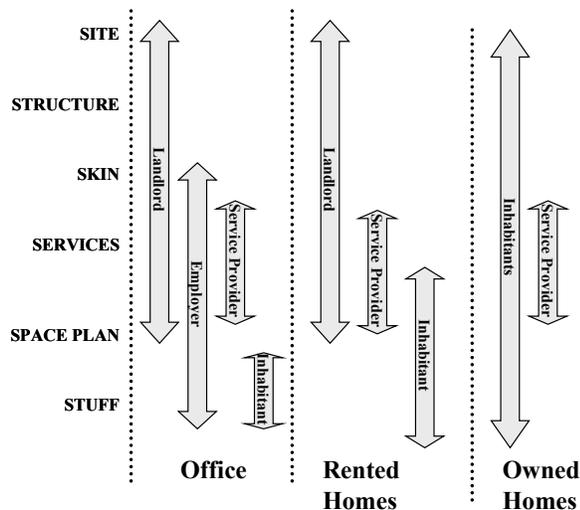


Figure 1: The parties involved in different buildings

In this section we have considered the nature of change in buildings and the way in which this change can be considered in terms of a number of different layers. We

have seen how these involve a broad range of stakeholders, how they exploit a range of different representations and how issues of ownership help control and manage these different layers of change. In the following section we briefly consider how current research approaches surrounding the development of ubiquitous environments for domestic settings relate to this framework and the issues to emerge for the different research communities involved.

RELATING ACTIVITIES TO EACH OTHER

How then might we consider the various research activities of those who would inform, design and realize domestic ubiquitous environments given our understandings of how buildings evolve and the framework outlined in the previous section? The framework provides a means of relating existing research activities to each other and to highlight new possibilities for research. It highlights the communication needed between different research areas to allow them to understand that they are addressing different but strongly related aspects of a common agenda. In order to do this it is worth mapping the different research areas involved onto Brand’s framework. The mapping between research activities and the layers suggested by Brand is summarized in figure 2 (over).

Our aim here is not to suggest any shortcomings in the research agenda of existing groupings but rather to provide a means for researchers to understand which part of the research puzzle they seek to address and how this may relate to other research endeavors. Currently, we see a predominant focus on the interior (STUFF, SPACE PLAN and SERVICE) with less concern for the broader SITE, STRUCTURE and SKIN of the exterior suggested by Brand. This suggests a significant opportunity for researchers. For example, until recently researchers within the built environment exploring the use of digital sensors have tended not to see this as part of the development of ubiquitous domestic environments. However, as Brand states the dependencies with these external layers is very strong [3]:

“Site dominates Structure which dominates Skin, which dominates the Services, which dominate the Space Plan, which dominates the Stuff”

Recent work at the Changing Places/House_n consortium has started to address how to more directly involve the work on the built environment and is actively exploring these links. In the rest of this section we explore some immediate observations surrounding current research activities before considering some broader reflections.

Understanding the Domestic

When we consider the various ways in which we have sought to understand the domestic we see a predominant focus on understanding the domestic from the perspective of the inhabitant. Essentially the focus has been on STUFF and the SPACE PLAN with less consideration of the activities involved in providing SERVICES. Considering these services highlight that our home is closely bound to activities that involve more than the inhabitants. It is

equally important that we understand the domestic from more than the perspective of inhabitants and broaden this to consider the activities involved in providing and changing services.

Developing Digital Devices

The development of artifacts to be placed in the home has unsurprisingly focused on the issues surrounding STUFF and the SPACE PLAN. The emphasis has been on how each device is interacted with by inhabitants. However, as Brand highlights the space plan is often defined through the arrangement of STUFF. He also stresses that the different levels are closely interwoven. In the case of digital devices they are closely tied to underlying digital services. It is important that this link is reflected in these devices.

Domestic Environments and Infrastructures

As we have already stated the work on developing environments and infrastructures has tended to focus on SERVICES. As Kidd et al put it when discussing the development of the aware home at Georgia Tech[18]

“we need to provide the capability for computational services to take advantage of these soon to be ubiquitous sensing capabilities”

We also need to understand how these emergent services may relate to the SPACE PLAN and STUFF. Existing views of interaction has focused on the development of “smart environments” where inhabitants live in a space that monitors their actions and invisibly reacts to their demands. A number of researchers have already highlighted the need to make interaction intelligible to inhabitants of sensorial environments [2]. We would add to this a need to consider the diversity of stakeholders and representations involved.

BROADER REFLECTIONS AND CHALLENGES

As well as highlighting the relation between these different activities the use of Brand’s Layers also allows us to

consider ubiquitous computing for domestic environments in the broader context of how the physical places within which technologies are placed are open to change. This reflection allows us to highlight a number of important research challenges.

Homes are never static

The homes we inhabit exist in buildings that are open to continual change. The effects of this change are central to the ways in which our domestic spaces are appropriated to meet our demands. As we saw in figure 1 inhabitants effect change across all the layers of change. However, little consideration has been given to understand the ways in which users change their surrounding environment and how we may make digital environments open to this change.

We need to understand this change and complement existing studies with an understanding of how users alter their environment. For example, the activities involved in DIY and redecoration of homes. We should consider the development of devices to help manage the changes involved in domestic environments. Part of this will involve those developing environments and infrastructures to consider how best to present appropriate details of the infrastructure to devices to allow dynamic modification.

Homes exist in a broader context

The layers outlined by Brand highlight the contextual nature of the home. The layers are interrelated and researchers need to consider the potential impact across these different layers. As a simple example, consider domestic technologies such as TV. Studies have highlighted how the placement of TV results in a rearrangement of the space plan with sofas oriented toward the TV as a focal point [26]. The placement of the TV then makes demands on Services and the placement of power and aerial points.

Equivalent dependencies will emerge for ubiquitous

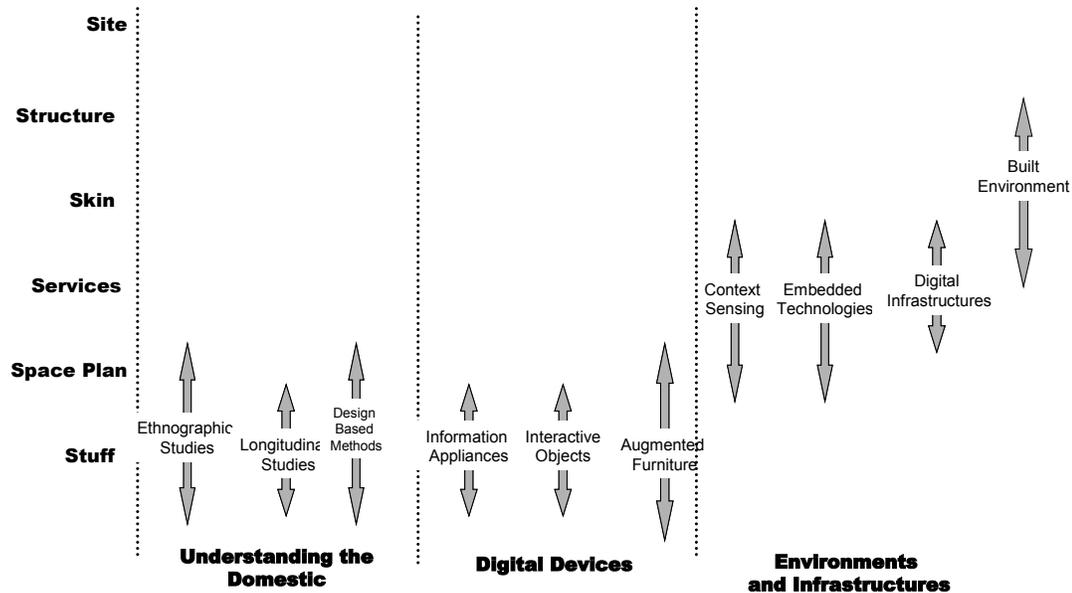


Figure 2: Mapping Current Research Activities to the Layers Suggested by Brand

environments for the home. Unlike existing services where we have physical wires that provide cues for these dependencies we will need appropriate representations to represent these dependencies and to design with sensitivity to them. For example, we currently may make part of our bedroom into an office by adding new power points and a new telephone line. How might we execute the digital equivalent to ensure a distinction between the devices in our bedroom and those in our new office? Moreover, what is the impact on the supporting service and who executes the change?

The coordinated activity of many stakeholders

One of the most striking reflections highlighted by the framework is the diversity of parties involved in supporting the home. Different stakeholders need to be coordinated in order to manage the ongoing process of change. For example, if we wish to alter our kitchen we need to coordinate the activities of plumber, joiners, heating engineers, electricians and decorators.

What are the potential professions to emerge to support the digital aspects of our home and how may we manage their activities. In particular:

- What representations will emerge for future digital services?
- Who will be involved in supporting these digital services?
- How will inhabitants engage with these services and those who maintain them?

We would like to emphasize that these challenges are not exhaustive rather they illustrate some immediate reflections that arise from considering the different activities involved within the broader context suggested by Brand. We would stress the advantage of the framework is that it places activities within this broader context and allows those involved to consider the potential impact of their work and the issues to be designed for.

As a final reflection it is worth noting that the layers suggested by Brand emerge from a consideration of American buildings. The layers reflect this cultural background and in fact Brand extended a framework by a British architect [9], which did not distinguish between SITE, SKIN and STRUCTURE but termed these all “shell”. This reflects the normal building practices in the UK where legislation often significantly restricts external change and the need for a separation is less significant.

There is of course a much wider range of cultures to be considered across the world. Other cultures and countries have different traditions of house building and evolution (including entirely self-built housing) and have greater or lesser degrees of regulation with regard to urban planning, preservation and environmental concerns. Research into ubiquitous domestic environments needs to take these into account too.

SUMMARY

This paper has reflected on the research activities involved

in developing ubiquitous computing environments for domestic spaces. To support this reflection we have turned to a consideration of the importance of change in buildings and built upon a framework suggested by Brand [3]. We have considered the diverse set of skills involved, the different representations used and the issues of ownership and responsibility in managing this process.

When we exploit this framework to place research activities in a broader context the current focus on the interior becomes apparent. The danger with this focus is that the broad settings within which our real world homes are placed get ignored. Our concerns about this focus on the interior is amplified by an apparent mismatch between those involved in understanding and building devices for the home who focus on the Space Plan and Stuff and those developing home environments and infrastructures who focuses on Services.

The challenge of ubiquitous computing is the need to marshal together a broad range of research interests. This is most evident in the case of developing these environments for domestic settings. It is important that those involved reflect on which elements of the overall research challenge they are addressing and coordinate them. The framework we propose offers a way to coordinating these activities and to relate these with the other influences on the home.

The challenges we outline stress the need to address the forces surrounding our homes as Brand states [3]:

“Because of the different rates of change of its components, a building is always tearing itself apart.”

We need to build our future ubiquitous environments in a manner that is sensitive to these forces and place our activities within this changing context. If we fail to do so then we may be constructing the 21st Centuries equivalent of the “homes of the future” that dominated the world trade shows of the 1950s.

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