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Including Smart Architecture in Environments for People with Dementia

Abstract

Environments which aim to promote human well-being must address both functional and psychosocial needs. This paper comprises a description of a framework for a smart home environment, which aims to comprehensively address issues of environmental fit, in particular for a person with cognitive impairment associated with dementia, by means of introducing sensing of user affect as a factor in system management of a smart personal life space, and in generation of environmental response, adapting to changing user need. The introduction of affective computing into an intelligent system managing environmental response and adaptation is seen as a critical component in successfully realizing an interactive personal life-space, where a continuous feedback loop operates between user and environment, in real time. The overall intention is to maximize environmental congruence for the user, both functionally and psychosocially, by factoring in adjustment to changing user status. Design thinking, at all scales, is perceived as being essential to achieving a coherent smart environment, where architecture is reframed as interaction design.

Keywords

Smart Homes - dementia - responsive architecture - affective computing - user-centred design

Introduction

"Residential healthcare" broadly describes a category of architecture for people who need considerable assistance in daily living. These needs can stem from either congenital or acquired disability, which can be physical, mental, or psychological. The increase in the population of elderly people in developed societies across the globe, and with that, a commensurate increase in the numbers of elderly people with dementia (Alzheimer's Association *2013*), has created demand in recent years for suitable living accommodation for these users, sometimes in the form of residential healthcare, or sheltered housing. Elderly people with dementia, in particular, require considerable support. As dementia is both progressive and systemic, the condition eventually comprehensively impairs functioning: it is far more than a matter of mere memory loss, but rather the related loss of ability to access a lifetime's worth of knowledge about "how to," including in relation to carrying out the many tasks of daily living, and the knowledge of how to interact successfully with environment. Total environment includes built environment and architecture, as well as social environment; however, it should be borne in mind that physical environment also impacts on the social possibilities available, as much as it does on the functional. In the latter stages of the disease, independent living is no longer possible, but quality of life remains an issue. Research and applied design solutions in recent years have demonstrated the capacity of good design to assist people with dementia in navigating and understanding the built environment, most importantly their own living environment (Day et al. *2000*; Judd et al. *1998*), whether that is their lifetime home, or purpose-built supported accommodation.

It is immediately apparent that smart technologies might prove of considerable benefit in the home environment of a person with either cognitive or physical impairment, or both, by providing compensation for loss of ability to interact successfully with the environment, effectively creating a prosthetic environment. So far, however, there seems to have been little by way of consideration of comprehensive and integrated approaches to the design of such environments. Much smart home research takes the approach of dealing on an individual basis with a plethora of computationally enabled applications or devices, rather than by taking a joined-up and more design-based approach to the whole concept. Ideally, the design of a smart home environment should be first approached from a broader perspective, and then broken down into its constituent parts, remembering always how they link to one another from a user perspective, interacting to form a total user experience (UX), which forms a constituent part of the user's experience of the complete architectural space.

User Experience in Interaction Design and the Architecture of Care

The concept of UX is common in web and application design, but how might it operate in a total architectural environment? To consider this, it is useful to conceive of a smart home as a total interface at the architectural scale, whether that is a single room, an apartment, or an entire building, so that the design of the built environment is effectively treated as an exercise in interaction design. The significance of the user, and of user experience, is acknowledged as critical to successful interaction and interface design, which is built around the trinity of person, context, and activity. Who exactly is the user, what are her defining characteristics, and how will they impact on the design of a successful interface? Where does the interaction take place? What does the user want to achieve, and what needs must be met? The architecture of residential care should similarly place the user, and detailed consideration of user characteristics, at the center of design decision making. However, it must be acknowledged that this particular concern with user-centered design has only emerged in recent years and that for many years preceding that, people who were extremely vulnerable by virtue of age, disability, illness, or even temporary impairment, including in the context of acute hospital care, were, and still are, routinely placed in environments inherently hostile to them and, which present, for them, considerably greater difficulties in use than they would for any fit and healthy person. Historically, the "architecture of care" has often poorly served those who had no choice but to inhabit it. For an example, one need look no further than the design of workhouses in Britain and its colonies, originally deliberately designed to contain and control those unfortunate to have no choice but to live in them. Many such buildings were subsequently adapted for healthcare use, often to house elderly people incapacitated by age-related conditions, including dementia. Their built form has continued, in some cases, to influence perceptions of what is still deemed appropriate as an architectural setting for users who are, by their very nature, more vulnerable than the general population and whose needs are ill met by the limited possibilities such environments afford. The tide has turned, but in many countries, it still carries with it the detritus of outdated thinking in design terms, founded on notions of the end-user as "other," rather than on contemporary ideas of a continuum of ability, and Universal Design. Though all human users share many needs and characteristics, when designing a compensatory interface or interaction, the designer must always be mindful of the particular characteristics of the end-user. In the case of the person with dementia, the designer, whether it is the architect or interaction designer (and in this scenario both, or some new hybrid), must grapple with the idea of a user with whom it can be especially difficult to identify, as this user has particular problems with both interpreting and interacting with the built environment. As the disease progresses, the individual's ability changes, and so, in a fashion, the design brief continually evolves. In a sense, the designer must design for many notional users, not one; in UX, this translates into designing for many "personas." So, in the particular case of a person with dementia, the idea of an adaptive environment that can alter to meet a range of user conditions makes particular sense. A responsive environment can also begin to address the transactive nature of the person's relationship with her environment and its effect on task performance, which is recognized in occupational therapy (Law et al. *1996*).

Context

In the case of architecture, and with reference to smart homes, the term "context," as used in interaction design, acquires the same meaning as that of "context" in architectural theory generally; that is, it implies a specific physical locale. In this discussion, that locale is taken to be the personal living space of an elderly person with dementia, though some of the conclusions that emerge may well have applications for other users in other contexts. Malcolm McCullough, in "Digital Ground" (McCullough *2004*), proposes that pervasive computing in architecture should be used to reinforce placemaking and context, making a case for a "quiet architecture," where focus returns once more to the user. McCullough further maintains that appropriate use of computational technologies in architecture should always be determined by context. For the elderly person with dementia, especially in the light of the associated loss of ability to perform previously learned tasks, or to easily learn new tasks, familiarity is an essential aspect of the personal environment. An appropriate approach might therefore be one which embodies a "quiet architecture," where ICT is subsumed, as "calm technology" (Weiser and Seely Brown *1996*), into the built fabric, remaining at the periphery until such time as it is called on by the user. In an appropriate intelligent home environment, technology does not need to be overt unless it is specifically required by the user to assist in a given task or interaction. Here, design for the sake of aesthetic novelty loses its power in the face of the inherent possibilities of an alternative embrace of technological potential.

McCullough goes as far as to suggest that interventions made using pervasive computing technologies might be compensatory in the case of existing architectural design that has failed to address concerns of usability and human-centeredness, so that "interactivity becomes a remedy for architecture, which as a discipline has ignored usability, performance and inhabitation in its quest for attention-seeking novelties in form" (McCullough *2004*). With the emergence of sophisticated computational systems to manage environment and interaction, there exists also the new possibility of designing remedial technological interventions, in order to improve the quality of user experience in architectural settings which fail to satisfy user needs by virtue of their existing physical characteristics.

Person-Environment Fit

"Congruence," or person/environment fit, is a useful perspective from which to examine the relationship between person and built environment in smart home design. Congruence breaks down into functional and psychosocial congruence. There are many and overlapping theories in environmental psychology, those of Kaplan (*1983*), Boyden (*1971*) and Kahana (*1980*) being of particular interest. Boyden theorizes that humans have well-being needs, in addition to basic survival needs, and that these higher needs must be met in order to maintain and promote both physical and psychological health, which are now generally seen to be inextricably linked. Boyden also refers to a need for meaningful change and sensory variability in environments which address well-being needs. While much effort in smart home design has been put into addressing functional needs, far less progress has been made in the direction of designing for psychosocial fit.

Lack of congruence can be a source of stress, in particular where the user is either physically or cognitively impaired, and all the more so where that lack of fit is continuous and persistent over time, leading to what Boyden terms the "Gray Life": a life of psychosocial maladjustment, of depression, of aggression, and furthermore of stress-related physical illness. The significance of psychological stress in the onset of acute illness, as well as lifestyle illnesses, including dementia, is beginning to be understood, through growing knowledge of neurochemical and biochemical mechanisms (Johannson and Guo *2010*; Khansari et al. *1990*; Sotiropoulos et al. *2011*). A healthful, or salutogenic environment , can contribute to optimizing human functioning (Heerwagen et al. *1995*; Day et al. *2000*). As the capacity of the person with dementia to cope with environmental stressors is progressively lowered over the course of the disease, design of long-term care accommodation must take a dual approach to addressing stressors of environmental origin, in order to promote well-being. Firstly, it should be designed to minimize unnecessary stress in interpreting and interacting with the built environment (Hall and Buckwalter *1987*) but, beyond that, should provide opportunities, through considered design intervention, for recovery from stress and for attentional restoration. The latter is particularly valid if it can contribute to recovery from cognitive overload, arising from progressive loss of function. Small tasks become large tasks; frustration at being unable to do "ordinary" things increases, while at the same time the person continues to be aware of and often embarrassed and frightened by a growing inability to manage ordinary day-to-day tasks and environmental interactions. In order to be truly "smart," smart home design needs to take consideration of both aspects of environmental fit. In "smart" architecture, the designer may begin to find integrated solutions that can potentially create an environment that delivers best user "fit" by continually adapting to the user, in a manner that is not possible without the integration of smart technologies. Computational technologies can thus serve to extend the remit of inclusive design, pushing the envelope outwards towards universality.

Environmental features which contribute to well-being have been usefully summarized by Heerwagen (Table 1). Very often, the same design feature in the built environment caters for both functional and psychosocial fit, and so it should be in Smart Home design. An example from built environment is that of the level threshold, which, functionally, allows a person with limited mobility to move from one space to another. In so doing, it can allow access to outdoors, facilitating visual change and spatial variability, but also gives the person ease of access, or independent access, to other behavioral settings, supporting personal control over socialization. This is not to say that architecture is deterministic, but that it can nonetheless contribute to shaping patterns of human behavior. How, then, does the designer of smart homes for elderly people, including people with dementia, go about integrating concerns of congruence into design approaches? A first step is to derive principles for interaction design in the built environment. Corcoran and Gitlin have previously derived principles for environmental interventions for people with dementia (Corcoran and Gitlin *1991*). These may be extrapolated into principles and recommendations for design interventions in an intelligent personal living space for an elderly person with dementia (Dalton *2014*), where environmental affordances are consciously manipulated to match user ability. While the original principles refer to total environment, including social environment, they can be usefully applied to built environment and interaction design embedded in the architectural environment. The latter, in its turn, can limit or enhance possibilities for social and psychosocial functioning. A simpler way of expressing this is with the maxim that "good design enables, bad design disables" (EIDD *2004*). For the architect and the interaction designer, or the new hybrid designer of Smart Homes, to think of dementia in terms of ability/disability can bring much clarity to design decision making.

Table 1

Features and attributes of buildings linked to well being needs and experiences (Heerwagen)

Experience / need	Environmental features and attributes
Connection to nature and natural processes	Daylight; views of outdoor natural spaces; views of the sky and weather; water features; gardens; interior plantings; outdoor plazas or interior atria with daylight and vegetation; natural materials and décor
Opportunity for regular exercise	Open interior stairways; attractive outdoor walking paths; in-house exercise facilities; skip-floor elevators to encourage stair climbing
Sensory change and variability	Daylight; window views to the outdoors; materials selected with sensory experience in mind (touch, visual change, color, pleasant sounds, and odors); spatial variability; change in lighting levels and use of highlights; moderate levels of visual complexity
Behavioral choice and control	Personal control of ambient conditions (light, ventilation, temperature, noise); ability to modify and adapt environments to suit personal needs and preferences; multiple behavior settings to support different activities; technology to support mobility; ability to move easily between solitude and social engagement and spaces to support both
Social support and sense of community	Multiplicity of meeting spaces, use of artifacts and symbols of culture and group identity; gathering "magnets" such as food; centrally located meeting and greeting spaces; signals of caring for the environment (maintenance, gardens, personalization, craftsmanship)
Privacy when desired	Enclosure; screening materials; ability to maintain desired distances from others; public spaces for anonymity

Affective Computing in a Smart "Life Space"

The central proposal made here is that in order to be user-centered, which is singularly appropriate as a design approach in the architectural context of care, any system which manages a personal living environment must of necessity include affective computing (Picard *1997*) as a consideration in the management of system response and thus of environmental response. MIT MediaLab's

Affective Computing Group describes affective computing as "computing that relates to, arises from, or deliberately influences emotion or other affective phenomena." The term implies that systems or devices, or in this case, an entire environment, are designed so as to become empathetic to human affect, or emotion. The goal can be to increase usability of systems, but also to inform decision making, by rendering it more efficient. Critically, affective computing is regarded as being, of its nature, multidisciplinary, cutting across such seemingly diverse areas of research and application as computer science, psychology, psychophysiology, engineering, and interaction design. User-centered design and architecture might now be included in that list.

To begin with, user data is required. In addition to data on user position, velocity, and so on, which can now readily be acquired from mobile healthcare applications, data from which the user's affective state can be inferred must be acquired though sensing of bio-signals which are indicative of affect. These can include heart rate (HR), galvanic skin response (GSR), and data acquired from processing of video of facial expression, which has proven extremely accurate in inference of affective state. The last is not usable in the latter stages of dementia, when facial expression is lost, no more so than with users who have autism spectrum disorders (ASD), and who, as a result, do not successfully express emotion facially. In order to usefully interpret user data, it must then be contextualized in data acquired from the ambient physical environment, and thus principles which apply generally to interaction design (those of user, context and activity), applied. Information which is indicative of user affect, specifically in relation to stress of environmental origin, is a useful indicator of when a user is interacting successfully or otherwise with a given application or with the room environment as a whole. In the context of care of an elderly person with dementia, it might conceivably provide carers with an invaluable source of information about the user's well-being, especially from the point in the progress of dementia at which that individual loses the ability to communicate needs successfully. The inability to communicate need, coupled with a growing inability to personally manipulate environmental affordances - even, for example, through the previously simple mechanism of switching on a light or altering the temperature of bathwater, can become source of much frustration and distress for the person with dementia and can limit maintenance of independent functioning.

Contextualization of user data gives meaning to that data. Is an increase in HR, which is an accepted indicator of stressed states, simply due to the person standing up or moving about? Is data indicating that a person has not moved for a period of some minutes a source of concern? Is the person sitting quietly or standing still in confusion? Are there patterns of behavior, such as agitated movement, which can predict whether the user is likely to have a "catastrophic event"? An intelligent system which includes a measure of affect can begin to address such considerations.

Intelligent System Design for an Affective Responsive Environment

In computational terms, the various applications and many user interactions which go to make up a smart living environment require an intelligent and embedded ICT system to manage them. The nature of the design problem suggests using a distributed system, which implies that intelligence is spread and shared between the various devices, applications, platforms, and interfaces which got to make up the complete system. Furthermore, in order to be successful, such a system requires a cognitive sensor network based on a dynamical paradigm, that is, a system which can "perceive, learn, reason, and act" (Henderson *2007*). If user-centeredness is regarded as an essential characteristic of a smart home in the context of residential healthcare, the system, by inference, must be equipped to observe and learn from the user as much as from the context. To date, much design which can be categorized as "adaptive architecture" has been predicated on the use of systems which learn from environmental context only, ultimately with the goal of reducing energy consumption. Responsive facades provide an example, where they are designed to respond to environmental cues such as light intensity and direction. Internal Building Management Systems (BMS) similarly respond primarily to contextual information, such as ambient temperature, humidity, or lighting levels, regulating the internal environment in order to maximize user comfort, and latterly, to minimize energy consumption. However, notions of user comfort are still predicated on average values, which may have little relevance in the domain of the personal living space and still less so in that of the person with dementia, where perception of environmental conditions, such as thermal, visual, or aural comfort, may be affected by the disease. Current adaptive applications in general use in building services include switching of environmental controls (e.g., lighting) which are actuated by RFID, while more sophisticated applications at the research stage also include factors such as room occupancy. A truly intelligent environment requires a more joined-up approach (Fig. 1).

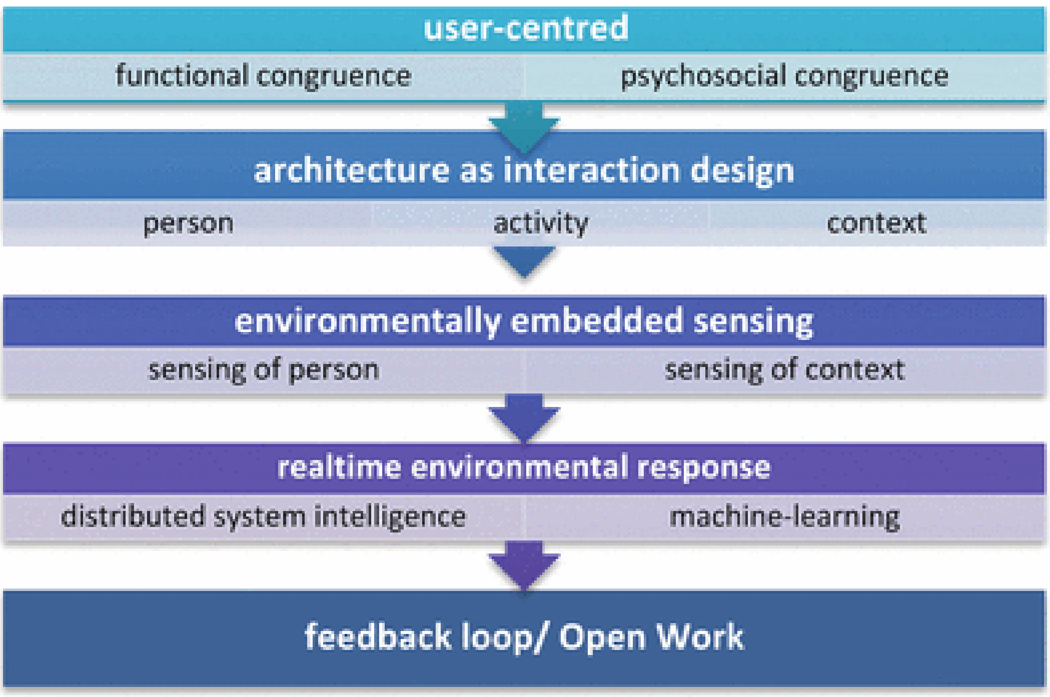

Fig. 1
System characteristics of an affective responsive personal life-space (Dalton *2014*)

Computational technologies in this context should quite literally become an intrinsic part of architecture of the building fabric, so that they are unobtrusive, and have minimal impact on the user, unless there is specific benefit to their being made overt. This approach is also in perfect keeping with Weiser and Seely-Browns' seminal paper "The Coming Age of Calm Technology" (Weiser and Seely Brown *1996*), which predicts the advent of pervasive or ubiquitous computing, referring to the benefits to the user of technologies which recede into the periphery of the user's awareness until such time as required and called into use. In the MyRoom model (Dalton and Harrison *2012*), notions of minimalism in architecture and product design coincide with the same principles in computing and interface design. However, Albert Einstein's maxim that things should be "as simple as can be but no simpler" should be applied. An intelligent environment created by an intelligent designer (or rather, an interdisciplinary team of intelligent designers) need not be "all-singing, all-dancing." The meshing of undoubtedly sophisticated technologies required to match individual needs and environmental affordances on a continuous and adaptive basis does not need to loudly announce its presence. If there was ever a scenario where technology should recede into the familiar and recognizable, where the technologically strange should consciously be made familiar through the efforts of the designer, it is in the physical context of design for a person with dementia. It is assumed as a general principle in this discussion that, while wearable sensors might provide short-term or interim solutions, the preferred situation for this user is likely to be one where all sensing becomes environmentally embedded and is literally subsumed into the built fabric. This excludes the possibility of a wearable sensor in itself becoming a source of additional stress, particularly as an unfamiliar object. The development of new sensors and sensing methods facilitates such an approach. McCullough's "quiet architecture" represents, in many ways, the antithesis of the "hyperfunctional" designed devices which Sarah Kettley queries in' "Interrogating Hyperfunctionality" (Kettley *2012*). However, when hyperfunctionality is moved outward into the domain of the built environment in a carefully managed fashion, space is readily found, both literally and metaphorically, for the personal, the crafted and the intimate. The inclusion of such items, which are often imbued with personal meaning, in environments for people with dementia, is now regarded as significant in supporting and maintaining a sense of self. Reminiscence is not limited to the verbal but also facilitated by places and objects.

Affective Environmental Feedback Loops

When response to affect is introduced as a consideration in an intelligent environmental management system, the system, and thus the environment, is equipped to learn how to respond to the user in new ways which are conscious of affect. Data acquired an intelligent system, from which the user's affective state is inferred, might firstly be used as a measure of the usability of a given interface or application, in that negative affect may indicate difficulty with using a specific interface or environmental feature. Similar applications are being piloted for online marketing and advertising applications, where webcams are used to gather video data of facial expression from which user reaction to online content is inferred. Continuous feedback on user interaction with the environment may prove invaluable in the case of a user with cognitive impairment, or where there are issues with communication of user need to a carer, coupled with an inability to independently carry out tasks or activities. Where it is feasible to acquire and process the necessary data regarding affect on a continuous basis, this allows the possibility of setting up a real-time feedback loop between user and environment. Such feedback loops are characteristic of responsive architecture, though design explorations to date have tended to be for aesthetic purposes, or playful in nature. In this scenario, which arguably takes a more inherently architectural approach, feedback might be used not solely for monitoring of usability, but to initiate changes which improve system performance through machine learning, thus enhancing person-environment fit. In addition, affective feedback could be utilized to actuate and manage real-time visual and multisensory changes in the room environment which in turn act on the user so that system and environment learn to respond to critical changes in the occupant's affective state. Research on the efficacy of natural imagery and the fractal patterns found in nature suggests design approaches to the production of therapeutic visual content (Taylor *2006*). This might be best delivered in tandem with an intelligent cycled lighting system and so also used to further reinforce circadian and seasonal rhythms. These rhythms are often disrupted as dementia progresses, not solely as a result of the neurological effects of the disease but also by the person frequently spending prolonged periods indoors, with little exposure to natural environments where daylight can reset the body's internal clock. (Fig. 2).

Machine learning in this particular smart environment might be refined through coaching from carers, described as "interactive reinforcement training" (Thomaz et al. *2005*) of the system, or "supervised learning" (Fiebrink *2010*). System training by carer intervention should aim at high level rather than micro-management of system operation.

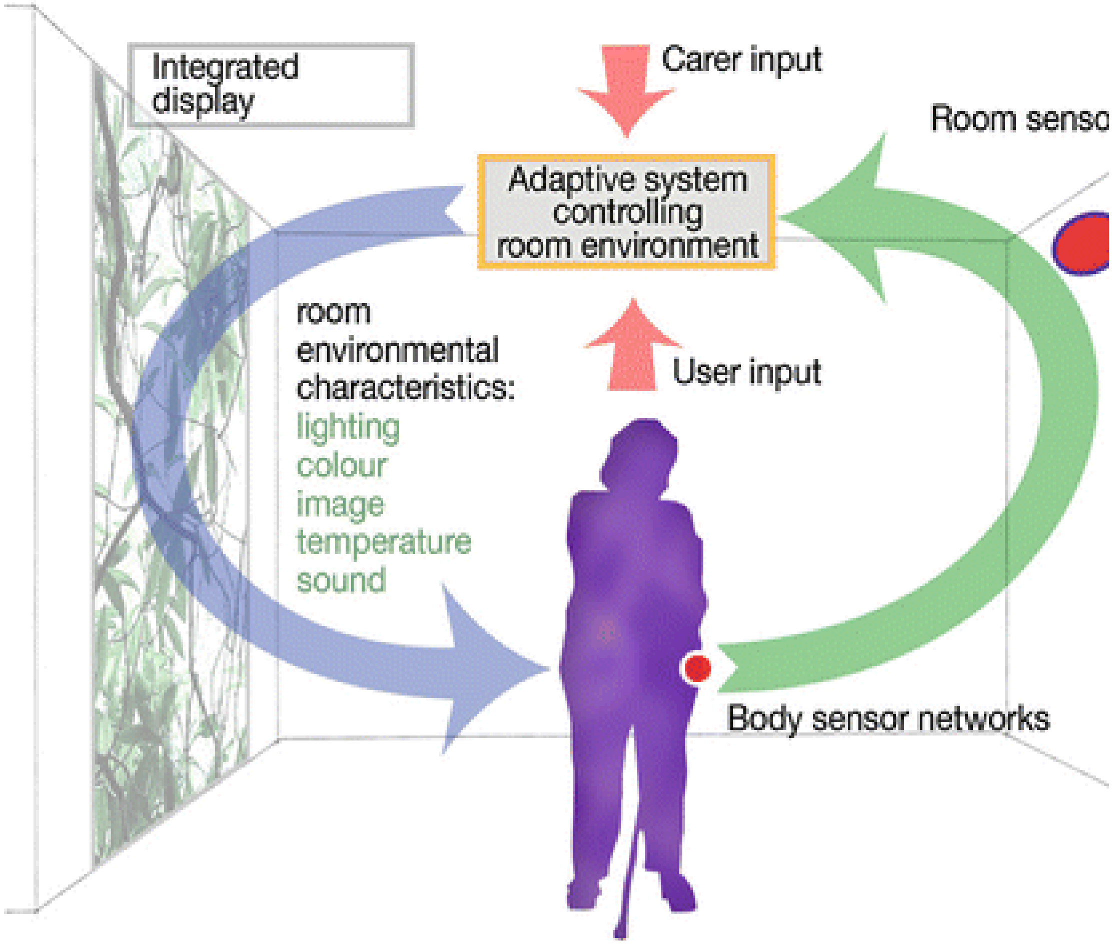

Fig. 2

MyRoom: diagrammatic representation of an affective responsive personal space (Dalton *2014*)

Conclusion

The addition of affective computing to the factors which manage response in a smart environment produces many possibilities for articulating the continuous functional, in a fashion which was hitherto simply not feasible. Real-time response to user affect closes the feedback loop between user and environment. Feedback based on sensing of the affective state can be used to reinforce system learning of user preferences, in order to maximize both functional and psychosocial congruence. This may in turn enable a degree of environmental management appropriate to the user's physical and cognitive status at any given time in the progression of dementia, or on a day-to-day basis, by tracking and responding to variation in user needs. The constant interaction between user and personal space might also be expressed through visual and other sensory changes in the ambient environment, reflective of, and even designed to impact on, the user's affective state. A responsive environment might also be "trained" to intervene, by initiating changes in the ambient environment prior to an anticipated negative user event, predicted through applying machine learning to sensed user data. While ideally, such interventions will be multisensory, ambient visual interventions, involving changes of color and imagery in the environment, may well be the least obtrusive. At the same time, more functional assistive technologies, operated by an intelligent system, and informed by considerations of user affect, also have the capacity to contribute to psychosocial congruence. Where interaction between user and environment is generated on a continuous basis, and creatively articulated within the space, impacting on the user's experience of that space, architecture finally acquires the capacity to operate as an "Open Work" (Eco *1989*), where the user/observer becomes implicitly involved in the generation of aesthetic output. In the context of the personal life-space of an elderly user with dementia, the expression of that interaction has potential to be therapeutic

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