CONFIGURING AN "ANIMATED WORK ENVIRONMENT": A USER-CENTERED DESIGN APPROACH

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Abstract

The dramatic shift in the nature, place and organization of working life, as well as the sophistication of information technologies employed in work, have prompted a trans-disciplinary team to develop an intelligent environment supporting increasingly digital lifestyles. This "Animated Work Environment" (AWE) is envisioned less as a design product and more as the locus of interaction between people, software, information, machines, furniture, and other physical surroundings. In realizing this vision, the team (representing architecture, robotics, human factors and sociology) employed a user-centered design approach to designing, prototyping, demonstrating and evaluating AWE. This paper presents, for the first time, findings from surveys and task analyses of workers employing digital technologies, and traces how these findings informed the design of six physical configurations and other aspects of the AWE robot-architecture prototype. Also presented is a reflection on the benefits and challenges of iterative, trans-disciplinary design approaches to complex systems supporting human activity. Following from a collaborative research approach which includes careful analyses of users' want and needs, AWE promises to better cultivate rich, engaged and connected lifestyles in an increasingly digital world.

1 Introduction and Key Elements

Developments in computer and information technology continue to revolutionize many aspects of human existence, particularly with respect to the working life of many people. However, while more information is becoming available in increasingly smaller packages in ever more locations, the physical environments within which humans use the information for their work have remained largely static. Workers continue to interact with information embedded inside static screens within conventional, statically configured spaces. Complex tasks, like those requiring non-trivial combinations of digital and printed matter, peer-to-peer collaboration within the computing environment, and tasks distributed across space and time, continue to be difficult to accomplish and a source of frustration for workers [10].

In this paper we present our efforts towards an alternative vision for working life in a digital society: what we call the "Animated Work Environment" or simply "AWE." AWE is envisioned as an intelligent, programmable physical space adjustable along a continuum, controlled by a user-friendly interface and embedded with IT (Information Technology). AWE takes advantage of recent advances in IT to integrate, within a programmable environment, multiple technologies such as flexible screens, input devices, and proximity sensors. AWE is viewed as part of a growing tendency within IT research which is concerned with various crosscutting issues related to working life, including the use of multiple displays [8][13], managing mixed-media [5], managing healthcare records [12]; and, more broadly, practices frequently defined as *Computer-Supported Collaborative Work* (CSCW) [1]. In particular, AWE builds on prior research in intelligent environments such as the *Interactive Workspaces Project* [3] and *Roomware* [11]. However, unlike these precedents which focus their concerns on the manipulation of information on computer screens, digital tablets and digital white boards of various kinds, AWE sits technologically at the interface between computer technology, architectural design and robotics, where *the physical environment (including display surfaces for paper) is also subject to manipulation.*

The aforementioned body of research, however, focuses not on robotics but mostly on collections of computer displays, whiteboards and novel peripherals to create electronic meeting rooms. AWE seeks to improve the quality of work, both "at work" and "at home," by intelligently adapting – *physically* – to work and leisure activities which employ digital and analog tools and documents. The AWE concept is inspired in part by William Mitchell's vision offered in "e-topia" [6]. Mitchell believes that "the building of the near future will function more and more like large computers" and that "our buildings will become…robots for living in" [6]. An elaboration of the motivations for and ambitions of the AWE Project was previously articulated by the authors [2].

The robotic dimension of the AWE project [figure 1] is enabled, in part, by recent progress in the exploration of continuum "links" to create active spaces [2]. This has been explored by the group of Kas Oosterhuis at the Technical University of Delft, which has constructed programmable flexible spaces framed by continuum structures [7].

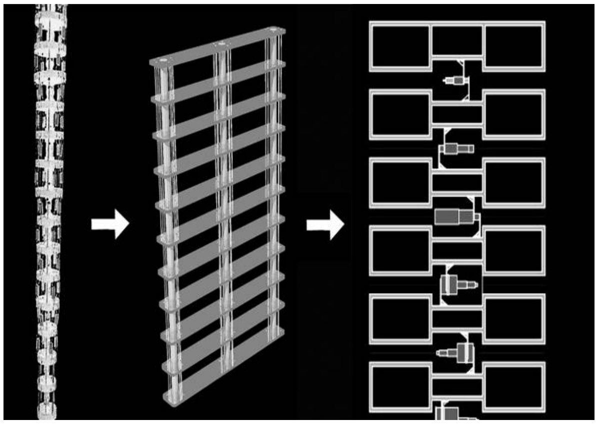

Figure 1. *A translation of "invertebrate-like" continuum robot technology in the AWE project* from a trunk-like form (left) previously developed and tested by the investigators, to a planar surface (center) as initially conceived for AWE, and to a hybrid of these two (right) at a different scale in the current AWE conception.

The physical AWE prototype presented here is, however, more complex, featuring in-concept continuum surfaces and focused on supporting and enhancing working life in an increasingly digital society. AWE has two key physical elements: the intelligent robotic system equipped with an array of embedded IT peripherals, and a collection of three work-surfaces which are reconfigurable, but not intelligent in the IT sense. A brief description of these are offered here as a means to introduce the project.

1.1 AWE's Robotic and Structural Backbone

AWE's robotic system consists of eight five-foot-wide aluminum frames of between one and two-feet in height, linked by eight motors (figure 2). The eight aluminum frames of AWE serve as the structure for sheathing (that transforms the frames into panels) and attached computer displays (four total), lighting, audio, and possibly other peripherals yet to be determined. We selected as the sheathing material Alucobond™, a lightweight but robust aluminum-and-plastic hybrid sheet material typically used to sheath larger buildings, which will completely encase the aluminum frames. Alucobond™ provides a "whiteboard" surface so that the system's panels become a large, configurable "easel" for writing on directly, or for displaying "annotatable" paper information, interspersed with computer displays.

To effectively alter the configuration of this system, designed for the worst-case but improbable scenario of having all eight frames cantilevered into an outstretched, horizontal configuration, the five motors closest to the floor are coupled with harmonic drives. To ensure the panels move fluidly together, through the various configurations, we placed hinges near to the two extremes of every frame. This allows the system of frames to move much like a typical linked, metal watchband, but at the scale of a room. A technical elaboration of the continuum robot system employed in the physical AWE prototype has previously been articulated by the authors [4].

Figure 2. Developing prototype of the robotic "wall" showing four of its eight panels.

1.2 AWE's Mobile Work-Surfaces

In addition to the robotic backbone, AWE consists of three horizontal, mobile work-surfaces which collectively afford various working and leisure activities, and which accommodate and organize larger IT peripherals, including a large printer and scanner (see figures 4-9 showing work-surfaces in context). The three work-surface units together provide ample horizontal surface area for team work as well as the handling and organization of paper documents of various sizes. To offer privacy – a feature of workplaces much requested by subjects of the surveys – AWE provides a work-surface "leaf" which folds upwards towards the vertical, as well as a pull-down screen. Both of these privacy elements help shield users visually (see figure 5). To shield users from unwanted noise, a noise cancellation system integral to AWE will be explored in future work.

2 Survey and Task Analysis Findings

As the motivations for AWE and its key physical elements have now been introduced, the focus of the next section of this paper is on our findings regarding current work practices and technology use – from surveys and task analyses conducted by the social science investigators – and how these findings have informed, firstly, the equipping of AWE with computer displays and CPUs; and secondly, AWE's six physical configurations.

It is important to note that the AWE prototype presented in this paper is not the first concept realized by the team; other prototypes were visualized and one of these early alternatives was physically prototyped and evaluated in the course of our iterative, human-centered design approach. In its final stages of development, the prototype presented here is informed by the qualitative research described in this section, and continues to be re-designed as we conduct Usability Testing involving participants engaged in real tasks (preparing tax forms, designing a small building) which require of them the use of both analog and digital materials and tools.

2.1 Phone and On-Line Surveys of Tech-Savvy Workers

The research team completed 400 phone surveys with individuals in two relatively affluent and technologically savvy communities, Cambridge, MA and Santa Monica, CA. Initial summaries of the findings confirm the initial assumptions that are the premises behind AWE.

Work that is done at home is often not done in an appropriate built environment. Nearly three-quarters of the respondents doing work at home are not performing this work in a home office/study. 65% of primary computers are not in an office/study and 45% of primary computers in home environments are not at desks.

Privacy is an issue for work at home. At first glance privacy concerns are not that great: 52.8% say "very much so" when asked if they have enough privacy. But this result is driven in large part by the number of one-person and two-person households in our sample. Only 30.3% of respondents in households with three members say "very much so." This number falls to 24.2% in households with four or more members. Interestingly, interruptions are more likely to come from phone calls than from people who are co-present.

Work-related storage concerns were reported by 40% of the respondents. These concerns were primarily with the amount of storage and not the type of storage or its location in the home.

Most of these respondents (89%) have a working computer in the home. Of those with a working computer in the home, more than half have more than one computer, though many of these computers are not networked. Asked to think about their primary computers, respondents indicated that 55% of their primary computers are desktop computers and 45% are laptops. 73% of the primary computers are used for work and 88% for recreation, 44% for school and 61% for personal business. 30% of respondents have more than one landline, and 75% have at least one cell phone.

Respondents are doing a variety of tasks on their home computers. 60% do at least some bill paying online; 55% do at least some banking; 42% do some credit card accounting; 55% do some of their newspaper reading online (though 50% of these individuals say they prefer printed newspapers to online ones). 70% of respondents reported that they gift-shop online, but in this case only 40% of these respondents would prefer to go to an actual store.

2.2 Task Analysis of Work Practices

A task analysis was conducted to provide a detailed look at user needs and preferences, and to help generate design requirements for AWE. The task analysis involved 1.5 hour interviews with knowledge workers in their everyday work settings. The participants interviewed were workers who gather and process large amounts of information and then compose new information products while doing their work. The participants included 4 architects, 4 teachers, and 4 accountants in order to assess workers who worked with primarily visual-spatial, verbal and numerical information. The interview data were analyzed with the goal of understanding, in fine detail, how these workers gather, organize, store, communicate and compose information, both electronic and paper-based, using their current work technologies. The results of this analysis were compared to similar but older studies of knowledge workers. As part of communicating the findings, a novel "hot map" was created by the investigators showing where across the vertical and horizontal work surfaces participants were engaged in activity. A summation of the findings is provided in text form here.

Despite the perceived trend in recent years away from paper information display and towards electronic information display, most of the workers in our study used both paper and electronic information displays at every step of their work process. The workers in this study used paper for tasks such as note taking, information storage, drawing, editing, composing and group discussion; they often printed electronic documents in order to work with them on paper; and they often categorized and laid out important paper documents near their focus of attention. Thus, the perceived trend towards the "paperless office" [9] was not strongly evident in our data. Our study supports and updates previous studies in this respect, and is not unlike the phone surveys that indicate that half of those who read the newspaper online prefer a paper format.

Electronic information processing technologies were frequently used along with paper. In a common sequence, workers composed a draft work product (e.g., a design drawing or a text report) in an electronic format while looking at both paper and electronic information sources, then they printed the work product out and edit and annotate it by hand, and finally the entered the edits into the electronic document.

Earlier, informal work products were communicated to other workers electronically; later, more formal work products were communicated using paper.

3 Design Guidelines Drawn from the Survey and Task Analysis Findings

Drawing from the findings of the phone and on-line surveys as well as the task analyses, the research team developed a list of design guidelines that informed the development of the physical AWE prototype. These follow here and are made evident in the current AWE prototype described in this paper:

(1.) Multiple information displays are desirable in work environments and should be located in close proximity to one another.
(2.) Displays of information that are digital, printed or a mix of both should be proximate to users for easy accessibility.
(3.) Space should be allocated for hand-written notations made by users in conjunction with activities involving printed and/or digital information.
(4.) Printed information that is used frequently should be made very accessible by making ample space for it, primarily atop horizontal work-surfaces, but also on vertical surfaces.
(5.) Work environments should accommodate multiple people, sitting side-by-side or across from one another, and engaged in collaborative activities that may involve computing.
(6.) Work environments should provide a large white board and/or computer display for group brainstorming and presentations.
(7.) Work environments should provide a degree of privacy by blocking unwanted visual access and auditory intrusion.

4 AWE's Computer Displays and Supporting CPUs

Our understanding of current information-processing practices and technologies gained from the surveys and task analysis guided the design of our current AWE prototype, particularly with respect to: (1) defining the computing environment (i.e. AWE's computer displays and CPUs; see figure 3), and (2) the physical configurations the robotic backbone assumes. The latter was informed, as well, by current ergonomics standards for the spatial layout of workstations drawn from the *Human Factors and Ergonomics Society*.

AWE is a platform to be equipped with numerous, varying and interchangeable digital and analog tools. While AWE can be equipped with such tools in a wide-range of manners, we are assembling a digital and analog "tool kit" that we believe will demonstrate the usability of AWE in supporting individual and collaborative work and play. This "tool kit" includes three computer displays in close proximity, as revealed by our task analysis. AWE is nevertheless an "open chassis" accommodating users' preferences with respect to its equipping.

As AWE permits up to three users computing at once, working individually or in collaboration, we have allocated four displays total for AWE. All of the displays are user-adjustable and are mounted following established ergonomic specifications. As shown in figure 3 and in subsequent figures, three of the screens are 19" diagonal flat-panel screens mounted on the two frames lowest to the base of the AWE backbone, and the fourth screen is 15" diagonal and mounted on the eighth (i.e. the final) panel from the base. Subjects in the task analysis also expressed a preference for aligning multiple displays vertically and horizontally. To accommodate this preference, the mounting hardware designed for AWE allows the two screens in the frame closest to AWE's base to slide horizontally. If these two screens are slid apart, they better accommodate two users working side-by-side; if they are slid together so their sides abut, these two screens can be used by a single user. The mounting hardware for the screen just above these two sliding screens allows this screen to be aligned over the left-most screen below it. All the screens are mounted with a ball joint to allow them to be angled to achieve a "wrap-around" configuration to best suit the user(s).

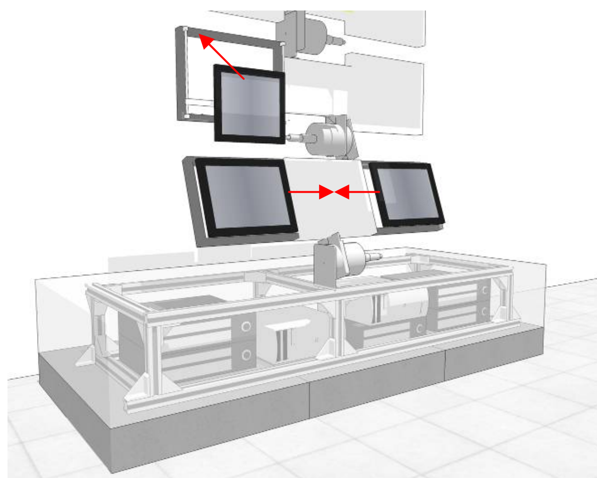

Figure 3. AWE's three 19" adjustable screens and base.

In locations on the eight frames where no computer displays are mounted, whiteboards of Alucobond™ are mounted, affording the attachment of printed documents (by clip, standard adhesive tape or magnetic strip) and the hand-writing of notes and annotations using standard dry-erase markers. AWE's mix of vertical and horizontal surfaces for the digital display of documents, for hand-written notes, and for the display of printed documents is again an attribute of work environments much valued and desired by subjects of the task analysis.

Taken together, the work-surfaces described earlier and the white board and computer array described here promise users of AWE the ability to effectively combine tasks involving printed and electronic information – the work activities most prevalent among subjects of our human-centered investigations. The physical configurations the various elements of AWE assume in supporting work and play activities are described in the following sections.

5 AWE’s Six Configurations

We have designed six standard physical configurations in support of individual and collaborative human activities afforded by AWE, including those defined more by work (e.g. composing and presenting) to those defined more by leisure (e.g. gaming and viewing). These configurations were informed by the findings of the surveys and task analyses as well as continual, regular exchange between members of the trans-disciplinary team.. To call-up a particular configuration, users select one of six numbered buttons located just below the first frame from the base. Fine adjustments by the user are made possible by touch sensors located at the ends of three of AWE’s panels. Such user adjustments can be saved and later recalled.

5.1 Configuration-1

Configuration-1 (figure 4) affords intensive composing and viewing of electronic and printed information by one or two users The focus in configuration-1 is on the three lowest screens which can be positioned so that either: (1.) one or two users can focus on the same set of displays, with all three screens positioned closest to center; or (2.) two users can work separately side-by-side with the two lower screens set apart, as shown in the figure.

5.2 Configuration-2

Configuration-2 affords intensive computing by a single user who might elect to position the two lower screens towards the vertical-center as shown in figure 5. A privacy screen can be pulled towards the floor to block visual access from behind the user. As well, the leaf in the foreground of the figure can be folded upwards to provide partial visual access from the side, presuming that AWE is set with its other side near a wall, as shown in the figure. Should AWE be placed in a room where the wall is to the right of the user, the two outer work-surfaces, both on casters, are easily repositioned to offer the same measures of privacy.

5.3 Configuration-3

Configuration-3 affords composing by two individuals engaging in activities that don’t require that they share the same intimate space. This might be the case where the two users are working alone on different pursuits or different aspects of the same pursuit and welcome the modest distance this spatial relationship creates between them (see figure 6).

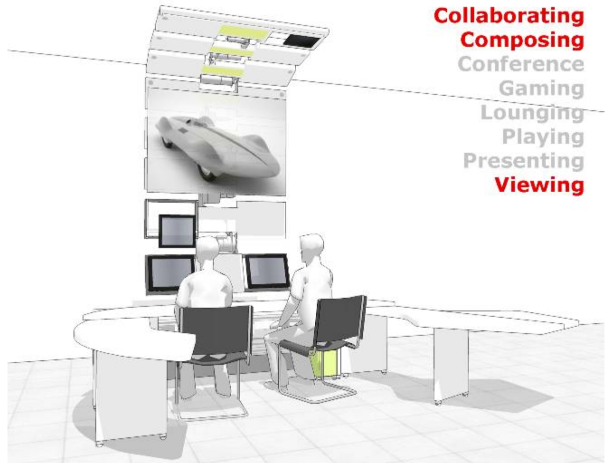

Figure 4. AWE Configuration-1, accommodating two users collaborating, composing and/or viewing.

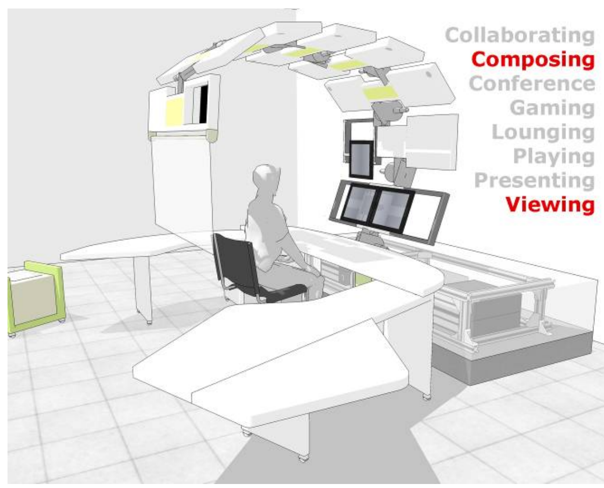

Figure 5. AWE Configuration-2, accommodating one user intensively composing and/or viewing.

5.4 Configuration-4

Configuration-4 affords two users to work in the same intimate space, but back-to-back (see figure 7). This configuration suits two people gaming. It is also suited to working collaboratively; but unlike the side-by-side collaboration of Configuration-1, this configuration better supports a scenario in which the collaborating individuals are working on different but related documents (say, pertaining to a single project), or are working on different aspects of a single document.

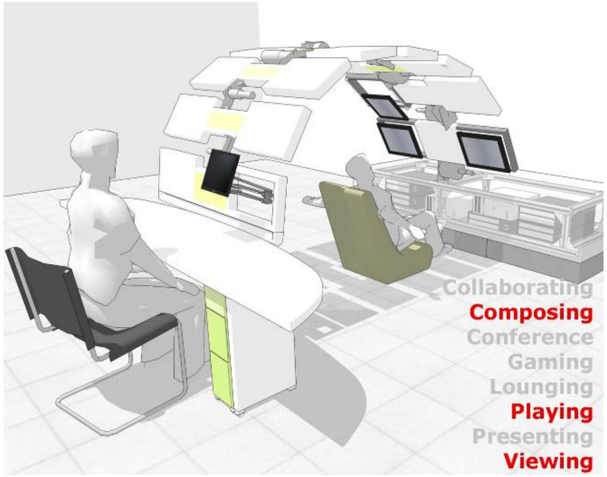

Figure 6. AWE Configuration-3, accommodating two or three users composing, playing and/or viewing.

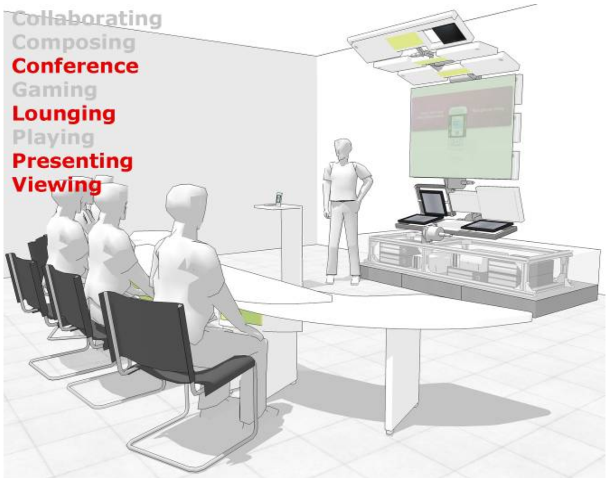

Figure 8. AWE Configuration-5, accommodating conferencing, lounging, presenting and/or viewing.

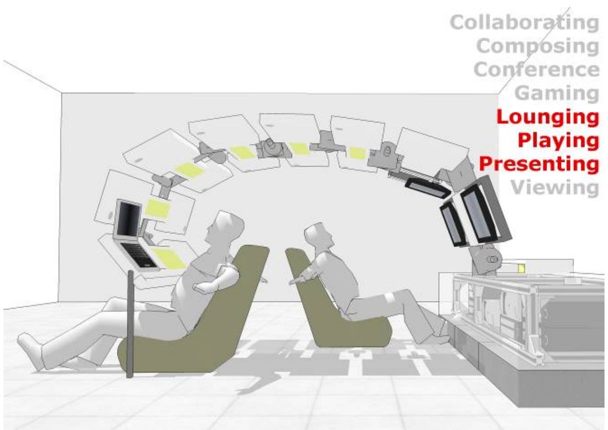

Figure 7. AWE Configuration-4, accommodating two or three users lounging and/or playing.

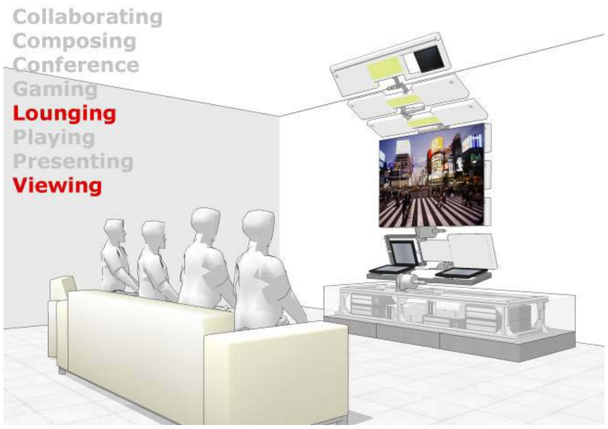

Figure 9. AWE Configuration-6, accommodating lounging and/or viewing.

5.5 Configuration-5

Configuration-5 affords, most particularly, formal presentations requiring a projection screen. The work-surfaces of AWE are repositioned and rotated 180 degrees to allow room for the presenter, a podium, and a pedestal supporting physical artefacts as part of the presentation (see figure 8). Lighting integral to AWE's panels is programmed to focus light onto the physical objects displayed.

5.6 Configuration-6

Configuration-6 affords leisurely viewing of videos or slide shows presented on the projection screen (see figure 9). This configuration suits the playback of movies, satellite television and other longer time-based media.

6 Conclusions and Future Work

Our understanding of current information-processing practices and technologies gained from the surveys and task analysis continue to guide the design of our current AWE prototype. As previously mentioned, Usability Tests of the physical prototype also have, and continue to be performed as the AWE prototype is iteratively improved. More specifically, we have recently observed participants engaged in the complex task of completing tax forms; and we are currently observing participants engaged in a design activity. In the near future we intend to continue Usability Tests focused more so on the movement between configurations by asking participants, working collaboratively, to first design and then present a small building as part of an informal, "in-house" design practice activity. The results of the Usability Tests will be presented in a future publication.

7 A Few Words on Collaborative Teamwork

Drawing on the findings of the multi-faceted, user-centered design approach described here, we continue refining a physical AWE prototype that will allow knowledge workers to spatially arrange and organize both electronic and paper information sources in a flexible manner as they gather, communicate and compose information at many stages of developing a work product, or as they engage in media-based leisure activities.

The interplay of the human-centered studies and the design process across our transdisciplinary research team continues throughout the research cycle. We believe this interplay – in the roles assumed by each team member as well as in the research processes employed in developing and evaluating AWE – will result in a more productive, more satisfying, and more compelling intelligent environment. AWE promises to support and enrich a digital lifestyle in which workers work both individually and collaboratively, at home and at work, across physical sites, and with both digital and "analog" tools and documents.

The development of new spatial patterns supporting human activities demands the attention of collaborative teams like ours. Such collaborative work follows from a basic premise followed by the AWE investigators in concert with the "call" to investigators from research universities and (to no surprise) the research funding agencies that help support them: that the complex problems and opportunities for living today warrant investigation by transdisciplinary teams of researchers drawn from different disciplines sufficiently complex in composition to address them. More than multi-disciplinary team work, which merely brings together investigators from various disciplines, "transdisciplinary" teamwork is defined by its members sharing a conceptual framework that integrates and transcends the disciplinary perspectives of individual team members so that each team member develops some reasonable understanding of how the other members, drawn from other disciplines, work.

There are challenges to working this way. The cultivation of a transdisciplinary team takes time: more time than some investigators have patience for. Also, the biases of the participating disciplines and the "ego" of participating investigators can create an obstacle to productive work. A healthy group dynamic must be achieved in which the various research activities result in contributions both to the participating disciplines as well as to the overall research ambition. This promotes investment in the research by all participating parties. Finally, transdisciplinary projects have relatively long project cycles (e.g. 3yrs) that might prove frustrating to investigators coming from disciplines accustomed to relatively quick outcomes from their efforts.

The ambition to realize, particularly, a robot-architecture presents new and difficult challenges to research and education in all the participating fields of this research. Towards educating a new generation of investigators from the participating fields, the respective faculty team members of the AWE project have offered classes in their respective disciplines running in tandem, and at the same educational level, which require student collaboration across the disciplines to promote knowledge exchange. In Spring 2006 for instance, we had Masters-level Architecture and Engineering students enrolled, respectively, in concurrent courses in Architectural Design and Robotics working collaboratively on robot-architecture projects; and in Spring 2007, we did the same for students enrolled in Masters courses in Architectural Technology and Human Factors. The collaborative research and educational activities exemplified in this paper cultivate in architects, engineers and social scientists of this and future generations new vocabularies and new, complex realms of understanding which promise both novel design propositions and the flourishing of the individual disciplines.

Acknowledgements

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